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Leg compressions improve ventilatory efficiency while reducing peak and post exercise blood lactate, but does not improve perceived exertion, exercise economy or aerobic exercise capacity in endurance-trained runners

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ABSTRACT

Purpose: The objective of this study was to determine if leg compressions would alter cardiorespiratory and perceived exertion measures during rest, submaximal and maximal exercise in endurance-trained runners.
Method: Thirteen young, endurance trained runners (10 males, 20.9 ± 3y, 58.9 ± 5.7 ml kg min^{-1}) completed a randomized design, leg compressions and non-compression control condition. The incremental graded exercise test consisted of baseline rest and submaximal intensities at 23%, 70%, 75%, 85% and then a progressive increase to 100% VO_2max. Running economy (RE), rating of perceived exertion (RPE), breathing rate (BR), heart rate (HR), ventilation (VE), blood lactate, VO_2max and ventilatory efficiency (VE/VO_2) were the primary outcome variables.
Results: Relative to the control condition, VO_2 at rest, during submaximal and at max were not different. Additionally, RE, RPE, BR, and HR were similar under both conditions. Leg compressions reduced lactate at VO_2max by 11% ($P < 0.05$) and at 10 min post-exercise recovery by 18% ($P < 0.01$). Additionally, peak VE was significantly reduced in the compression condition by 8% ($P < 0.0001$) relative to the control condition. Ventilatory efficiency was improved in compressions compared to control condition at 85 and 100% VO_2max (condition × time interaction, $P < 0.0001$).
Conclusion: These data suggest that leg compressions do not alter RE, RPE, BR, HR, or VO_2, during exercise. However, compressions may be beneficial for submaximal and maximal ventilatory efficiency while improving lactate clearance at VO_2max and during recovery in trained runners.

1. Introduction

Leg compressions have been reported to benefit clinical populations. In populations with poor blood circulation and impaired vascular function (*i.e.*, edema, diabetes, and peripheral arterial disease), compression therapy is utilized as the "gold standard" for the treatment of chronic venous insufficiency (Clayman et al., 2009; Teruya and Ballard, 2004; Wu et al., 2012). In these clinical patients, leg compressions improve hemoglobin and muscle oxygenation concentration during resting supine and while walking, suggesting the increased compression pressure of the sock is sufficient to overcome muscle contraction during walking (Agu et al., 2004; Charles et al., 2011). Likewise, lower limb compressions have been shown to improve the management of vasovagal syncope (Dos Santos et al., 2013), which is caused by a reduction of leg and brain blood flow. Thus, lower leg compression may benefit individuals with vascular impairments by reducing venous pooling, improving deeper tissue oxygenation, and assisting with venous blood return/circulation in the lower extremity (Agu et al., 2004).

Leg compressions are commonly advertised to improve exercise performance and are commonly worn by elite and recreational athletes for that purpose. As an ergogenic aid, the use of leg compressions is based on the premise that an increase in venous return, *via* calf muscle pump efficiency, will enhance aerobic capacity (*i.e.*, VO_2max$_)$ by enhancing cardiac output. Notably, endurance exercise performance is reliant on several factors such as maximal oxygen

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uptake (VO_2max), lactate threshold, and running economy (Coyle, 1999; Daniels et al., 1978; Robergs and Keteyian, 2003). At submaximal intensities, differences between highly trained endurance athletes can be attributed to the energy cost of movement or running economy (Daniels, 1985). Additionally, determinants that affect running economy may also be caused by biomechanical factors. The adaptations of optimal stride length and frequency as a result of an increase in aerobic training loads, along with improvements in fitness, strength, and coordination may improve running economy (Daniels, 1985; Paavolainen et al., 1985). It has been suggested that graduated compression design provides support and stability to muscles of the lower leg and joint complexes of the foot and ankle. Thus, the combination of compression and biomechanical support may enhance exercise metabolism and gait efficiency during athletic activity. Additionally, the improvements in blood flow while wearing lower leg compressions may assist in the clearance of byproducts of exercise fatigue.

Elastic compressions may improve aerobic exercise endurance capacity by altering hemodynamics, metabolism, and biomechanical support in the lower extremity (Ali et al., 2010, 2011; Berry and McMurray, 1987; Dascombe et al., 2011; Kemmler et al., 2009; Watanuki and Murata, 1994). Others have investigated compressions in diseased populations with positive findings (Agu et al., 2004; Berry and McMurray, 1987; Watanuki and Murata, 1994). Furthermore, the utilization of leg compressions may have post-exercise implications such as improving blood flow, clearing blood lactate, and reducing muscle soreness post-exercise (Ali et al., 2010, 2011; Berry and McMurray, 1987; Hill et al., 2014). In addition to these potentially beneficial physiological benefits, there may be a placebo effect that improves the perception of exertion to exercise. Though, each of the aforementioned characteristics of exercise has been assessed separately while utilizing various forms of compressions (total leg, above, and below the knee), none have assessed a combination of physiological and perception of exertion assessments that contribute to submaximal and maximal exercise capacity under the same experimental conditions. Therefore, the purpose of this study was to determine if commercially available below the knee lower leg compressions would improve resting/submaximal/maximal exercise test cardiorespiratory measurements (heart rate, breathing rate, ventilation, oxygen uptake), lactate metabolism, and perception of exercise intensity during running in endurance-trained athletes. We hypothesized that during rest, submaximal and maximal exercise test, the cardiorespiratory measurements (heart rate, breathing rate, ventilation, oxygen uptake), and perception of exercise intensity would be significantly enhanced during running and that lactate metabolism would improve at maximal and post-exercise with the lower leg compressions compared to without them.

2. Materials and methods

2.1. Experimental study design

The experiment was a repeated measure cross-over design with randomization to determine whether lower leg compressions (worn on either the first or second trial) would improve submaximal and maximal aerobic exercise capacity. Subjects visited the laboratory at the same time of day on three occasions: one occasion for familiarization and two for the experimental trials. During the familiarization day, subjects sign the consent forms and were familiarized with all procedures. Subjects were randomized to a treatment or control condition. The treatment condition consisted of either wearing lower leg below the knee compressions in both legs, and the control was non-compression ankle length sock Each experimental trial consisted of subjects completing a baseline resting and standing procedure followed by an incremental graded exercise test to exhaustion. This test was used to establish running economy at three velocities and VO_2max. Shoe size and calf circumference at the widest point and distance from the ground to the bend behind the knee measurements were recorded for precise compression sock fitting (Oxysox® Compression Technology, Patent US6173452 B1). According to manufacturer specifications, graduated lower leg below knee compression socks were 12–15 mmHg at the ankle and 9–12 mmHg over the calf.

Table 1
Subject characteristics (mean ± SD).

Number of subjects (m/f)	10/3
Age (y)	20.9 ± 2.5
Height (cm)	170.8 ± 6.8
Weight (kg)	63.3 ± 7.5
VO_2max (ml kg min^{-1})	58.9 ± 5.7
VO_2max (L min^{-1})	3.7 ± 0.4 ml kg min^{-1} which was ~71.0 ± 5.9%

2.2. Participants

Thirteen collegiate cross-country male and female student-athletes who were endurance-trained volunteered for the study. Subject characteristics are presented in Table 1. Prior to testing, each participant was fully informed of all of the risks/experimental procedures and signed health screening questionnaires as well as an informed written consent approved by the Institutional Review Board for the Protection of Human Subjects and Code of Ethics of the World Medical Association (Declaration of Helsinki). All subjects were healthy, not taking medications that would disrupt normal cardiovascular physiologic function, and free of musculoskeletal injury. Subjects were instructed to refrain from eating three hours before testing and to avoid caffeine six hours before testing. Subjects were instructed to wear the same footwear and apparel each day during testing except for the below the knee lower leg garments being investigated (ankle socks *vs* leg compressions). Both exercise bouts had a minimum of one week between tests to omit any carryover effects of fatigue and training effects on aerobic exercise performance. Up to 48 h prior to testing, subjects were asked to refrain from vigorous exercise training sessions.

2.3. Pre-exercise resting data

Subjects were fitted with a heart-rate monitor (Polar Accurex IIa) and mouthpiece interfaced with a Med Graphics Cardiorespiratory Diagnostic Systems (model CPX Express, MN, USA) metabolic cart and then rested in a supine position while oxygen consumption (VO_2) and heart rate (HR) was measured for two minutes after a 30 min baseline. Subjects then stood on the treadmill for another three minutes while these same variables were measured. Subjects were instructed to breathe normally during pre-exercise data collection and were given one minute to move from supine to standing. Pre and post-exercise blood lactate were also measured with a YSI 1500 Sport Lactate Analyzer (Yellow Springs Incorporated, USA) using a standard finger-prick method after baseline rest, immediately after VO_2max, and 10 min post-exercise recovery.

2.4. Submaximal and maximal graded exercise testing

After pre-exercise data collection, subjects began a warm up walk at 4.8 km/h for four minutes which was followed by three four-minute running stages (12.1, 12.9, & 13.8 km/h) during which running economy was assessed. These corresponding relative intensities were 23 ± 2, 70 ± 6, 74 ± 7, and 85 ± 7% of VO_2max, respectively. The VO_2max test immediately followed the submaxi-