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ORIGINAL ARTICLE

Effect of lower body compression garments on submaximal and maximal running performance in cold (10°C) and hot (32°C) environments

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Abstract No previous studies have investigated the effect of lower body compression garments (CG) on running performance in the heat. This study tested the hypothesis that CG would negatively affect running performance in the heat by comparing CG and non-CG conditions for running performance and physiological responses in hot and cold conditions. Ten male recreational runners (29.0 ± 10.0 years, $\dot{V}O_2$max: 58.7 ± 2.7 ml kg^{-1} min^{-1}) performed four treadmill tests consisting of 20-min running at first ventilatory threshold followed by a run to exhaustion at $\dot{V}O_2$max velocity in four conditions: 10°C with CG, 10°C without CG, 32°C with CG, and 32°C without CG (randomised, counterbalanced order). Time to exhaustion (TTE), skin and rectal temperature, $\dot{V}O_2$, heart rate and rating of perceived exertion (RPE) were compared between CG and non-CG conditions at each environmental temperature. TTE was not significantly different between the CG and non-CG conditions at 10°C (158 ± 74 vs. 148 ± 73 s) and 32°C (115 ± 40 vs. 97 ± 33 s); however, there was a small (0.15) and moderate effect size (0.48), respectively, suggestive of an improvement in TTE with CG. Lower limb skin temperature was 1.5°C higher at 10°C with CG ($P < 0.05$), but no significant differences in other physiological variables, including rectal temperature, were observed between garment conditions. Interestingly, RPE was lower ($P < 0.05$) during submaximal running at 32°C with CG (13.8 ± 2.0) compared with non-CG (14.5 ± 2.7). It was concluded that CG had no adverse effects on running performance in hot conditions.

Keywords Time to exhaustion · Oxygen consumption · Rectal temperature · Skin temperature · Rating of perceived exertion

Introduction

The use of lower body compression garments in sports has gained immense popularity amongst athletes of all levels. Such garments are commonly worn during exercise and in recovery by team sport athletes, and especially in individual sport athletes such as triathletes, cyclists and runners (Sperlich et al. 2010). Some studies have reported that compression garments improve running economy (Bringard et al. 2006b), reduce muscle oscillation (Doan et al. 2003), lower blood lactate levels (Berry and McMurray, 1987) and enhance muscle oxygenation (Bringard et al. 2006a; Scanlan et al. 2008). However, only a limited number of studies have critically examined their effect on endurance running performance in controlled settings despite their widely accepted use.

To the best of the authors' knowledge, only three previous studies (Ali et al. 2007; Bringard et al. 2006b; Sperlich et al.

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2010) have examined the effects of compression garments on submaximal running performance. For example, Ali et al. (2007) conducted a field-based 10-km run trial with 14 male recreational runners and demonstrated run times to be similar with and without graduated compression stockings (44.7, 45.0 min, respectively). In 15 well-trained runners and triathletes, Sperlich et al. (2010) evaluated the effect of varying the overall compression surface (i.e., socks, ankle-to-hip, whole-body, non-compression control) on running performance at 70% of the first ventilatory threshold (VT_1) for 15 min followed by a time to exhaustion run at the velocity associated with $\dot{V}O_2$max (v-$\dot{V}O_2$max). The authors reported that wearing compression garments had no effect on running performance, oxygen consumption, ratings of perceived exertion and time to exhaustion. Conversely, Bringard et al. (2006b) investigated the effect of compression garments on the aerobic energy cost of running over 3 min stages at 10, 12, 14 and 16 km h^{-1} in six well-trained runners and observed a lower $\dot{V}O_2$ consumption only at 12 km h^{-1} with compression garments.

None of these studies, however, have investigated the effects of compression garments on submaximal and maximal running performance in relation to contrasting environmental temperatures. While the primary goal of any sports apparel is to enable appropriate levels of heat transfer from the athlete to the environment, it is a general consensus that such clothing could cause thermal insulation, and subsequently detriment exercise performance (Brownlie et al. 1987; Gavin 2003). Despite this, there have been anecdotal reports on increased usage of compression garments in tropical climates during endurance events such as the marathon. Indeed, Brownlie et al. (1987) has shown that an increase in body surface area coverage by clothing caused significant increases in thermal stress during treadmill running in 25°C. Thus, compression garments may negatively affect running performance in the heat. Hence, it is important to investigate the effects of compression garments on endurance running performance in a hot environment.

The purpose of the present study therefore was to compare the effects of compression garments on running performance at VT_1 (submaximal) and at v-$\dot{V}O_2$max (maximal) in hot (32°C) compared with cold (10°C) ambient temperatures. It was hypothesised that wearing compression garments at 32°C would further reduce (1) submaximal running performance, as indicated by increases in oxygen consumption and core temperature, and (2) maximal running performance, as shown by a reduction in time to exhaustion running at v-$\dot{V}O_2$max, as compared with the control garment condition.

Methods

Participants

Ten recreational runners (mean ± SD; age: 29.0 ± 10.0 years, height 1.80 ± 0.06 m, body mass 78.5 ± 6.3 kg, $\dot{V}O_2$max 58.7 ± 2.7 ml kg^{-1} min^{-1}) volunteered to participate in this study. The number of subjects was determined using a Hopkins' formula (Hopkins 2003) for sample size estimation in cross-sectional studies ($N = 32/\text{Effect Size}^2$), based on a possible difference in the energy cost of running at 12 km h^{-1} between the compression garment and control conditions from a previous study (Bringard et al. 2006b). Subjects were instructed to continue with their normal dietary practices during the study period, and to specifically maintain a 3-day food record prior to testing. They were asked to refrain from training and strenuous activity in the 24 h period prior to testing, and a training record was kept throughout the five testing weeks. Participants were requested to keep their upper body wear and footwear constant for all trials. Participants were requested to drink as they normally would before a running session to standardise their hydration status. The study was approved by the Edith Cowan University Human Research Committee, in conformity with the Declaration of Helsinki.

Compression and control garment

The present study used Skins™ Sport Men's Compression Long Tights (Campbelltown, Australia), and the garment fit for each subject was in accordance with the manufacturer's instructions. The pressure exerted on the lower limbs by the compression garments was determined at two sites for each subject using a Kikuhime pressure monitor (TT MediTrade, SorØ, Denmark). The two sites were the frontal mid-thigh and above the main muscle belly of the gastrocnemius muscle. The pressure sensor was inserted from the top (for frontal mid-thigh) and bottom (for the gastrocnemius) of the compression garment and the average of two readings were recorded before the compression garment trials.

The control garment consisted of loose-fitting conventional running shorts which were kept constant for each control trial. The purpose of using conventional running shorts was to allow comparisons to be made between compression garments and garments which are more typically worn by recreational runners. For upper body wear, subjects wore an identical sleeveless running top for all conditions.

Study procedure

All tests were performed in a climate chamber. Subjects reported to the laboratory for five separate sessions, interspersed by 1 week to allow sufficient rest between sessions. Trials were performed at the same time of the day to minimise any influence of circadian rhythm. During each visit, water was offered freely to participants prior to the run. A urine sample was obtained immediately before the treadmill tests to determine urine osmolality using an osmometer (Advanced Instruments Inc, Massachusetts, USA) and urine specific gravity by a handheld refractometer (Nippon Optical Works, Tokyo, Japan). Body mass was recorded to the nearest 0.01 kg (Metter Instruments, Germany) immediately before and following exercise. During the first visit, subjects performed a $\dot{V}O_2$max test in thermoneutral conditions [22°C, 50% relative humidity (rh)] wearing the control garments described above. During visits 2–5, subjects performed a running performance test as outlined below in both hot (32°C, 50% rh) and cold conditions (10°C, 50% rh), in a randomized, counterbalanced order. The present study chose the temperatures of 10 and 32°C, as time to exhaustion at submaximal intensities has been found to be longest at 10 and 30–34°C is commonly chosen to represent a "hot" temperature in exercise research (Galloway and Maughan 1997; Gavin 2003).

The running performance test was completed under four different conditions: 32°C with compression garment (CG), 32°C without CG, 10°C with CG, and 10°C without CG; each condition was separated by 1 week. Subjects were randomly assigned to each testing condition in an attempt to limit any learning effects. They were also blinded to their trial condition until the commencement of testing. The same level of verbal encouragement was given throughout all tests. Running speed at VT_1 and v-$\dot{V}O_2$max was determined as the corresponding speed at which VT_1 and $\dot{V}O_2$max occurred at during the initial incremental test.

$\dot{V}O_2$max test

The progressive exercise test modified from a previously published method (Laursen et al. 2005) was used to determine the subjects' VT_1 and v-$\dot{V}O_2$max. Briefly, subjects commenced running on a treadmill (Trackmaster, JAS Fitness Systems, Kansas, USA) at 7 km h^{-1} for 5 min on a 0% gradient to warm-up. Speed was then increased by 1 km h^{-1} every minute until 16 km h^{-1} was reached, whereby gradient was increased by 2% each minute thereafter until volitional exhaustion. $\dot{V}O_2$max was determined as the point where (a) $\dot{V}O_2$ consumption plateaued over a 30 s period and decreased with subsequent increases in workload, (b) HR was within 10 beats min^{-1} of age predicted maximum HR, (c) a respiratory exchange ratio (RER) of >1.1 was achieved, and (d) volitional fatigue was attained (Dupont et al. 2003). To determine the treadmill velocity for the test, the gradient was converted to running velocity by equating a rise in gradient of 1.5% to an increase in speed of 1 km h^{-1} (Margaria et al. 1963).

Running performance test

Participants began trials seated in a chair for 10 min to record resting values in the climate chamber set for the assigned temperature. Running commenced on the treadmill at a velocity that elicited the subject's pre-determined VT_1 for 20 min, followed by a run to exhaustion at the subject's individual v-$\dot{V}O_2$max. Subjects were then seated immediately for 10 min to obtain recovery measures.

Measurements

Rectal and skin temperature

Rectal temperature (T_{re}) was recorded using a sterile rectal thermistor (Monatherm Thermistor, 400 Series, St. Louis, MO) inserted to a depth of 10 cm past the anal sphincter. Skin temperature was also recorded throughout the exercise at four separate sites, over the main belly of pectoralis major, biceps brachii, rectus femoris and gastrocnemius using copper skin thermistors (Grant, Cambridge, UK). Placement of sensors was standardised for every trial. Temperature data were logged intermittently at 30 s intervals (Squirrel 2020 data logger series, Cambridge, UK). Mean skin temperature and mean body temperature were calculated using the following formulae:

Mean skin temperature (T_{sk}): $T_{sk} = (0.3 \times T_{chest}) + (0.3 \times T_{bicep}) + (0.2 \times T_{thigh}) + (0.2 \times T_{calf})$ (Ramanathan 1964)

Mean body temperature (T_b): $T_b = (0.65 \times T_{re}) + (0.35 \times T_{sk})$ (Colin et al. 1971)

Respiratory gas exchange and heart rate

Inspired and expired air were analysed using the ParvoMedics metabolic measurement system (TrueOne 2400, ParvoMedics, Utah, USA) at a sampling rate of 30 s throughout rest, exercise and recovery. The gas analyser was calibrated immediately before and verified after each test using a calibration gas mixture (Airgas Mid South, Tulsa, OK, USA), while the flow-meter was calibrated using a 3-L calibration syringe (Series 5530, Hans Rudolph Inc., Kansas City, USA). Ventilatory threshold deflection point at VT_1 as well as $\dot{V}O_2$max were determined by two separate investigators according to the methods of Pereira and Freedson (1997) and Aunola and Rusko (1984), respectively. Heart rate was recorded using a s810i heart rate monitor (Polar Electro Oy™, Finland).

Rating of perceived exertion

The participants' rating of perceived exertion (RPE) using a Borg 6-20 scale (Borg 1982) was recorded at the end of each workload during both the $\dot{V}O_2$max test (at exhaustion) and running performance test (10 min at VT_1, 20 min at VT_1, TTE).

Time to exhaustion

Time to exhaustion at v-$\dot{V}O_2$max (TTE) was recorded from the start of the run at v-$\dot{V}O_2$max until volitional exhaustion, when the subject reached for the handrail to stop (Bernard et al. 2000). Exhaustion was determined by attainment of $\dot{V}O_2$max, as detailed above according to the methods of Dupont et al. (2003).

Statistical analysis

All dependant variables were tested for normality using a Shapiro–Wilk's test. A two-way repeated measures ANOVA was used to compare the changes in dependant variables over time between garment conditions for each temperature. A two-way repeated measures ANOVA was also used to compare the changes in the dependant variables over time between temperature conditions. A one-way repeated measures ANOVA was used to compare the pressure, hydration variables and TTE among the four conditions. When a significant interaction effect was found, a Tukey's post hoc test was used to identify where the difference existed. Effect sizes (ES) were determined by the formula: [$mean_1 - mean_2$]/pooled SD for the differences in TTE between garment conditions. Effect sizes were deemed small (0.2–0.6), moderate (0.6–1.2) and large (>1.2). Statistical significance was set at $P < 0.05$, and all values are reported as means and standard deviations.

Results

Pressure of compression garments

No difference in pressure was observed between 10 and 32°C. The pressure applied by the compression garment was 13.6 ± 3.4 mmHg at the calf site and 8.6 ± 1.9 mmHg at the thigh site. The pressure was significantly higher ($P = 0.001$) for the calf than the thigh.

Pre-exercise hydration status and weight loss

Hydration status prior to trials as indicated by osmolality (568 ± 251 mOsm L^{-1}) and urine specific gravity (1.015 ± 0.007) were not significantly different between all conditions. No significant difference in weight loss was observed between garment conditions at both 10 and 32°C. However, weight loss was greater ($P = 0.001$) at 32°C (0.64 ± 0.1 kg) compared with 10°C (0.38 ± 0.1 kg), regardless of the garment condition.

Rectal and body temperature

No significant difference was found for changes in rectal temperature between garment conditions at either ambient temperatures throughout the test (Fig. 2a). Rectal temperature increased ($P < 0.001$) over time from rest to VT_1 and TTE for both the 10 and 32°C conditions. Rectal temperature remained higher ($P = 0.026$) in the recovery period at 32°C (38.5 ± 0.33°C) compared with 10°C (38.0 ± 0.75°C) for both garment conditions. At 10°C, body temperature was higher ($P = 0.028$) for the compression garment condition at all time points compared with the control condition, but no significant changes in body temperature were found over time (Fig. 2b). In contrast, no significant difference in body temperature between garment conditions was evident at any time point for 32°C, but body temperature increased ($P = 0.004$) from rest to VT_1. When comparing between the ambient temperatures, body temperature was higher ($P < 0.001$) for 32°C compared with 10°C at all time points, and the increase in body temperature from rest was greater ($P = 0.001$) for 32°C compared with 10°C (Fig. 2b). Thigh and calf temperatures were higher (3.1°C, $P = 0.018$ and 2.6°C, $P = 0.01$, respectively) in the compression garment condition compared with the cold condition at 10°C. However, no difference was observed between the thigh and calf temperatures between garment conditions at 32°C.

Cardiorespiratory responses

As shown in Fig. 1a, absolute oxygen consumption (L min^{-1}) was found to increase ($P < 0.001$) from rest to TTE for both 10 and 32°C, and to decrease ($P = 0.002$, $P = 0.03$, respectively) from TTE to recovery. Changes in oxygen consumption were not significantly different between garment conditions for both 10 and 32°C. This pattern of change was mirrored in relative oxygen consumption (ml kg^{-1} min^{-1}). Changes in heart rate were also not significantly different between garment conditions for both 10 and 32°C (Fig. 1b). Heart rate increased ($P < 0.001$) over time at both 10 and 32°C from rest to TTE, and decreased ($P = 0.001$) from TTE to recovery.

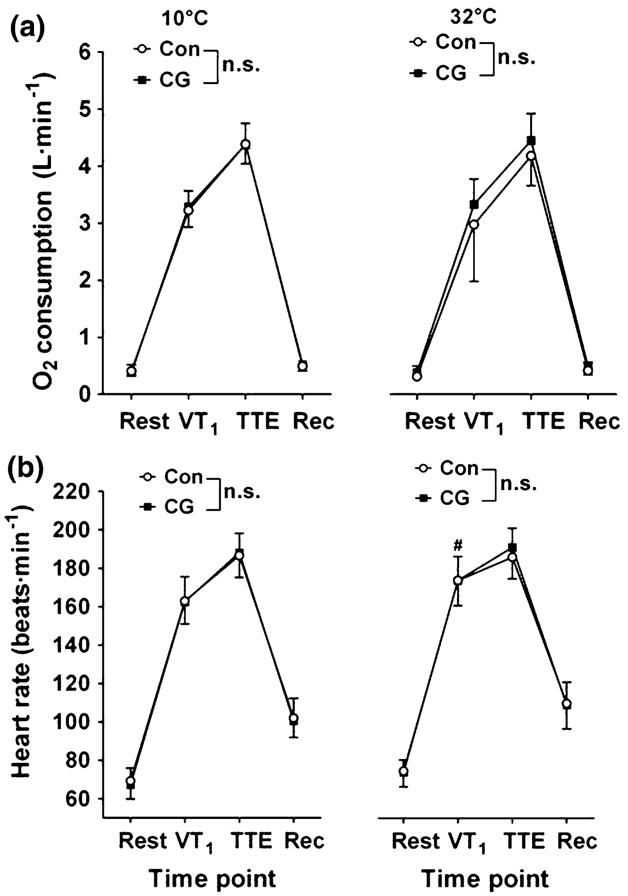

Fig. 1 Oxygen consumption (**a**) and heart rate (**b**) prior to exercise (Rest), at the end of 20-min VT_1 run (VT_1), time to exhaustion run (TTE), and 10-min recovery (Rec) between garments at 10 and 32°C. n.s.: no significant difference between garment conditions. #Significantly different between temperatures

When comparing between ambient temperatures, heart rate was higher ($P = 0.011$) for 32°C compared with 10°C at the VT_1 time point (11 ± 4.4 beats min^{-1}).

RPE

As shown in Fig. 4, increases in RPE were lower ($P = 0.018$) for the compression garment condition compared with control condition at 32°C. At 10°C, no significant difference was observed in RPE between garment conditions. When comparing between ambient temperatures, RPE was higher ($P = 0.001$) during the treadmill running at 32°C at all time points compared with 10°C.

TTE

TTE was longer ($P < 0.001$) at 10°C (153.5 ± 71.5 s) compared with 32°C (105.8 ± 36.4 s). The TTE was not significantly different between garment conditions at 10 and 32°C, respectively (Fig. 3). However, 7 out of 10 participants had a longer TTE (average +16%, range 13–75%) in the compression garment condition (ES = 0.48) at 32°C. At 10°C, five participants had an increased TTE in the compression garment condition, resulting in 6.5% (range = 1.3–41%) improvement in TTE (ES = 0.15).

Discussion

The present study evaluated the effect of compression garments on submaximal and maximal running performance based on oxygen consumption, cardiovascular responses, rating of perceived exertion and time to exhaustion. No physiological and performance differences were observed as a result of wearing compression garments in both hot (32°C) and cold (10°C) temperatures. These results did not support the hypotheses that wearing compression garments at 32°C would reduce running performance. However, the finding that compression garments had no effect on running performance is consistent with the literature reporting no significant effects of compression garments on physiological variables during submaximal runs (Ali et al. 2007; Sperlich et al. 2010) or the time to exhaustion run at v-$\dot{V}O_2$max (Sperlich et al. 2010).

It was initially hypothesised that submaximal running performance at VT_1 would be deteriorated at 32°C by CG, which might be indicated by an increase in absolute oxygen consumption when wearing compression garments as compared to the control garments. In support of this hypothesis, previous research reported increases in heat stress when extra layers of clothing were worn in the heat (Gavin 2003). In the present study, no differences in skin or rectal temperature were observed between garment conditions at 32°C during the running protocol. As skin temperature is typically regulated by the ambient temperature and is not significantly dependant on metabolism (Stolwijk and Hard 1966), an "upper limit" for skin temperature might have been established as a result of the high environmental temperature (32°C). It is possible that at 32°C, the exercise duration (20 min) might have been insufficient to cause a significant rise in rectal temperature (Fig. 2a). The skin and rectal temperatures reported in the current study are similar to those reported by Gavin (2001). These authors showed no differences in these temperatures when wearing a synthetic clothing ensemble (short-sleeve T-shirt, cycling shorts) compared with being semi-nude (lycra swim suit) during submaximal exercise in 30°C. The authors suggested that a modest amount of clothing does not alter thermoregulation in a moderately warm condition, which compares to the results of the current study.

The thigh and calf temperatures were significantly higher (3.1 and 2.6°C, respectively) with the compression

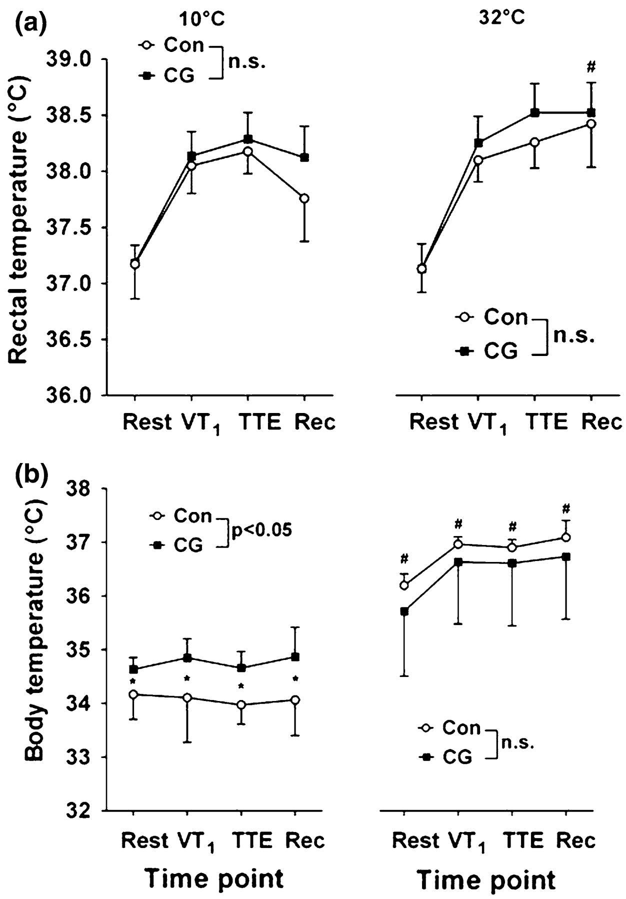

Fig. 2 Changes in rectal temperature (**a**) and body temperature (**b**) prior to exercise (Rest), at the end of 20-min VT_1 run (VT_1), time to exhaustion run (TTE), and 10-min recovery (Rec) between garments at 10 and 32°C. n.s.: no significant difference between conditions. *Significantly different between garments. #Significantly different between temperatures

garment at 10°C compared with the control condition, which was most likely due to the insulation effect of the garment. Doan et al. (2003) reported similar results where compression shorts caused a significant increase (~0.9°C) in anterior thigh skin temperature during a 5-min warm-up protocol. However, the rectal temperature was not affected by the compression garment at 10°C (Fig. 2a). Thus, the similar changes in rectal temperature over time between the garment conditions in both hot and cold ambient temperatures could explain the lack of difference in the submaximal running performance between them.

Previous research has reported a lower aerobic energy cost when running at 12 km h^{-1} with compression garments (Bringard et al. 2006b). The authors suggested that increased proprioception and increased venous blood flow contributed to the improvement in oxygen consumption. Indeed, compression garments have been shown to improve femoral blood flow in post-operative patients (Lawrence and Kakkar 1980) and increase the tissue oxygenation index at the gastrocnemius muscle in healthy individuals (Bringard et al. 2006a). The compression garments used in the present study exerted a lower level of pressure on the covered limbs compared with previous studies. For instance, the pressure measured on the main belly of the gastrocnemius muscle (13.6 mmHg) and at mid-thigh (8.6 mmHg) in the present study were notably lower than that (~23 mmHg over the gastrocnemius muscle) shown to increase muscular oxygenation by Bringard et al. (2006a). Furthermore, a study utilising the same brand of compression garments (Skins^{TM}) reported higher pressure on the limbs (gastrocnemius 17.3 mmHg, vastus lateralis 14.9 mmHg), and found a significant improvement in muscle oxygenation economy during a 1-h cycling time trial (Scanlan et al. 2008). In this study, however, Scanlan et al. (2008) found no significant changes in $\dot{V}O_2$ consumption or performance despite alterations in muscle oxygenation. Hence, changes in muscle oxygenation due to the pressure of compression garments may not necessarily translate into increases in $\dot{V}O_2$ or performance, suggesting that they may only improve venous blood flow. Further, the choice of compression garment size made in the current study strictly adhered to the manufacturer's guidelines, to maintain ecological validity within the study. Further studies are needed to evaluate the dynamics of muscular oxygenation and oxygen consumption during endurance running with compression garments.

During exercise in hot conditions, there is an increase in cardiovascular workload in order to simultaneously deliver oxygen to the working muscles and dissipate excess heat by diverting blood to the skin (Galloway and Maughan 1997; Parkin et al. 1999). As a result of the increase in cardiovascular workload, previous studies showed that the exercise time to exhaustion was attenuated (Galloway and Maughan 1997; Romer et al. 2004). Thus, it was hypothesized that the time to exhaustion would decrease at 32°C with compression garments. However, no significant difference was observed in time to exhaustion between garment conditions at 32°C (Fig. 3). This is consistent with previous research by Sperlich et al. (2010) who reported that the time to exhaustion was similar at the maximal aerobic speed with three different compression garments (socks, tights, whole-body) and control conditions. It may be that the exercise duration and intensity in the present study was insufficient to increase rectal temperature, which could explain the lack of difference between garment conditions (Fig. 2a). Indeed, Gavin (2001) has shown that thermoregulation was not negatively affected by 45 min of submaximal exercise consisting of running and walking with crew neck short sleeved T-shirt and cycling shorts at 30°C. Hence, it appears that the compression garment did

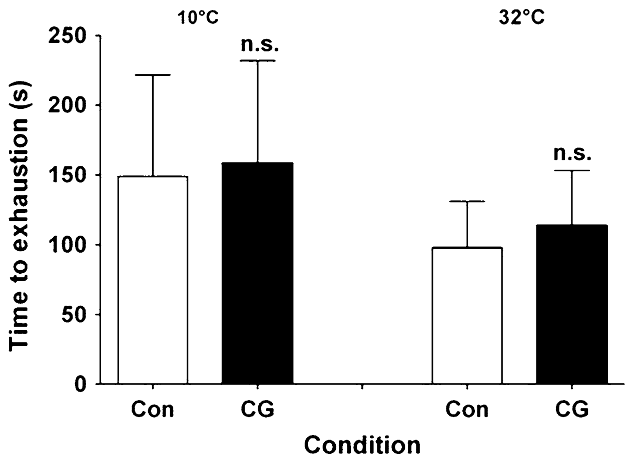

Fig. 3 Time to exhaustion in the control (Con) and compression garment (CG) conditions at 10 and 32°C. n.s.: no significant difference from control (Con) condition

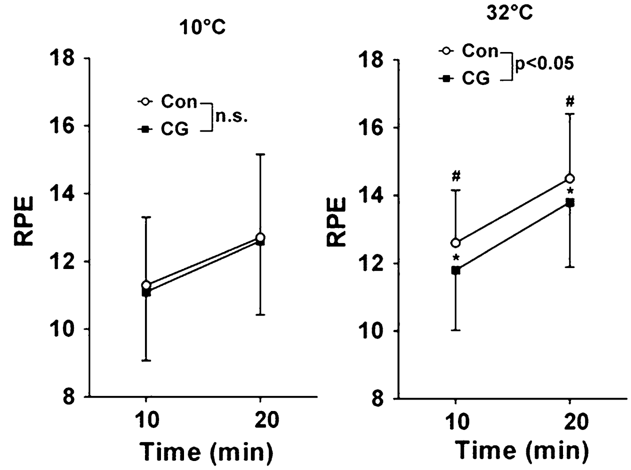

Fig. 4 Rating of perceived exertion (RPE) at 10-min into VT_1 run and at the end of 20-min VT_1 run (VT_1) between garments at 10 and 32°C. n.s.: no significant difference between conditions. *Significantly different between garments. #Significantly different between temperatures

not negatively affect time to exhaustion in the current study.

However, it is important to note that an increase in time to exhaustion was observed when wearing compression garments for some runners (13–75% at 32°C, 7 out of 10 participants; 1.3–41% at 10°C, 5 out of 10 participants) in the present study. Because of the large standard deviation in the time to exhaustion among participants, the ANOVA analysis showed no significant difference between garment conditions; however, the effect size calculation indicated a moderate (0.48) and small (0.15) effect for the 32 and 10°C conditions, respectively. Practically, any improvement in the time to exhaustion (average of 16 and 6.5% improvement, respectively) is beneficial for athletes. It is interesting that the compression garment had a positive effect on the time to exhaustion, especially at the hot temperature. It is possible that the compression garment induced a positive psychological effect (Pontrelli 1990), as represented by the RPE responses discussed below.

The RPE was significantly lower at both 10 and 20 min during the run at VT_1 in 32°C when wearing compression garments as compared to the control clothing (Fig. 4). As subjects were not blinded to the garment condition, prior knowledge of the presumed benefits of compression garments may have predisposed them to believing that their performance would benefit from using the garment (Desharnais et al. 1993). A previous study reported that 93% of subjects believed that compression shorts were "supportive" with regard to physical activity, despite no improvement in sprint, agility or maximal aerobic capacity running performance (Bernhardt and Anderson 2005). Bringard et al. (2006b) found no differences in sweating or comfort sensations, perceived exertion and thermal sensation during submaximal running with compression garments compared with elastic tights and compression shorts, but a lower energy cost of running was reported during running at 12 km h^{-1}. Thus, it is possible that wearing compression garments provides a positive psychological effect even in the heat, when core temperature is unaltered and comfort levels are not affected.

When comparing between ambient temperatures, the time to exhaustion at v-$\dot{V}O_2$max was significantly shorter under the ambient temperature of 32°C (106 s) as compared with 10°C (154 s) (Fig. 3). This difference is comparable to that reported in a previous study (Galloway and Maughan 1997) showing 82% longer TTE at 10.5°C compared with 30.5°C during a prolonged bout of cycling exercise. During exercise in the heat, cardiovascular workload is increased. For example, Parkin et al. (1999) showed the heart rate to be 13 beats min^{-1} higher at 40°C compared with 3°C during exercise at an intensity of 70% $\dot{V}O_2$max. In the present study, the heart rate was on average 11 beats min^{-1} higher in hot (32°C) compared with cold (10°C) conditions during submaximal running at VT_1 (Fig. 1b). The pattern of change in heart rate was similar to that seen in oxygen consumption during submaximal and maximal running (Fig. 1). Thus, the choice of the hot temperature in the present study seemed appropriate to examine the effect of compression garments on running performance in the heat. However, it should be noted that running is often performed in a hotter (e.g. 36°C) and more humid environment than that of the present study. Moreover, running time can be much longer than that used in the present study in some events (e.g. marathon). Further studies are therefore necessary to investigate the effect of compression garments on running in a hotter environment and on more prolonged running or other endurance activities.

In conclusion, lower body compression garments did not reduce endurance running performance or negatively affect thermoregulation at VT_1 in a hot ambient temperature (32°C). It seems possible that wearing compression garments during running can provide a psychological benefit, even in the heat, allowing them to perceive a lower exercise exertion. Thus, athletes need not be too concerned about the potential for impaired thermoregulation when exercising with compression garments in the heat, up to duration of around 30 min.

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