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Long-term effects of graduated compression stockings on cardiorespiratory performance

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ABSTRACT: The use of graduated compression stockings (GCS) in sport has been increasing in the last years due to their potential positive effects for athletes. However, there is little evidence to support whether these types of garments actually improve cardiorespiratory performance. The aim of this study was to examine the cardiorespiratory responses of GCS during running after three weeks of regular use. Twenty recreational runners performed three tests on different days: test 1) – a 5-min maximal effort run in order to determine the participants' maximal aerobic speed; and tests 2) and 3) – a fatigue running test of 30 minutes at 80% of their maximal aerobic speed with either GCS or PLACEBO stockings at random. Cardiorespiratory parameters (minute ventilation, heart rate, relative oxygen consumption, relative carbon dioxide production, ventilatory equivalents for oxygen and carbon dioxide, and oxygen pulse) were measured. Before each test in the laboratory, the participants trained with the randomly assigned stockings (GCS or PLACEBO) for three weeks. No significant differences between GCS and PLACEBO were found in any of the cardiorespiratory parameters. In conclusion, the present study provides evidence that running with GCS for three weeks does not influence cardiorespiratory parameters in recreational runners.

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INTRODUCTION

The use of compressive garments in sport is becoming very popular due to their potential positive effects on athletes [1,2]. These benefits appear to be related to circulatory improvements [3,4]. Different studies have reported a reduction in the severity of delayed onset muscle soreness [5,6], lower perception of fatigue [2], better recovery of muscle strength [7] and lower concentration of muscle damage markers in blood (creatine kinase) as a result of using compressive garments during exercise [8,9]. These results suggest that the use of compressive garments could be an effective strategy to enhance recovery [10]. However, to date there is little evidence that these garments may effectively benefit cardiorespiratory performance [11,12].

Two possible mechanisms have been proposed to explain the improvement in cardiorespiratory performance as a result of using compressive garments: the increase in venous return and the reduction of muscle oscillations. The improvement in venous blood flow and venous return may be a consequence of the pressure gradient applied by the garments [13]. This increased venous return may result in a higher cardiac output and stroke volume, and thus, in a lower heart rate [1,3]. However, whether these garments actually influence cardiorespiratory performance remains unclear since no differences in heart rate, blood lactate and oxygen uptake with the use of compressive garments have been observed in previous studies [2,3,12,14]. A systematic review by Born, Sperlich and Holmberg [15] concluded that endurance-related parameters during continuous exercise, such as submaximal oxygen uptake, blood lactate, heart rate and cardiac output, were not influenced by compressive garments. On the other hand, some studies have suggested that the reduction of muscle oscillations may improve muscle economy and performance [16,17]. However, there is also some controversy regarding this hypothesis, since Scanlan et al. [3] did not observe any improvement in performance with the use of compressive garments, and further research is therefore needed to support this idea.

Previous studies have reported similar VO_2max and VO_2peak values during exercise of incremental intensity and during running at constant speed with and without graduated compression stockings (GCS) [14,18,19]. However, in recent studies these compressive garments have been suggested to positively influence some cardiorespiratory parameters. In this sense, the use of GCS improved the recovery rate of oxygen saturation after exercise [20] and enhanced running performance by improving the participants' aerobic and anaerobic thresholds [18]. Moreover, the use of these garments led to a reduction in the VO_2 slow component (difference between the end and the beginning of exercise in VO_2/kg) during a running test while wearing compression tights compared to shorts and to elastic tights [17]. However, due to the discrepancies found between studies, further research analysing the influence of GCS on cardiorespiratory parameters and their potential role in running performance is needed.

The majority of the studies have analysed the effects of GCS during an acute intervention [14,18,21] and, to the author's knowledge, there is no study to date that analyses the influence of these garments after longer use. In this sense, it is known that an adequate and individualized training stimulus in terms of duration and intensity is needed in order to observe significant improvements in cardiorespiratory performance [22,23]. Previous studies have reported that a training period of three weeks is long enough to produce cardiorespiratory and metabolic adaptations [24–26] and therefore a training intervention of this duration might be the most adequate choice when analysing the effects of compressive garments on the human body for such a long period for the first time.

The aim of this study was therefore to analyse the effects of running with and without GCS for three weeks on different cardiorespiratory parameters in runners. It was hypothesized that the use of GCS for three weeks would improve the athletes' cardiorespiratory parameters (e.g. heart rate [HR], minute ventilation [VE], or relative oxygen consumption [VO_2/kg]) during running.

MATERIALS AND METHODS

Participants. Twenty recreational runners – 13 males and 7 females (age 28.1 ± 5.4 years, body mass 67.9 ± 9.8 kg, height 172.7 ± 9.2 cm, body mass index 22.7 ± 1.8 $kg \cdot m^{-2}$, and running mileage 37.0 ± 9.4 $km \cdot week^{-1}$) – took part in a cross-over study. All participants gave written informed consent before participation. The study procedures complied with the Declaration of Helsinki and were approved by the local Ethics Committee on Human Research (no. H138256048831).

Graduated compression stockings

The GCS used in this study were below-knee stockings that provided greater pressure at the ankle (24 mmHg), which gradually dissipated at the calf (21 mmHg). These values of pressure were provided by the manufacturer. The GCS were composed of 85% polyamide and 15% elastane (Lycra). The pressure of these GCS can be considered a moderate compression, comparable with "class 2" compression used in the clinical field [27]. Following the manufacturer's guidelines, the proper fit for each participant was determined by measuring the leg circumference immediately below the knee. A pair of non-graduated compressive stockings with the same appearance and design was included in the study to offset any "placebo" effects.

Intervention

Participants performed three running tests on different days. In the first test, each participant underwent a 5-min maximal effort run on a 400-m track in order to determine their individual maximal aerobic speed (MAS) [28,29].

In the second and third tests, participants ran on a treadmill (Technogym SpA, Gambettola, Italy) so that the running speed and the characteristics of the running surface (slope, hardness) could be controlled. These two tests followed the same protocol: participants warmed up at a self-selected pace for 10 min (which also served as familiarization time on the treadmill [29,30]), and subsequently performed a 30-min run at 80% of their MAS while wearing at random either the graduated compression stockings (GCS) or the placebo stockings (PLACEBO). All cardiorespiratory variables were constantly registered throughout the run (30 min), and perception of fatigue was reported during the last minute of the running test by means of a 20-point Borg scale [31].

Prior to each laboratory test (second and third running tests), the runners trained with the randomly assigned stockings (GCS or PLACEBO) for three weeks. Participants were not aware of which stocking condition (GCS or PLACEBO) they were using. In order to ensure that all runners underwent a similar training load, participants were asked to train during those three weeks following some training specifications: 3-4 $days \cdot week^{-1}$, with a training volume around 30 $km \cdot week^{-1}$, and with an intensity of 60-80% of their maximum HR. Participants were given a training log which included the following items: i) training days per week, ii) mileage per training session, and iii) a confirmation cell for each session where the participants had to confirm that each session was performed at an intensity between 60 and 80% of their maximum HR. At the end of the second test of the study (first running test at the laboratory), participants received the second pair of stockings and a second training log. Participants were asked not to use the new assigned stockings for a week (washout week), and then they were asked to train for another 3 weeks with the new pair of stockings before returning to the laboratory for the third and last test (Figure 1).

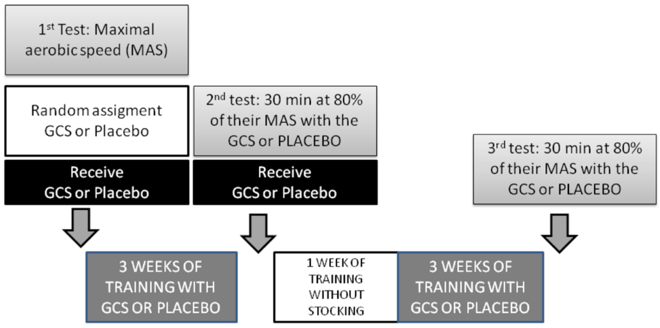

FIG. 1. Protocol design

Measurements

Gas exchange measurements were registered throughout the run with a portable indirect calorimeter (Cosmed K4b2, Rome, Italy). Standard calibration procedures were performed before each test including gas calibration by using a calibration gas mixture with a known composition (O_2: 16.00% and CO_2: 5.00%). Heart rate was also registered via a portable HR belt (Polar FT-2, Polar Electro, Kempele, Finland).

Data collection

Cardiovascular data were smoothed and a median filter over 5 breaths was applied for each test using a custom made spreadsheet in Excel (Microsoft Inc., USA). Mean values of pulmonary data from minutes 5 to 10 (V1), the last five minutes of the test (V2) and the slow component, measured as the difference between the end and the beginning of the test (V2-V1), were used for statistical analysis. The cardiorespiratory variables selected for the analyses were: minute ventilation (V_E), heart rate (HR), relative oxygen consumption (VO_2/kg), relative carbon dioxide production (VCO_2/kg), ventilatory equivalents for oxygen (V_E/VO_2) and carbon dioxide (V_E/VCO_2), and oxygen pulse (VO_2/HR).

Statistical analysis

The statistics package SPSS 21 (SPSS Statistics, IBM) was used for the statistical analysis. After checking the normality of the variables ($p>0.05$), a 2-way ANOVA with two repeated measure factors, moment (V1 and V2) and stocking condition (GCS and PLACEBO), was performed for the cardiorespiratory variables. Also, the effect of the stocking condition on the slow component (V2-V1) of the cardiorespiratory parameters was assessed with a 1-way repeated measures ANOVA. After checking the normality of the values of perceived fatigue ($p>0.05$), a Student t-test was used to analyse the influence of the stocking condition on the perception of fatigue. Data were reported as means with the 95% confidence intervals (95% CI). Significance was set at $\alpha = 0.05$.

RESULTS

Participants underwent a similar training load with GCS and PLACEBO stockings (training days, GCS vs PLACEBO: 3.5 ± 0.5 vs 3.4 ± 0.4 days·week^{-1}, p=0.89; weekly mileage, GCS vs PLACEBO: 37.2 ± 4.7 vs 37.5 ± 4.4 km·week^{-1}, p=0.78).

The average MAS of the runners was 16.0 ± 1.5 km·h^{-1}, and the lab tests were therefore carried out at 12.8 ± 1.2 km·h^{-1} (80% MAS). The running protocol (30 minutes at 80% MAS) had a significant influence on the cardiorespiratory variables measured in the present study. V_E, HR, V_E/O_2 and V_E/VCO_2 increased significantly throughout the test in both conditions (Table 1). VCO_2/kg significantly decreased when running with GCS and PLACEBO stockings. VO_2/HR decreased only in the PLACEBO condition. However, no differences between moments (V1 and V2) (Table 1) or in the slow component (V2-V1) (Figure 2) were found for any of the garment conditions. Finally, the average perception of fatigue was 16.3 (95% CI [15.5-17.0]), and it was similar with GCS and PLACEBO stockings (p=0.9).

DISCUSSION

The present study analysed the effects of using GCS for three weeks on different cardiorespiratory parameters in runners. It was hypothesized that the use of GCS for three weeks would improve the athletes' cardiorespiratory parameters during running. However, the results of the present study do not support this hypothesis, since no effect on any of the cardiorespiratory parameters was observed after three weeks of running with GCS. On the other hand, as expected, the

TABLE 1. Mean with the 95% confidence intervals (95% CI) of the selected cardiorespiratory parameters at the three moments in GCS and PLACEBO condition

	GCS				PLACEBO				p (GCS vs PLACEBO)	
	V1	V2	Diff	p	V1	V2	Diff	p	V1	V2
V_E (l·min^{-1})	83. 8 [75.3-92.3]	92.2 [82.6-101.8]	8.5	**<0.001**	82. 9 [74.5-91.3]	91.8 [81.7-101.8]	8.9	**<0.001**	0.24	0.81
HR (beats·min^{-1})	163.6 [159.1-168.1]	174.1 [168.8-179,4]	10.5	**<0.001**	163.1 [157.9-168.2]	173.1 [167.1-179.1]	10.0	**<0.001**	0.63	0.55
VO_2/kg (ml·min^{-1}·Kg^{-1})	45.2 [41.1-49.3]	44.7 [40.6-48.9]	-0.5	0.28	45.4 [41.7-49.2]	44.7 [41.1-48.3]	-0.8	0.05	0.85	0.98
VCO_2/kg (ml·min^{-1}·Kg^{-1})	41.8 [37.9-45.6]	41.0 [37.2-44.9]	-0.7	**0.01**	42.1 [38.4-45.7]	41.3 [37.8-44.8]	-0.7	**0.03**	0.78	0.81
V_E/VO_2 (l·min^{-1})	28.3 [25.6-31.0]	31.5 [28.4-34.6]	3.2	**<0.001**	28.2 [25.5-30.9]	31.6 [28.5-34.7]	3.4	**<0.001**	0.84	0.90
V_E/VCO_2 (l·min^{-1})	30.6 [28.0-33.2]	34.2 [31.3-37.2]	3.6	**<0.001**	30.5 [27.7-33.3]	34.2 [31.0-37.4]	3.7	**<0.001**	0.86	0.99
VO_2/HR (ml·beats·min^{-1})	18.8 [16.7-20.9]	18.0 [16.3-19.7]	-0.8	0.15	18.7 [16.8-20.5]	17.4 [15.5-19.2]	-1.3	**<0.001**	0.88	0.24

Note: Differences between V1 and V2, and between GCS and PLACEBO, are presented with statistically significant p values indicated in bold letters ($p<0.05$). V_E – minute ventilation, HR – heart rate, VO_2/kg – relative oxygen consumption, VCO_2/kg – relative carbon dioxide production, V_E/VO_2 – ventilatory equivalent for oxygen, V_E/VCO_2 – ventilatory equivalent for carbon dioxide, and VO_2/HR – oxygen pulse; V1 – 5th to 10th minute; V2 – last 5 minutes of test

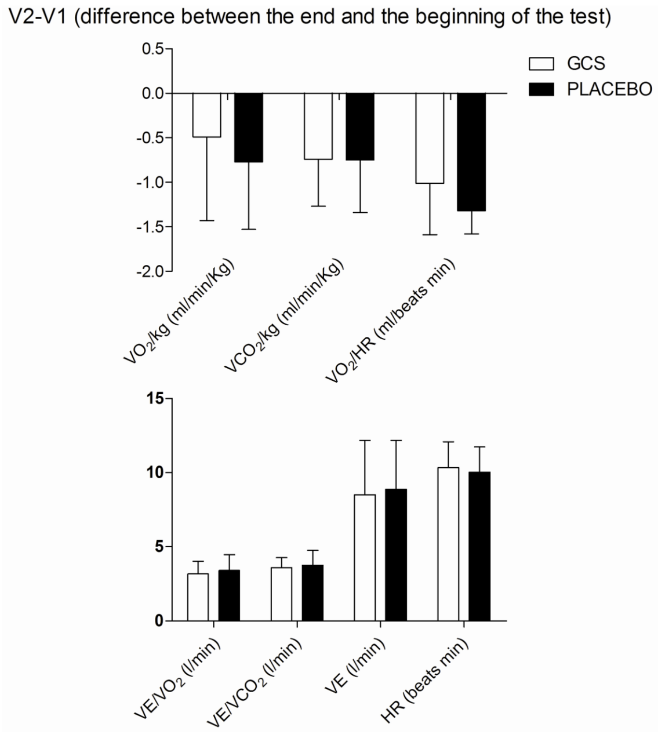

FIG. 2. B Differences between GCS and PLACEBO condition in V2-V1 (difference between the end and the beginning of the test). Mean and standard deviations of the different cardiorespiratory parameters (V_E – minute ventilation, HR – heart rate, VO_2/kg – relative oxygen consumption, VCO_2/kg – relative carbon dioxide production, V_E/VO_2 – ventilatory equivalent for oxygen, V_E/VCO_2 – ventilatory equivalent for carbon dioxide, and VO_2/HR – oxygen pulse). No statistically significant differences were found.

running test performed in the study (a 30-min run at 80% MAS) was intense enough to provoke changes in the cardiorespiratory parameters as a consequence of the development of the fatigue state in the runners. These results indicate that the running test used in this study led to alterations in the cardiorespiratory response, and it can therefore be considered an adequate test to assess the effects of GCS on the human body during running [17].

Interventions aiming to influence the cardiorespiratory system during exercise such as special types of clothing (compressive stockings, arm sleeves or full body suits) may potentially influence oxygen uptake in running [17]. In this sense, the VO_2 slow component is considered an important parameter to evaluate performance and efficiency, especially in exercises performed above the lactate threshold [32–34]. Bringard et al. [17] found that wearing compressive tights improved by 26% and 36% the VO_2 slow component during running compared to classic tights and shorts, respectively. In the present study, no differences in the VO_2 slow component were found when using GCS or the PLACEBO stockings. Most of the studies have analysed the effect of compressive garments by means of acute interventions [14,18,21]. To the authors' knowledge, this is the first study to analyse the effects of a longer intervention of compressive garments on cardiorespiratory parameters in runners. However, no difference in any of the cardiorespiratory parameters analysed, independent of the moment of analysis, was observed. Therefore, the results of this study suggest that even after a 3-week intervention, the use of GCS did not improve cardiorespiratory parameters in recreational runners.

Previous studies have suggested that the increase in venous return results in a reduction of heart rate [1,3]. In the present study, no differences in heart rate were observed when using GCS or the PLACEBO stockings, in agreement with previous studies [6,14,17]. In this sense, the distance between the garments (which were worn on the lower leg) and the heart may explain this result.

Moreover, the participants in the current study had some running experience, which may imply that their cardiorespiratory system may be already adapted enough to deal with the physiological loading stress of the run [35]. If that were the case, their cardiorespiratory system would not need the external support of the GCS. Even though this is pure speculation at this point, it is likely that use of GCS may not influence the venous return in the lower limb strongly enough to provoke significant changes in heart rate in experienced runners.

The minimum pressure required to influence cardiac output has been estimated to be about 17 mmHg at the leg [36]. Thus, the pressure provided by the GCS used in the study should be high enough to produce cardiovascular adaptations. However, no differences were observed between GCS and the PLACEBO stockings for any of the variables analysed. The values of compression of these GCS (21–24 mmHg) are similar to those reported in other studies that analyse the effects of using GCS [18,19,21], which may indicate that the compression gradient does not account for the different results between studies. Furthermore, a control stocking (PLACEBO) was also used in the present study in order to control the effects produced only by the compression. However, it is unknown whether a different level of compression of the garments would have influenced the cardiovascular parameters analysed in the present study.

CONCLUSIONS

This study demonstrates that running with GCS for three weeks did not influence cardiorespiratory parameters in recreational runners. However, future studies are needed to compare stockings with different levels of compression in order to observe whether these adaptations occur and to analyse their relationship with the different levels of compression.

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