EFFECT OF COMPRESSION STOCKINGS ON RUNNING PERFORMANCE IN MEN RUNNERS

WOLFGANG KEMMLER,[1] SIMON VON STENGEL,[1] CHRISTINA KÖCKRITZ,[1] JERRY MAYHEW,[2] ALFRED WASSERMANN,[3] AND JÜRGEN ZAPF[4]

[1]*Institute of Medical Physics, University of Erlangen-Nürnberg, Nürnberg, Germany;* [2]*Truman State University, Kirksville, Missouri;* [3]*Department of Mathematics, University of Bayreuth, Bayreuth, Germany; and* [4]*Society for Preventive Care Management and Sports Medicine, Bayreuth, Germany*

ABSTRACT

Kemmler, W, von Stengel, S, Köckritz, C, Mayhew, J, Wassermann, A, and Zapf, J. Effect of compression stockings on running performance in men runners. *J Strength Cond Res* 23(1): 101–105, 2009—The purpose of this study was to determine the effect of below-knee compression stockings on running performance in men runners. Using a within-group study design, 21 moderately trained athletes (39.3 ± 10.9 years) without lower-leg abnormities were randomly assigned to perform a stepwise treadmill test up to a voluntary maximum with and without below-knee compressive stockings. The second treadmill test was completed within 10 days of recovery. Maximum running performance was determined by time under load (minutes), work (kJ), and aerobic capacity ($ml \cdot kg^{-1} \cdot min^{-1}$). Velocity ($km \cdot h^{-1}$) and time under load were assessed at different metabolic thresholds using the Dickhuth et al. lactate threshold model. Time under load (36.44 vs. 35.03 minutes, effect size [ES]: 0.40) and total work (422 vs. 399 kJ, ES: 0.30) were significantly higher with compression stockings compared with running socks. However, only slight, nonsignificant differences were observed for $\dot{V}O_2max$ (53.3 vs. 52.2 $ml \cdot kg^{-1} \cdot min^{-1}$, ES: 0.18). Running performance at the anaerobic (minimum lactate + 1.5 $mmol \cdot L^{-1}$) threshold (14.11 vs. 13.90 $km \cdot h^{-1}$, ES: 0.22) and aerobic (minimum lactate + 0.5 $mmol \cdot L^{-1}$) thresholds (13.02 vs. 12.74 $km \cdot h^{-1}$, ES: 0.28) was significantly higher using compression stockings. Therefore, stockings with constant compression in the area of the calf muscle significantly improved running performance at different metabolic thresholds. However, the underlying mechanism was only partially explained by a slightly higher aerobic capacity.

KEY WORDS aerobic, compression, lactate threshold, running performance, stockings

Address correspondence to Wolfgang Kemmler, wolfgang.kemmler@imp.uni-erlangen.de.

23(1)/101–105

Journal of Strength and Conditioning Research

INTRODUCTION

The positive effects of compression garments have become increasingly interesting for athletes across various disciplines. Some authors have determined favorable effects of compression stockings, tights, or sleeves on venous hemodynamics (3,17), arterial perfusion (6,8), deeper tissue oxygenation (1), and muscle oscillation (7,12), with corresponding effects on lactate kinetics (5,9,22) and muscular soreness (2,13). Although these alterations should positively affect aerobic capacity and overall performance, no study with healthy athletes has shown higher aerobic capacity, and only a few studies (9,12,18) have reported more favorable effects of compression garments. Interestingly, 2 of these studies have indicated that compression garments maintained either maximum jumping (18) or cycling power (9) during or after repetitive work. Although this performance maintenance is of high relevance, the physiological effects of compression garments described above should also affect aerobic and anaerobic performance during a single running test to exhaustion.

If compression stockings produce beneficial effects among runners, they could provide an ergonomic benefit in both training and competition. Such information might aid runners, strength and conditioning specialists, and athletic trainers in gaining the most of training programs designed to enhance running physiology and performance. Thus, the aim of this study was to determine the effect of beneath-knee stockings with constant compression on selected parameters of running performance in healthy men runners.

METHODS

Experimental Approach to the Problem

This study used a randomized crossover design to determine the effect of wearing beneath-knee compressive stockings vs. conventional running socks on physical performance and aerobic capacity in moderately trained runners. This within-group study design allowed each subject to serve as his own control.

Subjects

Twenty-one moderately trained men runners participated in the study. The runners were recruited by announcements in local running clubs. Inclusion criteria were a running history of at least 4 years, a running volume between 25 and 70 km·wk^{-1} during the previous year, and a time of more than 34 minutes for 10,000 m. A detailed questionnaire completed by all study subjects combined recent and present physical activity and exercise levels and specific exercise parameters such as years of exercising, running volume, average running speed, and records on various distances (Table 1). Further, the wearing comfort and correct fit of the stockings were determined. All study participants gave written informed consent, and the study was approved by the university institutional review board. Table 1 shows the physical and training characteristics of the study subjects.

Procedures

Anthropometry. Height, weight, and body composition were measured for each subject. Body composition was determined using the leg-to-leg bioelectric impedance technique (Tanita BF 305, Tanita, Japan).

Exercise Test. Endurance was assessed using a stepwise speed-incremented treadmill test to voluntary maximum termination. The initial running speed depended on the known performance capacity of the athlete and was 9–11 km·h^{-1} to ensure a time under load >30 minutes. Every 5 minutes, speed was increased by 1 km·h^{-1} with a treadmill slope of 0%. Oxygen uptake ($\dot{V}O_2$), carbon dioxide production, and pulmonary ventilation ($\dot{V}E$) were continuously determined breath by breath using an Oxicon mobile (Viasys, Conshohocken, Pa) open spirometric system. Maximal values were determined from the average of the last minute of exercise. Analyzers were calibrated with a known gas mixture before each session. The coefficient of variation was better than 3% for all parameters (volume, O_2, CO_2).

The lactate concentration in hemolyzed whole blood was determined by an enzyme-chemical method (Lactat Scout, Senslab, Leipzig, Germany) at rest and after the end of each exercise level. Heart rate (HR) was continuously evaluated during the treadmill test using a Polar monitor (Polar RS 400, Kempele, Finland). Average HR of the last minute was used to represent maximal HR. The temperature in the exercise room was 20–22° C, with a relative humidity of 40–50%.

Individual Aerobic and Anaerobic Thresholds. Each individual's anaerobic (AnT) and aerobic thresholds (AT) were determined by the method described by Dickhuth et al. (11). Accordingly, the AT was defined as minimum lactate under load + 0.5 mmol·L^{-1} lactate, whereas the AnT was defined as minimum lactate under load + 1.5 mmol·L^{-1} lactate. Speed, HR, and lactate levels at both thresholds were automatically calculated by the "Schwelle" software (Wassermann, University of Bayreuth, Bayreuth, Germany). The curves for speed vs. HR and lactate level, respectively, are computed via cubic regression splines from the measurement values (14). We interpolated the few measured values by a curved function and determined each threshold from these curves.

Compressive Stockings. Beneath-knee compressive stockings (Running O_2max, cep GmbH & Co. KG, Himmelkron, Germany) with "slightly" degressive pressure from the ankle (24 mm Hg) were composed of 85% Polyamid and 15% Elasthane (Lycra). The stockings produce circular pressure on the lower leg. The pressure is comparable with a class 2 compression, used in the medical field. An extra "compression thread" made of Elasthane is knitted with a defined tension into the fabric. In addition to the tension, the compression varies: it decreases from the ankle (24 mm Hg) upward, but it stays stable the same in the area of the calf muscle (18–20 mm Hg). This special gradient is patented. To determine the correct size of the stockings, the calf circumference was measured. The same running shoes were used in both conditions.

Statistical Analyses

Data were analyzed using SPSS 14.0 (SPSS Inc., Chicago, Ill). The Kolgomorov-Smirnov test was used to check for normal distribution. Homogeneity of variance was investigated using Levine's F test. Paired t-tests were used to detect between-intervention (with vs. without stocking) changes for normally distributed variables; otherwise, nonparametric tests (Wilcoxon-test) were performed to assess the statistical relevance of our results. All tests were 2-tailed, and a 5% probability level was considered significant. To estimate the practical relevance of our results, relative effect sizes (ESs) were calculated using Cohen's d. According to Cohen (10), ESs were defined as small, d = 0.2; medium, d = 0.5; and large, d = 0.8.

Table 1. Anthropometric and training characteristics of the subjects.

	Mean ± *SD*	Range
Age (y)	39.3 ± 10.7	25–60
Height (cm)	178.5 ± 4.8	170–188
Weight (kg)	75.4 ± 7.4	62.4–90.0
Body fat (%)	13.7 ± 2.6	8.1–17.3
Training volume (km·wk^{-1})	40.1 ± 17	25–70
Years of exercise (y)	16.0 ± 9.4	4–35
10,000 m (min) (n = 21)	40:36 ± 6:29	34:25–61:00
Half-marathon (min) (n = 15)	94 ± 9	79–106
Marathon (h) (n = 12)	3:11 ± 0:13	2:49–3:32
$\dot{V}O_2$max (ml·kg^{-1}·min^{-1})	52.0 ± 6.1	43.5–62.4

Results

All subjects reported correct fit and comfortable wearing conditions for the compression stockings during the test. The results of the stepwise treadmill test to voluntary maximum demonstrated that running performance as determined by time under load (36.44 ± 3.49 vs. 35.03 ± 3.55 minutes, ES: 0.40) and total work (422 ± 78 vs. 399 ± 77 kJ, ES: 0.30) were significantly higher with compression stockings vs. without stockings (Figure 1A and B). Also, maximum speed was significantly superior ($p = 0.002$) using compressive stockings (16.96 ± 1.15 vs. 16.61 ± 1.05 km·h^{-1}; ES: 0.32). However, compression did not significantly affect $\dot{V}O_2$max (53.3 ± 5.8 vs. 52.2 ± 6.2 ml·kg^{-1}·min^{-1}, ES: 0.18) as shown in Figure 1c. Further, no significant differences or relevant ESs were observed between the compression stockings and normal socks for maximal lactate (8.3 ± 2.2 vs. 8.2 ± 2.5 mmol·L^{-1}), HRmax (180.6 ± 11.6 vs. 180.6 ± 12.5 bpm), $V_E$max (142.8 ± 18.3 vs. 141.1 ± 19.7 L·min^{-1}), the ventilator equivalent (EQ) ($\dot{V}E/\dot{V}O_2$: 35.4 ± 3.4 vs. 35.8 ± 3.4), and the respiratory exchange ratio (RER; 1.04 ± 04 vs. 1.05 ± 0.4).

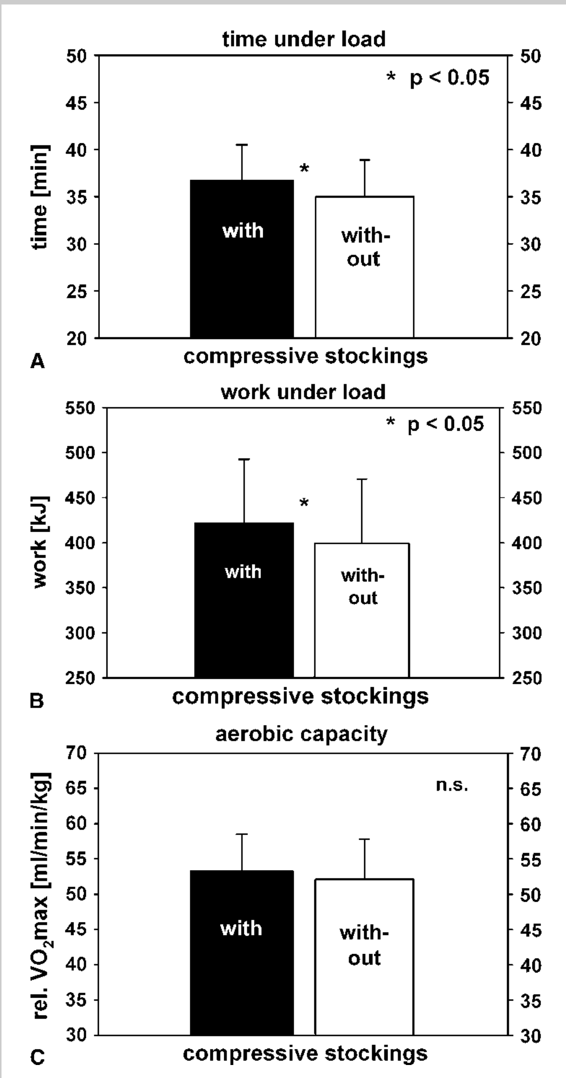

Figure 1. Time under load (a), total work (b), and aerobic capacity (c) after a stepwise treadmill test up to a voluntary maximum: compressive stockings vs. conventional running socks.

Running performance at the AnT significantly differed (14.11 ± 1.13 vs. 13.90 ± 1.13 km·h^{-1}, ES: 0.22) between both conditions, with more favorable effects with compression (Figure 2A). Subjects' HR, $\dot{V}O_2$, $\dot{V}E$, RER, and other parameters were comparable between compression stockings and control at the AnT. Running performance at the AT (Figure 2B) was also significantly higher with compressive stockings (13.02 ± 1.10 vs. 12.74 ± 1.04 km·h^{-1}, ES: 0.28). Again, other physiological parameters (HR, $\dot{V}O_2$, $\dot{V}E$, EQ, and RER) did not show relevant differences between the compressive stocking and sock conditions.

Discussion

In this study, we clearly demonstrated the benefit of compressive stockings on running performance in moderately trained men runners 25–60 years old. Most interestingly, constant compression over the calf muscle affected running performance at various metabolic stages. Differences between both conditions were not only determined for total time

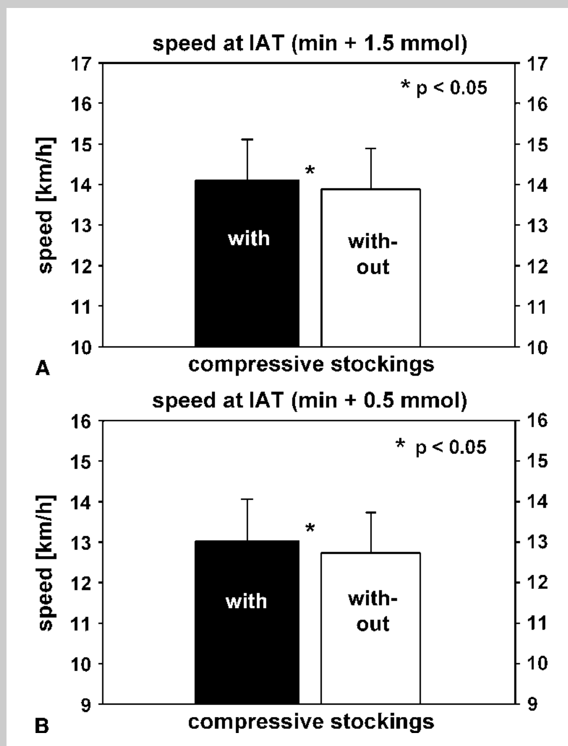

Figure 2. Interpolated speed at the individual (a) aerobic-anaerobic (min + 1.5 mmol·L^{-1} lactate) and (b) aerobic (min + 0.5 mmol·L^{-1} lactate) threshold as described by Dickhuth et al. (11).

under load, total work, and maximum speed but also for performance parameters at the individual ATs and AnTs as calculated by the Dickhuth et al. (11) method. When expressed as percentage differences between both conditions, modifications of maximum performance parameters range from 2.1 to 6.2%. Submaximal performance parameters expressed as speed at the ATs and AnTs were 1.5–2.2% higher with stockings. It is difficult to judge the relevance of these differences in our cohort of moderately trained runners. However, transferred to a top athlete's level, the smallest enhancement of performance that has a relevant effect on the athlete's chance of a medal is about one-third of the variation of competitive performance (15), which has been shown to be about 3% (CV) for comparable men long-distance runners (16). Thus, compressive stockings may provide substantial, favorable, physiological advantages for all ambitious runners independently of their preferred running distance.

The literature concerning the effects of compression garments on performance parameters seems controversial. Although positive effects of compression on venous hemodynamics (3,17,21), arterial perfusion (6,8), deeper tissue oxygenation (1), and muscle oscillation (7,12) have been noted, with corresponding effects on lactate expression/clearance (5,9,22), lower CK levels (13,20), muscle fatigue (19,21), and muscular soreness (2,13), only a minority of studies (9,12,18) have reported significant effects on performance parameters in healthy subjects. Concerning endurance performance, no study has determined more favorable values for time under load (5), distance performed (2,13), or power (22) for running or wheelchair cycling exercise to a voluntary maximum. However, when comparing the types of compression, there are grave differences between these studies and our trial. Primarily, contrary to other studies (2,4,9) using stockings with decreasing compression, the stockings tested in our lab have a constant compression gradient over the calf muscle. Continuous compression over the whole range of the muscle may be more effective than graduated compression during running exercise in healthy subjects because the lower effect on venous pooling (which was negligible during running exercise) was overcompensated for by the higher arterial blood flow (6). Further, although the intensity of compression at the ankle was comparable (24 mm Hg) compared with most other studies (18–22 mm Hg) that have focused on the effect of compression stockings in healthy subjects (2,5), the compression at the calf was relevantly higher because of the relatively continuous compression distribution of the stockings used.

Concerning the mode of operation, the primary pathway of compression garments was expected to be an increase of aerobic capacity by improved oxygen transport capacity (22). However, in our study, $\dot{V}O_2max$, which is primarily dependent on oxygen transport capacity and oxygen use, was only slightly influenced, although all performance parameters were significantly affected. From a pragmatic point of view, 2 main reasons may be responsible for this scenario. First, the accuracy of the $\dot{V}O_2max$ measurement was lower than that of the performance parameters "time under load," "work," and "speed"; thus, the higher variance of the $\dot{V}O_2max$ may have prevented the manifestation of significant differences between interventions. Second, along with O_2 kinetics, other pathways may contribute to a better performance with compression stockings. In that context, although speculative, we favor the possibility that the increased compression and biomechanical support of the muscle tissue and muscle-tendon unit may lead to a higher mechanical efficiency, resulting in less metabolic costs at given workloads. Assessing lower aerobic energy costs (with comparable $\dot{V}O_2$) at submaximal levels wearing compression tights during running exercise, Bringard et al. (8) support this idea. Thus, along with $\dot{V}O_2max$ changes, the "ergonomic interplay" (18) between compression and some biomechanical/biological mechanisms may explain a relevant amount of the variance of the effect of compression on running performance.

Our study has the limitation of nonblind ability. Thus, one may ask whether the higher performance levels obtained with compression stockings might at least partially be dependent on the increased motivation of the participants. It is difficult to decide on this issue; however, none of the physiological parameters that described the voluntary maximum (i.e., HRmax, RER, $\dot{V}E$) differed between conditions. Further, although not scientifically investigated, most of our athletes tended to have negative attitudes regarding the below-knee stockings concerning the effect, wearing comfort, heat sensation, and design, at least before the exercise test.

Practical Applications

The aim of this study was to determine whether compression stockings add any significant effect to running performance in moderately trained runners. Our data clearly indicate that wearing compression stockings with constant compression in the area of the calf muscle increases performance parameters at different metabolic stages during an all-out task. Thus, compression stockings were effective for enhancing performance during submaximal and maximal running exercise.

Acknowledgments

We would like to thank the subjects of this study. We also acknowledge cep GmbH & Co. (Himmelkron, Germany), who supplied compressive stockings for the study participants.

None of the authors declare any conflicts of interest with respect to any products used in the study or referred to in this article.

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