A. Bringard[1,2]
S. Perrey[1]
N. Belluye[2]

Aerobic Energy Cost and Sensation Responses During Submaximal Running Exercise – Positive Effects of Wearing Compression Tights

Abstract

This study aimed to examine the effects of wearing compression compared to classic elastic tights and conventional shorts (control trial) on oxygen cost and sensation responses during submaximal running exercise. In part I, aerobic energy cost was evaluated in six trained runners at 10, 12, 14, and 16 km · h^{-1}. In part II, the increase in energy cost over time (i.e., slow component expressed as difference in $\dot{V}O_2$ values between min 2 and end-exercise) was determined in six trained runners at a constant running pace corresponding to 80% of maximal $\dot{V}O_2$ for 15 min duration. All tests were performed on a 200-m indoor track with equivalent thermal stress conditions. $\dot{V}O_2$ was determined with a portable metabolic system (Cosmed K4b^2, Rome, Italy) during all testing sessions. Runners were asked their ratings of perceived exertion (RPE) and perceptions for clothing sweating, comfort, and whole thermal sensations following each trial. Results showed in part I a significant lower energy cost only at 12 km · h^{-1} by wearing compression and elastic tights compared to conventional shorts. During part II, wearing compression tights decreased significantly $\dot{V}O_2$ slow component by 26 and 36% compared to elastic tights and conventional shorts, respectively. There were no differences in sweating and comfort sensations, RPE, and for whole thermal sensation between clothing conditions in parts I and II. Wearing compression tights during running exercise may enhance overall circulation and decrease muscle oscillation to promote a lower energy expenditure at a given prolonged submaximal speed.

Key words
Compressive garments · fatigue · oxygen cost · running · slow component

Introduction

Modern training clothing are often worn simply as a fashion garment and the wearer requires neither performance nor protection beyond that offered by normal sports clothing. In fitness and leisure sports, compressive garments (e.g., tights, pants, stockings) have become more and more popular with the need to minimise the stress of walking or running, by improving physiological factors such as the energy cost of locomotion (EC, i.e., energy expenditure per unit of distance, [10]) and comfort. With this in mind, many fabrics have been introduced to the athletic apparel market with manufacturers' claims of improved health benefits. Individualised exercise programs used in conjunction with compressive garments may enhance lymphatic drainage, minimise subjective complaints, and restore strength, flexibility, and endurance of the lower limbs [13, 31]. Aerobic EC has been identified as a critical element of overall success in distance running [1] and skiing [25] activities. Among the number of factors that affect EC, clothing and possibly fatigue are additional factors that can change EC in running [9]. During submaximal heavy constant running exercise, a delayed rise in oxygen uptake ($\dot{V}O_2$) response occurs after about 2–3 min of exercise onset and

Affiliation
[1] EA 2991 Efficience et Déficience Motrices, Montpellier, France
[2] Centre de Recherche Décathlon, Villeneuve d'Ascq, France

Correspondence
Stephane Perrey, Ph.D. · EA 2991 Motor Efficiency and Deficiency Laboratory · Faculty of Sport Sciences · 700 avenue du pic saint loup · Montpellier 34090 · France · Phone: +33 4 67 41 57 61 · Fax: +33 4 67 41 57 08 · E-mail: stephane.perrey@univ-montp1.fr

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causes $\dot{V}O_2$ to rise above the expected energy requirement [2,6,7,12,16,20,29,30], that is an increase in EC. This continued rise in $\dot{V}O_2$ termed the slow component (SC) of $\dot{V}O_2$, and usually expressed as the difference in $\dot{V}O_2$ between the end-exercise and the second minute of exercise [2,16] is attributable to the working muscle [29,30]. Technical innovations in clothing are one possible intervention that may decrease EC of running at a given intensity and alleviate stresses during aerobic exercise, as endurance training [7] did.

To date, the effects of compressive clothing on athletic performance have been mainly evaluated during power sports (volleyball, [18]; track and field, [11]) and after supramaximal running exercises [3,4]. Kraemer et al. [18] demonstrated that compressive garments enhanced repetitive vertical jump power in varsity volleyball players. Based on lower body kinematics and jump performance, Doan et al. [11] have suggested that particular compressive pants may improve short, explosive types of athletic performance, and reduce injuries. Possible mechanisms contributing to the enhanced performance include a reduction in muscle oscillation [11] and increased resistance to fatigue [18]. Wearing compression stockings during and after an exhaustive running exercise has been shown to lower blood lactate levels [3] but this effect was not evident when wearing compression tights [4]. These authors hypothesised that the pressure exerted by tights was too low compared to compression stockings and was not sufficient to increase venous return. Thus, it is still unknown whether or not wearing compressive garments can have positive effects on some physiological parameters especially during submaximal running exercise. Recently, Moritani [26] showed that $\dot{V}O_2$ and muscle activity tend to decrease during submaximal cycling exercise whilst wearing long compression pants compared to control garments. Yet it is still unknown whether such pants have any influence on some "muscle efficiency" indices, such as EC and $\dot{V}O_2$ SC during submaximal running exercise. These issues remain to be investigated. Even if the efficacy of the compressive garments is confirmed with physiological assessment, subjective evaluations of comfort, sweating, and fatigue need also to be addressed.

Therefore the purposes of this study were to examine the effect of wearing compression tights compared to wearing shorts and classic tights on aerobic EC of running at various submaximal running intensities in experiment 1, and to evaluate the effects of wearing compression tights on the excess in $\dot{V}O_2$ over time (i.e., $\dot{V}O_2$ SC) usually observed during a constant running pace of 15 min duration in experiment 2. It was hypothesised that wearing compression tights would (i) decrease both EC and $\dot{V}O_2$ SC in a group of trained middle-distance runners compared to wearing classic tights and no tights, and (ii) enhance comfort, thermal and fatigue sensations. This study was possible through using a portable telemetric gas exchange system, which measured continuously the time course of $\dot{V}O_2$ in real conditions of practice.

Methods

Subjects

The present study contains two separated parts (PI and PII). The aim of PI was to determine EC and subjective sensation responses during different submaximal exercise intensities with three types of clothing. Six male trained runners ([mean ± SD] age 31.2 ± 5.4 yrs, body mass 66.0 ± 8.8 kg, height 177.3 ± 6.6 cm) volunteered to participate in PI. The purpose of PII was to examine whether wearing compression tights influenced the $\dot{V}O_2$ SC and subjective sensation responses during prolonged submaximal running exercise. Six male trained runners (age 26.7 ± 2.9 yrs, body mass 68.7 ± 10.6 kg, height 179.5 ± 7.2 cm) took part in PII. All subjects were healthy and non-smoking, with no history of cardiopulmonary disease. All the subjects were given full details (except the purposes of the present study) of the experimental protocol and any possible risks or discomforts associated with the experiment. Then each subject gave written informed consent before the first day of testing. This study complies with the Declaration of Helsinki for human experimentation.

Experimental protocol

A repeated-measures experimental design in which subjects served as their own control was used in both PI and PII. All subjects performed several track-running trials from July to September (mean temperature of 31 °C in PI and of 23.6 °C in PII) on the same indoor 200-m track marked every 25 m. In both PI and PII, all subjects wore during running trials either compression tights (Decathlon®), classic elastic tights, or conventional shorts (control trial) in a counterbalanced order. The same compression tights were used in 4 sizes according to the anthropometrical characteristics of each subject. The classic elastic tights were made of 80% polyester and 20% elasthan. The same running shoes were used for all clothing conditions.

To assess maximal $\dot{V}O_2$ ($\dot{V}O_{2max}$) in PI, the runners carried out on three different days a continuous incremental exercise test to voluntary exhaustion. The running pace was set by sounds emitted through a speaker controlled by independent digital chronometers to ensure precise control of speed by setting an audible cadence. This test was derived from the protocol proposed by Léger and Boucher [23]. The initial speed was $10\,km\cdot h^{-1}$ and was increased by $2\,km\cdot h^{-1}$ each stage until the end of the test. Each stage consisted of a 3-min period. Each subject was encouraged to exert a maximum effort. The test was stopped when the athlete could not maintain the required velocity, and when the subject had a delay of more than 25 m (that is one mark). The criterion used to assess $\dot{V}O_{2max}$ included a respiratory exchange ratio greater or equal to 1.10, a heart rate (HR) in excess of 90% of age predicted HR_{max} (220 – age), and an identification of a plateau (< $150\,ml\cdot min^{-1}$ increase) in $\dot{V}O_2$ despite a further increase in velocity. In all tests, at least two of three criteria were met. In PII, the runners performed a constant running exercise at ~ 80% of $\dot{V}O_{2max}$ of 15 min duration on three different days. Before performing this test, $\dot{V}O_{2max}$ was determined once with a ramp-like protocol.

For each test, pre- and postexercise values for body mass were determined. Body mass loss was then calculated as the difference in pre- and postexercise body mass (expressed as a percentage), which was determined using a bioelectrical impedance balance (TBF-300 Body composition analyser, Tanita Corporation, Tokyo, Japan) accurate to ± 100 g. Pressure contact electrodes on the platform allowed determination of impedance and estima-

Table **1** The degree of subjective ratings of clothing comfort, clothing sweating, and whole thermal sensations

Rating	*Clothing comfort*	*Rating*	*Clothing sweating*	*Rating*	*Whole thermal*
1	comfortable	1	dry	1	very hot
2	moderately comfortable	2	clammy	2	hot
3	a little comfortable	3	moist	3	warm
4	not at all	4	wet	4	slightly warm
5	uncomfortable	5	dripping wet	5	neutral
				6	slightly cool
				7	cool
				8	cold
				9	very cold

tion of total body water. Each session was conducted on a separate day and at the same time of the day (± 1 h) to prevent circadian effect on the physiological parameters.

Gas exchange measurements

Gas exchange measurements ($\dot{V}O_2$, carbon dioxide production [$\dot{V}CO_2$], respiratory exchange ratio [$RER = \dot{V}CO_2 \cdot \dot{V}O_2^{-1}$], and minute ventilation [$\dot{V}_E$]) were determined breath by breath with a telemetric portable (weight of 450 g) metabolic system (Cosmed K4b^2, Rome, Italy) during all testing sessions. Immediately before each test, gas analysers were calibrated with ambient air (O_2: 20.93 % and CO_2: 0.03 %) and a gas mixture of known composition (O_2: 16.00% and CO_2: 5.00%). An O_2 analyser with a polarographic electrode and a CO_2 analyser with an infrared electrode sampled expired gases at the mouth. At the end of exercise the drift rate for both analysers (drift rate = analyser drift/time collection) we observed a few times was minimal (less than – 0.008%/min for O_2 analyser and + 0.004%/min for CO_2 analyser), and therefore did not affect VO_2 values (% error < 0.3) at the end of exercise. The facemask, that had a low dead space (70 ml), was equipped with a low-resistance, bidirectional digital turbine (28 mm diameter). This turbine was calibrated before each test with a syringe of known volume (3 L, Hans Rudolph Inc, Dallas, USA). Face masks allowed subjects to simultaneously breathe with mouth and nose, for more comfort. HR was continuously measured via a wireless Polar-monitoring system (Polar Electro Oy, Kempele, Finland).

Rating of perceived exertion and subjective ratings

Following the gas exchange measurement, subjects were asked to provide a rating of perceived exertion (RPE) between 6 and 20 for the whole body [5]. Perceptions of clothing sweating sensation [14], clothing comfort sensation, and the whole thermal sensation [15] were also obtained after each testing session. The scales are listed in Table **1**.

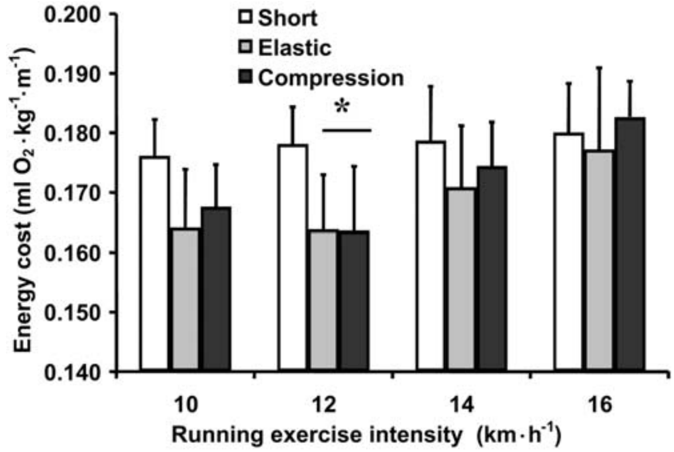

Fig. **1** Mean values (± SE) of net aerobic energy cost for different submaximal running exercise intensities among different clothing conditions. * Significantly different from Shorts condition at $p < 0.05$. $n = 6$.

Gas exchange analyses

Values for $\dot{V}O_2$ (in absolute and relative terms) were smoothed over 5 breaths for each testing session to de-emphasise breath-to-breath variation in $\dot{V}O_2$. As initially proposed by di Prampero [10], net aerobic EC ($ml \cdot kg^{-1} \cdot m^{-1}$) in PI was calculated by dividing the net $\dot{V}O_2$ (exercising $\dot{V}O_2$ minus resting $\dot{V}O_2$) averaged over the last 15 s of each 3-min stage by speed for the following running exercise intensities: 10, 12, 14, and 16 $km \cdot h^{-1}$. In PII, The SC of $\dot{V}O_2$ ($ml \cdot min^{-1}$) was calculated by subtracting the $\dot{V}O_2$ (mean values during 20 s) at the second minute of exercise from the end-exercise $\dot{V}O_2$ [2,16]. We used absolute terms for $\dot{V}O_2$ SC especially for comparison purposes with literature in the field [2,7, 12,16,20,29,30].

Statistical analysis

The running test response for cardiorespiratory and subjective variables was evaluated by a one-way analysis of variance (ANOVA) with repeated-measures across clothing conditions, followed by a Student Newman-Keuls post-hoc analysis used to isolate differences among conditions. The Friedman rank test was used when the normality or the equality of variance was violated. Data was reported as mean ± SD unless otherwise specified. The level of significance was set at $p < 0.05$ for all analyses.

Results

There were no differences in thermal stress, in body mass loss, in clothing comfort and sweating sensations, and perceived exertion between the three clothing conditions in both PI and PII (see Table **2**).

Responses during incremental exercise: PI

The overall results of the incremental tests performed in PI are shown in Fig. **1** for EC.

At 12 $km \cdot h^{-1}$, there was a significant effect among the three clothing conditions ($F[2.5] = 4.61$, $p < 0.05$ with a statistical power of 0.53). Aerobic EC was significantly lower by wearing compression and elastic tights compared to shorts (Fig. **1**). Note

Table 2 Mean values (± SD) of subjective ratings of perceived exertion (RPE), clothing comfort, clothing sweating, and whole thermal sensations in PI (at the end of the incremental exercise) and PII (at the end of the constant heavy submaximal exercise of 15 min) among different clothing conditions. S: short, E: elastic, C: compression

	Temperature (°C)			*Body mass loss (%)*			*RPE scale*			*Clothing comfort*			*Clothing sweating*			*Whole thermal*		
	S	*E*	*C*	*S*	*E*	*C*	*S*	*E*	*C*	*S*	*E*	*C*	*S*	*E*	*C*	*S*	*E*	*C*
PI	30.8	31.0	31.2	0.57	0.51	0.53	16.7	16.3	16.3	1.0	1.5	1.5	2.7	2.4	2.5	2.7	2.0	1.5
	±0.4	±0.6	±1.2	±0.23	±0.09	±0.18	±0.5	±1.3	±1.5	±0.0	±0.5	±0.8	±1.0	±1.2	±0.8	±1.9	±0.6	±0.5
PII	23.7	23.5	23.7	0.35	0.40	0.41	12.0	12.5	12.0	1.2	1.8	1.2	1.7	2.0	1.5	3.8	3.0	3.3
	±1.0	±1.5	±1.4	±0.16	±0.07	±0.12	±2.4	±1.8	±1.3	±0.4	±0.4	±0.4	±0.5	±0.9	±0.5	±0.8	±1.1	±0.8

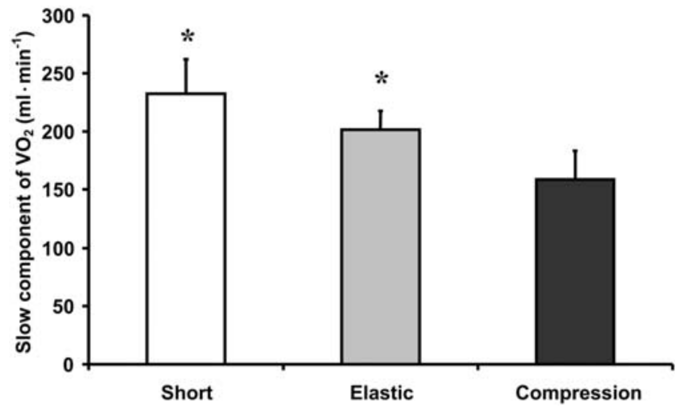

Fig. **2** Mean values (± SE) of the amplitude of the oxygen uptake taken as the difference between minutes 2 and 15 during constant heavy running exercises among different clothing conditions. * Significantly different from Compression condition at $p < 0.05$. $n = 6$.

that there was the same trend at 10 and 14 km·h^{-1} ($p < 0.1$). There were no differences in HR and $\dot{V}_E$ values among clothing conditions for each stage of the incremental exercise test. Values of $\dot{V}O_{2max}$ were not different between shorts, elastic and compression tights (60.9 ± 4.4, 59.0 ± 10.3, 60.3 ± 4.8 ml·min^{-1}·kg^{-1}, respectively).

Responses during the constant work load exercise: PII

Values of $\dot{V}O_{2max}$ and associated maximal aerobic speed for the group of subjects tested in PII were 52.2 ± 7.1 ml·min^{-1}·kg^{-1} and 17.3 ± 0.9 km·h^{-1}(range of 16.3 – 18.4). The mean running speed corresponding to 80% of $\dot{V}O_{2max}$ was 13.8 ± 0.7 km·h^{-1}.

The $\dot{V}O_2$ SC magnitude values (defined as the difference between min 2 and end-exercise value) are displayed on the Fig. **2** for the three clothing conditions tested. Magnitude of $\dot{V}O_2$ SC was significantly different among the three clothing conditions ($F[2, 4] = 7.96$, $p = 0.013$ with a statistical power of 0.79). Post-hoc tests revealed that magnitude of $\dot{V}O_2$ SC was significantly lower when wearing compression tights compared to shorts ($p = 0.01$) and to elastic tights ($p = 0.04$). There were no differences in HR and $\dot{V}_E$ between clothing conditions at some specific times (2 and 15 min, Table **3**) corresponding to the development of the $\dot{V}O_2$ SC.

Discussion

The present study aimed to evaluate the effects of wearing compression tights on some traditional "muscle efficiency" indices (EC and $\dot{V}O_2$ SC), degree of fatigue, and comfort sensations during various submaximal exercises. In the environmental conditions tested, the major finding of the present study was that wearing compression tights decreased (i) the energy cost of running at some submaximal intensities compared with conventional shorts (control trial) but not with classic tights during short-term duration exercise (PI), (ii) and the $\dot{V}O_2$ SC compared with wearing shorts (by 36%) and classic tights (by 26%) during prolonged submaximal exercise (PII). The ratings of perceived exertion were not significantly different between clothing conditions, as well as clothing comfort and sweating sensations.

Table **3** Mean values (± SE) of the difference in heart rate (HR) and minute ventilation ($\dot{V}_E$) between minutes 2 and 15 during constant heavy running exercises among different clothing conditions

	$\dot{V}_E$ (l · min^{-1})			*HR (beats · min^{-1})*		
	Short	***Elastic***	***Compression***	***Short***	***Elastic***	***Compression***
Amplitude of increase	12.3 ± 2.8	11.5 ± 2.1	13.1 ± 2.5	12.2 ± 2.3	11.4 ± 3.0	9.8 ± 2.8
Minute 2	77.5 ± 5.9	79.1 ± 7.8	78.1 ± 5.9	162.1 ± 2.5	163.6 ± 3.9	165.2 ± 2.8
Minute 15	89.8 ± 5.8	90.6 ± 6.7	91.2 ± 7.8	174.3 ± 3.5	175.0 ± 3.2	175.1 ± 1.3

Human physiological responses may be influenced by various kinds of garments. To date in the literature, many studies have been performed on the role of several thermal parameters in the determination of whole body and local exercise performance [17]. However, although clothing could influence humans thermally, to our knowledge there is no systematic study as to the role of clothing for the exercise efficacy, that is the physiological and perceptual advantages of wearing compressive garments on fatigue. Fatigue is a complex phenomenon that is characterised by a decrease in performance. It has been reported that fatigue induces an increase in energy expenditure per unit of distance (i.e., energy cost of locomotion). Running economy may be a better predictor of endurance performance than $\dot{V}O_{2max}$ in a group of trained athletes [8]. In the present study, no differences in $\dot{V}O_{2max}$ were found among the three clothing conditions (PI). However EC was significantly lower at 12 km · h^{-1} (Fig. **1**) by wearing either compression tights or elastic tights compared to conventional shorts. The positive effect of wearing tights may assist motion pattern by increasing proprioception, muscle coordination, and the propulsive force, resulting in less metabolic cost of running at a given speed. Previous studies have shown an increased proprioception with compressive garments which may improve technique [28]. A sleeve worn on the knee improved the integration of the balance control system and muscle coordination [21]. Note that in the present study, EC did not differ significantly between compression and elastic tights. Some further advantages of the compression compared to elastic tights may be not apparent during exercise of too short duration (3 min for each stage in PI) as in this experimental protocol. The "mechanical" support (if any) of compression tights may have a measurable effect during a longer submaximal exercise at a constant pace to judge exercise tolerance and energy expenditure changes over time.

The $\dot{V}O_2$ SC has been suggested to be an important determinant of exercise tolerance in both patient populations and athletic groups [12]. A reduction of the SC with exercise is therefore highly desirable, as this adaptation may allow undertaking longer periods of physical activity, and increasing work tolerance before early fatigue development [12]. Although no consensus exists, several variables have been identified as predictors of $\dot{V}O_2$ SC during prolonged exercise including blood lactate concentration, cardiorespiratory work, muscle O_2 availability, and motor-unit recruitment patterns [12]. However most recent evidence points toward motor unit recruitment patterns in the aetiology of the $\dot{V}O_2$ SC [6,20,29]. Moritani [26] have shown with electromyographic technique that during cycling exercise, fatigue of thigh muscles was decreased when subjects wore compressive garments compared to a control condition. We noted in the present study (PII) a 26% and 36% decrease in $\dot{V}O_2$ SC by wearing compression tights compared to classic tights and shorts, respectively. This indicates that there may be a subtle ergonomic interplay between the close fitting garment and some biological mechanisms over time. Wearing a lower-body compressive garment may reduce muscle fatigue by supporting more active muscles and applying pressure in such a way as to support muscle fibers in their contraction direction. Reduced longitudinal and anterior muscle oscillation upon landing from a maximal vertical jump [11] was speculated to be a contributing factor to increase repetitive jump performance by reducing fatigue [19]. The proposed ergonomic mechanism is that reduced muscle oscillations with support may optimise neurotransmission and mechanics at the molecular level [24], and in turn, reduce myoelectric activity ([27], a paradigm of muscle tuning). Effects of the muscle tuning associated with an ergonomic interface such as a compressive garment could be seen in performance, fatigue, and comfort characteristics of repetitive impact loading during running. Compressive garments have been shown also to be beneficial in that they help the muscle pumping action of the cardiovascular system (increased venous return) to remove blood lactate from exercising muscle [3,19]. Although coincidental rather than causal, several previous cross-sectional studies have shown a close relationship between the magnitude of the blood lactate increase and the $\dot{V}O_2$ SC [7,12]. Indeed Saunders et al. [30] reported that increased motor unit recruitment was responsible for the close relationship between the $\dot{V}O_2$ SC and blood lactate increase. Altogether, effects of compressive garments on blood lactate removal and muscle support function may lead to a reduced muscle fatigue and a better exercise tolerance (i.e., lowered $\dot{V}O_2$ SC). The mechanisms for such improvement remain speculative and require further study.

In the present study we did not observe any difference in environmental temperature during the experimental tests in PI as in PII. During exercise, clothing can influence exercise HR due to differences in tympanic temperature [22]. However we did not observe any differences in HR among clothing conditions both in PI and PII. Thus, the thermoregulatory stress associated with each exercise test was likely identical. In spite of differences in the amount of skin surface covered by elastic and compressive clothing compared to shorts condition, we did not observe any differences in sweating and comfort sensations, perceived exertion, and for whole thermal sensation between clothing conditions in both PI and PII. Note however that during PII, comfort sensation for wearing compression tights was perceived as comfortable as wearing shorts. There were no significant differences in weight loss between clothing conditions, suggesting that in the moderately warm temperature test conditions (range of 24 – 31 °C), neither clothing nor skin coverage affects body mass loss. Overall, our results are in accordance with those of Gavin et al. [14] who demonstrated that at ~ 30 °C neither the addition of a modest amount of clothing nor the fabric characteristics of the clothing alters thermoregulatory and thermal comfort, and sweating sensation responses during and after 30 min running (70 % $\dot{V}O_{2max}$) and 15 min walking (30 % $\dot{V}O_{2max}$) exercises.

In conclusion, these preliminary results showed for the first time that in the same environmental conditions a lower energy cost was obtained at a submaximal exercise intensity (~ 12 $km \cdot h^{-1}$) by wearing compression and elastic tights compared to conventional shorts. During heavy running exercise for 15 min duration, wearing compression tights decreased by 26 and 36 % the $\dot{V}O_2$ slow component compared to elastic tights and conventional shorts, respectively. Wearing compression tights during running exercise may enhance overall circulation and decrease muscle oscillations to promote a lower energy expenditure at a given submaximal speed (i.e., lessening muscle fatigue). Further studies in this area are needed to understand the mechanisms of this ergonomic interface during submaximal and prolonged running exercise.

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