Effects of compression garments on surface EMG and physiological responses during and after distance running

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Abstract

Background: The few previous studies that focused on the effects of compression garments (CG) on distance running performance have simultaneously measured electromyogram, physiological, and perceptual parameters. Therefore, this study investigated the effects of CG on muscle activation and median frequency during and after distance running, as well as blood-lactate concentration and rating of perceived exertion (RPE) during distance running.

Methods: Eight healthy male recreational runners were recruited to randomly perform two 40 min treadmill running trials, one with CG, and the other with control garment made of normal cloth. The RPE and the surface electromyography (EMG) of 5 lower extremity muscles including gluteus maximus (GM), rectus femoris (RF), semitendinosus (ST), tibialis anterior (TA), and gastrocnemius (GAS) were measured during the running trial. The blood-lactate levels before and after the running trial were measured.

Results: Wearing CG led to significant lower muscle activation ($p < 0.05$) in the GM (decreased 7.40%–14.31%), RF (decreased 4.39%–4.76%), and ST (decreased 3.42%–7.20%) muscles; moreover, significant higher median frequency ($p < 0.05$) in the GM (increased 5.57%) and ST (increased 10.58%) muscles. Wearing CG did not alter the RPE values or the blood-lactate levels ($p > 0.05$).

Conclusion: Wearing CG was associated with significantly lower muscle activation and higher median frequency in the running-related key muscles during distance running. This finding suggested that wearing CG may improve muscle function, which might enhance running performance and prevent muscle fatigue.

Keywords: Blood lactate; Compression garment; Fatigue; Muscle activation; Rate of perceived exertion; Running

1. Introduction

Compression garments (CG) have become quite popular and are widely used for distance running by both well-trained athletes and recreational runners. During distance running, runners must maintain a mechanical output while minimizing metabolic energy expenditure, resisting fatigue, and accelerating recovery.1 It has been documented that runners who wear CG have improved post-exercise muscle function and recovery.2,3 Previous studies focused on the effects of CG on measured post-running muscle function by examining runners’ vertical jumping height4,5 and also physiological recovery using reported blood lactate.5,7 The improved scores in CG-wearers have been attributed to decreased oscillation of muscles8 and enhanced venous hemodynamics.9 Moreover, studies have shown that wearing CG while running improved runners’ subjective ratings, such as rating of perceived exertion (RPE), as measured by the Borg scale.5

Despite the above documented benefits, the effects of CG on distance running performance still remain ambiguous. Some studies have indicated that compression stockings or sleeves on the lower legs have little or no beneficial effect on performance during and after distance running.10,11 It remains unclear whether any change occurs in the local muscles of the lower extremities, as previous studies assessed muscle
function after distance running using a comprehensive performance measure, specifically vertical jumping.\textsuperscript{5,10} Such measurement does not give a detailed understanding of specific or sensitive changes in local muscles of the lower extremity. Thus, the question of whether wearing CG improves muscle function in the lower extremities during submaximal endurance running remains unanswered. To evaluate the efficacy of CG during and after distance running, this study combined muscular activation measures with physiological and perceptual assessments.

Muscular activity while running has been well documented using surface electromyography (EMG).\textsuperscript{12–14} In this technique, the average EMG amplitudes for a given period are used to quantify the level of muscle activation over the running time. While running, localized muscular fatigue induced by prolonged and sustained muscular activity may affect the ability to produce or maintain a certain force level. The median frequency (MDF) is a common parameter obtained from the power spectrum analysis of EMG signals, and shifts toward lower frequencies are taken as an index of muscle fatigue during muscle contractions.\textsuperscript{10,15,16} Recently, EMG has been used to evaluate the effect of CG during calf-raising exercise,\textsuperscript{17} 20 s runs,\textsuperscript{18} and isometric and isokinetic knee extension tasks.\textsuperscript{19} However, the effect of CG on EMG parameters during distance running has not yet been explored.

Blood-lactate concentration, an indicator of muscle metabolites and recovery, has been widely used to investigate the effects of CG during running and post-running recovery.\textsuperscript{5,20,21} Some studies indicated that running with CG reduced blood-lactate\textsuperscript{6,22} by inducing greater blood flow. However, when CG were worn by well-trained athletes during high-intensity exercise,\textsuperscript{17} 20 s runs,\textsuperscript{18} and isometric and isokinetic knee extension tasks,\textsuperscript{19} the effect of CG on EMG parameters during distance running has not yet been explored.

2. Methods

2.1. Participants

Eight healthy male recreational runners (age 24.9 ± 2.3 years, height 170.0 ± 3.3 cm, weight 60.0 ± 7.1 kg; mean ± SD) participated in the study. The inclusion criteria were age of 20–35 years old with regular running habits (8–12 h/week). The exclusion criteria were history or complaints of any cardiovascular disease, lower limb trauma, and current use of medication.

2.2. Garments

The CG, the full lower body garments from ankle to waist, were individually produced (74% polyamide and 26% Spandex) and fitted for each subject. A pressure sensor (Tekscan, Inc., South Boston, MA, USA) was used to assess the pressure of the CG for each subject and was placed between skin and the CG on the muscle belly of lateral gastrocnemius (GAS), rectus femoris (RF), and gluteus maximus (GM). The CG pressure was 32 ± 2 mmHg at shank, 22 ± 2 mmHg at thigh, and 16 ± 2 mmHg at hip. Normal sports clothing without any pressure was used in this study as the control garment (CON) (Fig. 1).

2.3. Measurement

Each participant’s average maximal oxygen consumption (VO\textsubscript{2max}) was measured with an incremental exercise test to exhaustion using the Bruce protocol with a metabolic system (Cortex METALYZER, Leipzig, Germany).\textsuperscript{24} The VO\textsubscript{2max} was 44.00 ± 3.41 mL/kg/min and the maximal heart rate was 188.98 ± 2.25 beats/min. Seven days after the VO\textsubscript{2max} measurement, the study participants performed two 40-min treadmill running sessions wearing either the CG or CON. The tests used a randomized counterbalanced design and each session was separated by a 7-day recovery period to avoid any residual effect and fatigue. Each running trial began with a 10-min warm-up, consisting of 5-min of running on the treadmill at a speed corresponding to the individual’s aerobic threshold followed by 5-min of lower extremity stretching. The participants then performed a 40-min treadmill run at a predicted oxygen uptake to estimate the velocity at 75% VO\textsubscript{2max} and at a gradient of 1% to correct for the effect of air resistance.\textsuperscript{25}

With an external trigger, the EMG signals and digital video data were synchronously collected for 1 min during the first (initial stage) and last (end stage) minute of the 40-min running trial. The EMG signals of the 5 lower extremity muscles, GM, RF, semitendinosus (ST), tibialis anterior (TA), and GAS, were measured using preamplified surface electrodes (Trigno Wireless EMG systems; Delsys, Boston, MA, USA) at a sampling rate of 2000 Hz. The skin was shaved and scrubbed with alcohol to reduce interelectrode resistance before the
2.4. Statistical analysis

To analyze the EMG and MDF variables of each muscle during the stance and swing phases, paired comparisons between 2 garment conditions (CG and CON) and between 2 time points (the initial and end stages of running) were performed using Wilcoxon signed-rank test. For the blood-lactate and RPE variables, the Wilcoxon signed-rank test was also performed to compare the garment conditions at each time point. The significant level was set at α = 0.05. SPSS Version 19.0 (IBM Corp., Armonk, NY, USA) was used for the statistical analysis.

3. Results

The muscle activations, as shown in Table 1, were significantly smaller in CG condition than in CON condition for GM and ST at both stages during stance phase and for RF at both stages during swing phase. At the end of the running trial,
the muscle activation of TA significantly decreased during stance phase in 2 conditions (CG: \( p = 0.018 \), mean difference = −13.98% ± 18.82%; CON: \( p = 0.018 \), mean difference = −8.56% ± 10.46%).

As shown in Table 2, regarding the MDF, CG exerted significant effects on ST at the initial stage during stance phase and GM at the initial stage during swing phase; the MDF values were both greater in CG condition than that in CON condition. At the end of the running trial, the MDF of TA significantly increased during stance phase in both conditions (CG: \( p = 0.018 \), mean difference = 13.00% ± 10.93%; CON: \( p = 0.012 \), mean difference = 13.23% ± 10.15%).

No difference in blood-lactate concentration was observed between CG and CON conditions at any measurement time points (Table 3). The blood-lactate concentration increased after the 40-min running trial in both CG and CON conditions. Furthermore, the RPE in both conditions significantly increased after the 40-min running trial. Additionally, no differences were observed between the CON and CG conditions at the beginning (0 min), and after 10 min, 20 min, 30 min, and 40 min of running (Table 4).

### 4. Discussion

This study is the first to simultaneously measure EMG and physiological and psychological parameters to investigate the effects of CG on distance running. It examined muscular activation, MDF, blood-lactate concentration, and RPE. The major results revealed reduced muscle activation and increased MDF of certain running-related key muscles as GM, ST, and RF in CG condition, which indicated CG effects on muscle function during distance running, although wearing CG did not improve the blood-lactate concentration and RPE during distance running.

Previous studies evaluated the effects of CG on muscle function by vertical jumping after endurance running. Instead, this study used EMG signals to directly measure muscle activation and MDF, and thus to examine specific changes in the running-related muscles during endurance running. Under CG condition, smaller average muscle activation of GM and ST during stance phase and RF during swing phase at the 1-min initial and the 40-min final running phase was found, suggesting that CG reduces the demand for muscle activation in the GM, ST, and RF during the 40-min run. Although no previous study has directly monitored EMG signals during long-distance running while wearing CG, one study did

### Table 2

| Phase, muscle, and time | CG (mmol/L) | CON (mmol/L) | Mean difference | \( p \) |
|------------------------|-------------|--------------|-----------------|------|
| Stance                 |             |              |                 |      |
| GM                     |             |              |                 |      |
| Initial                | 44.08 ± 14.62 | 42.12 ± 15.11 | 1.97 ± 20.67    | 0.674 |
| End                    | 51.64 ± 13.69 | 44.66 ± 24.57 | 6.98 ± 27.61    | 0.208 |
| RF                     |             |              |                 |      |
| Initial                | 61.33 ± 10.37 | 54.63 ± 9.06  | 6.69 ± 12.14    | 0.208 |
| End                    | 64.54 ± 16.64 | 53.33 ± 14.40 | 10.21 ± 25.71   | 0.327 |
| ST                     |             |              |                 |      |
| Initial                | 78.18 ± 12.75 | 72.41 ± 14.61 | 5.77 ± 14.12    | 0.208 |
| End                    | 83.49 ± 14.97 | 72.91 ± 19.45 | 10.58 ± 11.80   | 0.049*|
| TA                     |             |              |                 |      |
| Initial                | 69.63 ± 16.75 | 69.06 ± 18.80 | 0.57 ± 21.31    | 1.000 |
| End                    | 82.63 ± 17.18* | 82.29 ± 15.13* | 0.31 ± 14.46    | 0.779 |
| GAS                    |             |              |                 |      |
| Initial                | 117.43 ± 22.99 | 124.44 ± 20.09 | −7.01 ± 15.84  | 0.263 |
| End                    | 126.63 ± 19.14 | 119.87 ± 19.05 | 6.77 ± 20.47    | 0.208 |
| Swing                  |             |              |                 |      |
| GM                     |             |              |                 |      |
| Initial                | 57.15 ± 7.52  | 51.88 ± 8.91  | 5.57 ± 6.61     | 0.036*|
| End                    | 60.26 ± 7.27  | 46.72 ± 14.69 | 13.54 ± 20.61   | 0.161 |
| RF                     |             |              |                 |      |
| Initial                | 65.42 ± 11.00 | 59.60 ± 4.80  | 5.81 ± 14.29    | 0.208 |
| End                    | 62.54 ± 17.02 | 53.85 ± 9.22  | 8.69 ± 23.97    | 0.575 |
| ST                     |             |              |                 |      |
| Initial                | 82.13 ± 10.90 | 75.97 ± 7.19  | 6.15 ± 14.55    | 0.401 |
| End                    | 74.78 ± 9.19  | 75.33 ± 8.35  | −0.55 ± 7.62    | 1.000 |
| TA                     |             |              |                 |      |
| Initial                | 86.85 ± 18.50 | 85.93 ± 14.18 | 0.92 ± 14.29    | 0.575 |
| End                    | 92.26 ± 14.73 | 82.44 ± 13.35 | 9.82 ± 15.59    | 0.123 |
| GAS                    |             |              |                 |      |
| Initial                | 74.70 ± 12.16 | 64.15 ± 14.20 | 10.56 ± 13.73   | 0.123 |
| End                    | 74.01 ± 13.39 | 65.16 ± 4.91  | 8.85 ± 17.52    | 0.208 |

* Significant difference between time points.

* Significant difference between conditions.

\( \text{CG} = \) compressive garment; \( \text{CON} = \) normal control garment; \( \text{RF} = \) rectus femoris; \( \text{ST} = \) semitendinosus; \( \text{TA} = \) tibialis anterior.

### Table 3

Lactic acid accumulation and clearance before and after running (mean ± SD).

|                  | CG (mmol/L) | CON (mmol/L) | \( p \) |
|------------------|-------------|--------------|------|
| Pre              | 2.30 ± 0.55 | 1.88 ± 0.54  | 0.50 |
| AWU              | 2.33 ± 1.07 | 2.39 ± 0.69  | 0.48 |
| Post-0           | 6.82 ± 3.60* | 8.38 ± 3.51* | 0.21 |
| Post-5           | 7.24 ± 2.56 | 7.69 ± 3.34  | 0.58 |
| Post-15          | 4.91 ± 2.76 | 4.93 ± 1.58  | 0.58 |
| Post-30          | 2.87 ± 0.71 | 2.82 ± 0.78  | 0.78 |

* Significant difference between Pre and Post-0 time points within group.

\( \text{Pre} = \) before any warm-up or any exercise.

\( \text{AWU} = \) after warm-up. Abbreviations: \( \text{CG} = \) compressive garment; \( \text{CON} = \) normal control garment; \( \text{RAU} = \) after running; \( \text{Post} = \) after the end of running.

### Table 4

RPE at the beginning (0 min), 10 min, 20 min, 30 min, and 40 min of running (mean ± SD).

|                  | CG          | CON          | \( p \) |
|------------------|-------------|--------------|------|
| 0 min            | 6.33 ± 0.52 | 6.33 ± 0.52  | 1.00 |
| 10 min           | 8.33 ± 2.58 | 7.83 ± 1.94  | 0.78 |
| 20 min           | 10.50 ± 2.59 | 10.17 ± 2.04 | 0.50 |
| 30 min           | 12.33 ± 2.73 | 12.17 ± 1.47 | 0.86 |
| 40 min           | 13.83 ± 3.43* | 13.83 ± 2.14* | 0.95 |

* Significant difference between 0 min and 40 min time points within group.
Compression garments in muscle activation

observe lower limb muscle activation in the RF and GAS during a short run when CG was worn. Another study found that wearing CG significantly decreased muscle activation during the MVIC performance and isokinetic knee extension. The reduction in muscle activation while wearing CG may be due to the reduction of muscle oscillation, which decreases the recruitment of muscles to maintain joint stability. Most importantly, it has been reported that CG help to delay the onset of fatigue and to maintain muscle function, which may be associated with the enhancement of running performance and a reduced risk of running-related injuries. RF plays a major role in hip flexion and GM and ST, which help to extend the hip in the first half of stance phase and the second half of swing phase, are crucial for producing forward propulsion. A previous study showed that the elasticity of CG can enhance running performance by providing additional force in hip flexion and extension. Moreover, ST also decelerates the momentum of the swing limb as the knee extends during the late swing phase, which has important eccentric and concentric functions. The tight fit and elastic nature of CG may assist the hamstrings in limiting knee extension at the terminal swing phase, a period that is particularly risky for hamstring injuries. Thus, the enhancement of support and compressive pressure brought about by wearing CG appear to increase the efficiency of muscle contraction.

It is well-known that a shift in MDF toward lower frequencies is an index of muscle fatigue. In our study, the MDFs did not decrease in any muscle, with or without CG, during the 40-min running trials with constant 75%VO₂max. This indicated that there was no fatigue during the high-intensity running. This result is consistent with the study of Ali et al., in which a 40-min treadmill running test was also performed among runners with 75%-85%VO₂max and found that compression stockings did not affect muscle fatigue measured by vertical jumping height after running. Although according to the current testing protocol, the subjects were not in fatigue condition, interpretations of the CG effect on muscle fatigue were limited. The current study determined that wearing CG induced higher MDF in ST during stance phase and in GM during swing phase; the participants who wore CG also maintained higher MDF between the 1-min and 40-min running phases. Fu et al. also used nonfatigue protocol and reported that the mean power frequency of the knee extensor under CG condition was significantly higher than the control condition during isokinetic muscle contractions at 60°/s. They suggested that local CG increase muscle efficiency, which might reduce muscle fatigue. The shift in MDF toward higher frequencies may be due to increment in the conduction velocity of muscle fibers. Thus, higher MDF in CG condition of this study indicated greater muscle efficiency in GM and ST, and possibly greater resistance to fatigue during endurance running. This is in agreement with previous studies on other nonfatigue testing protocol. After fatigue-induced exercise, Miyamoto et al. discovered that wearing compression stockings could relieve leg muscle fatigue with less decline in mean power frequency.

The possible mechanisms for the enhancement of muscle function or recovery using CG are still unclear. These positive effects on muscle function may commonly be explained by the effect of CG on improved proprioception, increased venous flow velocity, and decreased muscle oscillation, which have been reported previously. Recently, some studies focused on the influence of transversal muscle loads on muscle function by experimentation and simulation. Their findings indicated that transversal loads or pressures induced by external compression had negative effect on muscle force production and gearing, especially on explosive muscle performance, due to the change of muscle architecture. On the other hand, this transversally compressed muscle may be a benefit to repetitive and dynamic locomotion, such as running. The transversal loads can lead to more positive work of the contractile component of muscle. Moreover, passive restoring and recoil of muscle elastic elements, which are induced by transversal loads, may decrease metabolic energy expenditure. These reactions may be another mechanism to improve muscle efficacy during distance running in the present study. However, it remains unclear how much transversal loads or pressures induced by CG can result in the alternation of muscle structure and negatively or positively influence muscle function. According to further research, it is still required to investigate the effect of transversal loads or pressures on muscle function and sport performance.

Our results support the hypotheses that wearing CG does not improve lactate clearance after a 40-min submaximal running session. Excessive workload may result in lactate production in the blood faster than its removal. It is postulated that the blood-lactate clearance mechanism is enhanced by the external mechanical pressure provided with CG. However, our study did not find any significant effect of CG on lactate clearance. Lactate concentration might be a factor in MDF shift. Consistent with previous studies in which the run-to-exhaustion protocol was not adopted, we also identified no significant changes in blood-lactate levels after nonexhaustive high-intensity running when the participants wore CG. Different testing protocols, however, may lead to different results. The run-to-exhaustion graded protocol used in Rider’s study could improve recovery by lowering blood-lactate levels after exercise. It has been suggested that there is no simple relationship between MDF shift and lactate concentration. The finding of this study indicated that wearing CG led to higher MDFs but no changes in lactate levels, which suggested that MDF could be used to evaluate the effect of CG in future studies.

RPE may not be a sensitive index of the CG effect during distance running, as indicated by the nonsignificant findings in our RPE score. CG had no significant effect on RPE during running, indicating that the perceptual demands of our participants were similar in both conditions. This finding contradicted our hypothesis that the participants would successfully perceive a positive effect of CG. This hypothesis was based on the positive effect of CG on RPE during 400-m sprints and a 15-min running session. However, our results of RPE were consistent with some previous studies, which suggests that wearing CG may not affect psychological fatigue during or after runs of 40 min or 10 km. In other words, the duration and distance of the running protocol may affect the results of perceptual fatigue.
The current study had several limitations. First, regardless of the effort to assess the pressure between the skin and CG on the muscle belly, there is a limitation that the real pressure when the muscle is working during running was not available. Second, unlike other methods such as those that involved dynamometers, which are commonly used to measure maximal muscle contractions, the inherent limitations of using the EMG for measuring maximal muscle contractions should be noted, whereas for a running protocol, the EMG remained a feasible measurement. Third, the CG used in the current study covered hip and knee joints but not the ankle joint, and the findings indicated that the changes of the EMG parameter were mainly identified in GM, ST, and RF but not in TA and GAS. The evidence of the CG effect in the current study may encourage the use of CG around the ankle joint, which may thus influence TA and GAS. Fourth, generalizations on the significant effect of the MDF should be limited to nonfatigue exercise protocols. The benefit of using the MDF as an index to examine the effect of the MDF should be limited to nonfatigue exercise protocols.

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Authors’ contributions

WCH and CL designed research and drafted the manuscript; LWT, FCC, and LCW collected all data; WWY and YJL analyzed the data and performed the statistical analysis. All authors have read and approved the final version of the manuscript, and agree with the order of presentation of the authors.

Competing interests

The authors declare that they have no competing interests.

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