Technology and Health Care 24 (2016) S533–S539
DOI 10.3233/THC-161179
IOS Press

Reduced muscle activity during isokinetic contractions associated with external leg compression

Xi Wang[a], Rui Xia[a] and Weijie Fu[a,b,*]
[a] *School of Kinesiology, Shanghai University of Sport, Shanghai, China*
[b] *Key Laboratory of Exercise and Health Sciences of Ministry of Education, Shanghai University of Sport, Shanghai, China*

Abstract.
BACKGROUND: The potential mechanism of compression apparel remains unclear to date because of insufficient knowledge on the influence of compressive level on muscular responses.
OBJECTIVE: To explore the influence of external leg compression on (a) the muscle force and endurance of the quadriceps femoris and (b) the muscle activation patterns during prolonged muscle actions.
METHODS: Twelve male participants performed consecutive maximal concentric muscle actions of the quadriceps in compression garment (CG) and control condition (CON) at two angular velocities on the Contrex. The EMG amplitude and frequency of the rectus femoris (RF), vastus lateralis (VL), and vastus medialis were quantified during the concentric phase of the knee extension movement.
RESULTS: There was no significant compression effect on muscle force and total work during knee extensions. Contrarily, the overall EMG amplitude was significantly lower in CG than in CON at 60 and 300°/s. Additionally, the EMG frequency of the RF and VL was significantly higher in CG than in CON at 60°/s.
CONCLUSION: Increased external pressure is associated with changes in EMG time and frequency domain behavior. These effects can potentially relieve muscle fatigue and improve muscle endurance during long-term exercise.

Keywords: External leg compression, muscle contraction, EMG amplitude, EMG frequency

1. Introduction

During the last decade, compression garments have been proposed as playing a positive role in improving the strength, endurance, and recovery of athletes and patients [1,2]. External compression garments comprise a series of elastic fabric designed to follow the body mold. They provide the proper stretch and pressure to compress evenly on the limbs, trunk, and other specific body areas according to different materials and designs [3]. Mechanisms that explain the promoted performance and postoperative healing of compression include three aspects, namely, enhancement of blood flow and lactate removal, improvement of muscle function and proprioception, and damping of soft tissue vibrations [4–6]. The potential mechanism of compression apparel, however, remains unclear to date because of insufficient

*Corresponding author: Weijie Fu, Key Laboratory of Exercise and Health Sciences of Ministry of Education, Shanghai University of Sport, 200438 Shanghai, China. Tel.: +86 21 51253239; Fax: +86 21 51253242; E-mail: fuweijie@sus.edu.cn.

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knowledge on the influence of compressive level on muscular responses. Moreover, some publications demonstrate the benefits of compression, but other studies do not support the positive effects claimed by manufacturers of compression apparel [7,8].

Surface electromyography has been widely applied to examine and evaluate muscular activition in the research area of medical science [9]. The amplitude and frequency domains of electromyographic (EMG) signal patterns reflect electrical activity changes, motor unit recruitment, and conduction velocity of the active muscle fiber membrane during movement [10]. A majority of current EMG studies on compressive apparel focused on the relationship between varying intramuscular pressure and muscle reactions [11,12]. Previous results indicated that compression definitely increases intramuscular pressure [12]. However, the mechanism by which increased intramuscular pressure affects EMG time and frequency domain behavior during long-duration muscle actions has yet to be elucidated.

The purpose of this study aims to explore the influence of compression on (a) the muscle force and endurance of the quadriceps femoris by using a dynamometer and (b) the EMG amplitude and mean power frequency of the rectus femoris (RF), vastus lateralis (VL), and vastus medialis (VM) during repeated concentric muscle actions of the dominant leg. This study was also considered to serve as a reference to improving the design and applications of compression garments.

2. Methods

2.1. Participants

Twelve healthy athletes (gender: male; age: 21.2 $\pm$ 1.4 years; weight: 67.1 $\pm$ 6.4 kg; height: 177.5 $\pm$ 4.8 cm) in the sport of track and field were recruited for this experiment. The inclusion criterion for participants was the absence of musculoskeletal injuries of the lower extremity 6 months prior to testing. Potential participants with a history of significant lower limb problems or systemic or neurological disorders were excluded from the study diagnosed by an orthopaedist. Each participant signed an informed consent approved by the local ethics committee.

2.2. Isokinetic tests

The participants completed strength testing with one of two randomly selected compression conditions (CG or CON) during each visit. A period of 48-hour rest was required between the two visits. Muscular force was generated by voluntary contractions measured with the calibrated Contrex isokinetic system. They were allowed to familiarize themselves with the strength testing equipment. A 5 min, low-resistance warm-up on the Contrex was completed at the outset. During the isokinetic tests, the participants performed one set of 25 consecutive maximal concentric muscle actions of the quadriceps at randomly ordered angular velocities of 60 and 300°/s on the Contrex. A 15 min rest period was required between two velocities. The EMG and position signals were exported synchronously with DasyLab 8.0 software and a data collection system.

2.3. Devices

An isokinetic dynamometer was used to measure the isometric and isokinetic strengths of the quadriceps. The structure and manipulation of the Contrex system were similar to that in the Biodex system.

The Biovision EMG system (Biovision, Wehrheim, Germany) was used to record EMG signals from the RF, VL, and VM of the dominant leg [13]. Disposable bipolar Ag/AgCl surface electrodes were placed on the reference positions of these muscles. EMG signals were analog processed with a double differential amplifier (bandwidth = 10–700 Hz, input impedance = $10^{12}\Omega$, CMRR = 120 dB at 60 Hz, and gain adjustable for 1000, 2500, and 5000).

The elastic compression garment (CG) was modified through a compressive kneecap that was mainly composed of polyamide, cotton, and elastodiene. The covered area was from the thigh to just above the knee. The other compression condition was a control shorts condition (CON) with no compression at all. The order of the compression conditions was randomized by using a computerized random number generator.

2.4. Signal processing

The main parameters used to evaluate the muscle endurance of the lower extremity under two compression conditions were as follows.

Strength production (normalized by body mass) was assessed on the basis of the peak moment (PM, Nm/kg), peak power (PP, W/kg), average power for the first five repetitions (AP, W/kg), and total work (TW, J/kg) during isokinetic knee extensions. TW corresponds to all the work done throughout the 25 extensions normalized by body mass.

Endurance performance evaluation was based on the suggestion of a previous research on isokinetic strength testing; that is, the peak moment decreases with the repetition of concentric muscle actions [14]. Subsequently, work output and decline in moment were utilized to evaluate muscle endurance during repetitive dynamic contractions [15]. In the present study, a work fatigue index (WF) was chosen to reveal the decreasing trend of the peak moment across the 25 repetitions and to evaluate the anti-fatigue ability of muscle during long-duration tasks.

For EMG amplitude and frequency determination, raw signals were band-pass filtered at 10–500 Hz for EMG and then full-wave rectified [16]. For each of the entire 25 repetitions, the EMG amplitude (root mean square, EMG_{RMS}) was calculated over the middle third of each repetition based on a total range of motion of 90° (a 30° range of motion; 0.5 s for 60°/s and 0.1 s for 300°/s) during the concentric phase of the knee extension movement. Meanwhile, the mean power frequency (EMG_{MPF}) was quantified from the power spectrum of EMG signals using the Fast Fourier Transformation algorithm.

2.5. Statistics

The distribution of all dependent variables was examined using the Shapiro-Wilk test in order to make sure that their distribution did not differ significantly from normality. In addition, homogeneity of variances was tested using Levene's statistic, and not found to be significant for the variables of interest ($p > 0.05$). A two-way ANOVA (2 velocities $\times$ 2 conditions) for repeated measures was used to determine significant differences between different compression conditions. Tukey's post-hoc test was performed to determine individual significant differences using SPSS 13.0 (SPSS Inc., Chicago, IL, USA). The significant level was set at $\alpha = 0.05$.

3. Results

No significant compression effect on peak moment, peak power, average power, and total work during repeated concentric muscle actions at 60 and 300°/s (Table 1). As expected, a significant velocity change

Table 1
Muscle force and endurance of knee extensors during 60°/s and 300°/s of isokinetic knee extensions in compression garment (CG) and control condition (CON)

	60°/s		300°/s	
	CG	CON	CG	CON
PM (Nm/kg)	$2.52 \pm 0.33^*$	$2.63 \pm 0.49^*$	1.88 ± 0.36	2.08 ± 0.42
PP (W/kg)	$2.63 \pm 0.36^*$	$2.74 \pm 0.52^*$	8.50 ± 1.51	9.17 ± 1.07
AP* (W/kg)	$1.50 \pm 0.25^*$	$1.61 \pm 0.23^*$	3.34 ± 0.66	3.48 ± 0.47
TW* (J/kg)	$45.6 \pm 8.8^*$	$46.5 \pm 9.1^*$	36.5 ± 7.5	37.1 ± 6.3
WF	23.9 ± 16.1	25.0 ± 15.7	22.6 ± 16.2	22.8 ± 10.7

PM = peak moment normalized by mass; PP = peak power normalized by mass; AP = average power for 1st five repetitions normalized by mass; TW = total work; WF = work fatigue. $^*p < 0.05$, compared with 300°/s for the same garment group.

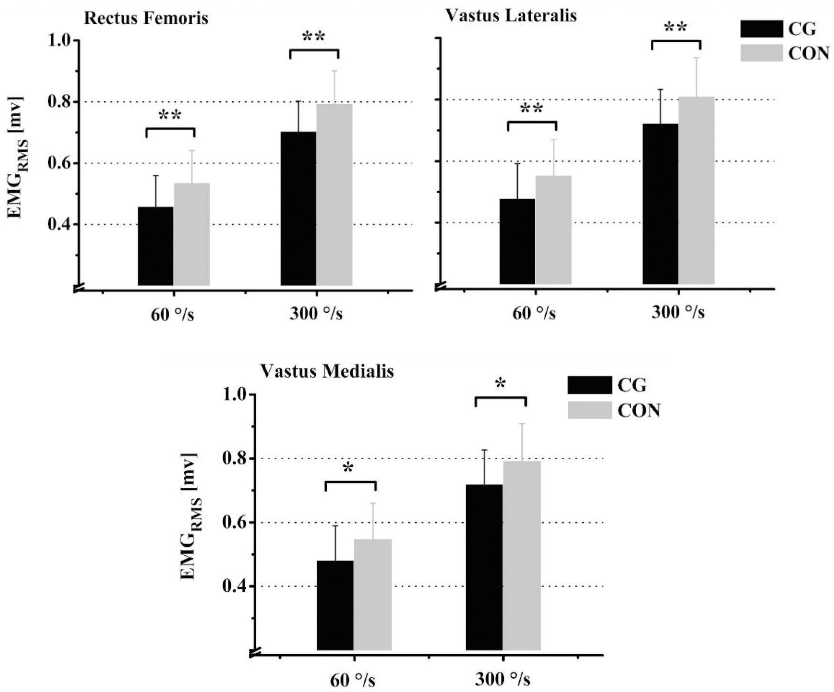

Fig. 1. EMG amplitude (EMG$_{RMS}$) of the rectus femoris, vastus lateralis, and vastus medialis muscles during 60°/s and 300°/s of isokinetic knee extensions in compression garment (CG) and control condition (CON).

($p < 0.05$) was observed for PM, PT, AP, and TW. Meanwhile, no significant differences in WF were found between CG and CON during isokinetic knee extensions.

For the entire 25 repetitions, the overall EMG$_{RMS}$ was significantly lower ($p < 0.05$) in CG than in CON at 60 and 300°/s (Fig. 1). In particular, post-hoc comparisons revealed that the EMG$_{RMS}$ values of the RF, VL, and VM were lower by 14.7% ($p < 0.01$), 14.1% ($p < 0.01$), and 12.5% ($p < 0.05$) in CG than in CON at 60°/s, respectively. Similarly, the EMG$_{RMS}$ values of the above three muscles at 300°/s were also lower in CG than in CON ($p < 0.05$, Fig. 1).

The EMG$_{MPF}$ values of both RF and VL were significantly higher ($p < 0.05$) in CG than in CON at 60°/s (Fig. 2). By contrast, compression exerted no significant effect on the EMG$_{MPF}$ of the tested thigh muscles at 300°/s of isokinetic knee extensions.

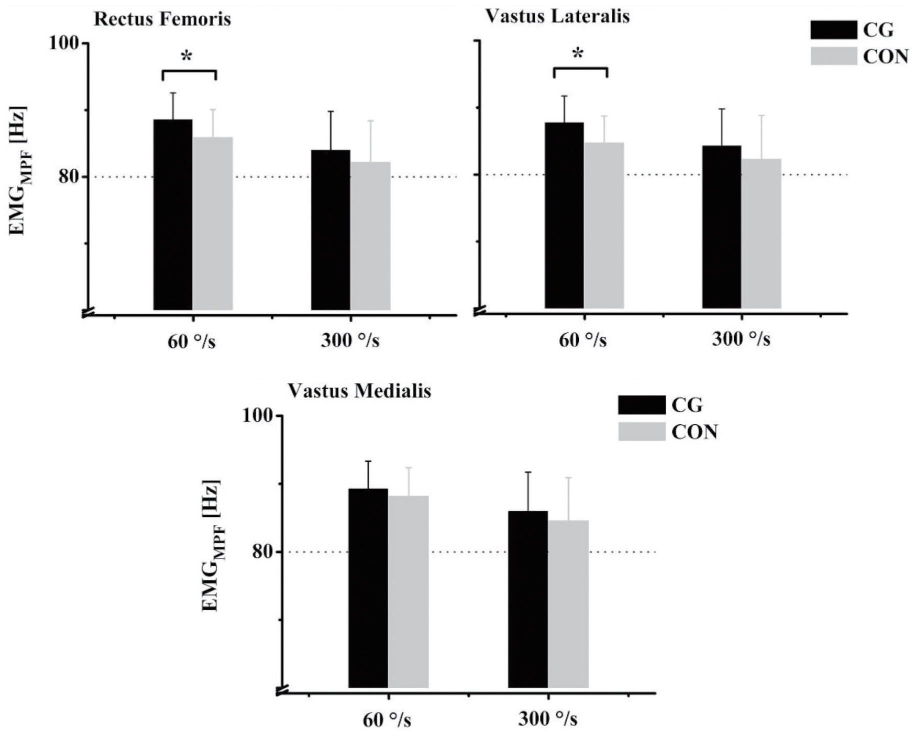

Fig. 2. EMG frequency (EMG$_{MPF}$) of the rectus femoris, vastus lateralis, and vastus medialis muscles during 60°/s and 300°/s of isokinetic knee extensions in compression garment (CG) and control condition (CON).

4. Discussion

The purpose of this study was to explore the influence of the changes in compression conditions on force production and muscle responses during prolonged muscle actions. We found that the compression of the lower extremity did not significantly enhance strength production in a short period. However, wearing a compression garment decreased the EMG amplitude and increased the EMG frequency. These effects can improve muscular endurance and muscle fatigue resistance during repetitive isokinetic movements.

Kraemer and colleagues [5,17–19] systematically investigated compression garments made of Lycra® fabric and discovered that compression garments exerted less effect single maximal jump power than loose apparel. However, compressive shorts did not contribute to any additional fatigue in repetitive high-intensity exercises and were still important in soft-tissue-injury management. In the present study, we adopted 25 repeated concentric muscle actions to examine the effects of compressive garment on force output. Compression exerted no significant effects on the outcomes of the PM, PP, AP, and TW. These findings suggest that compression rendered no obvious effect on the muscle force and power (e.g., peak moment and peak power) of the quadriceps femoris in short periods during isokinetic concentric contraction. These results were in agreement with one of Kraemer's systematic researches [19], which reported that compression demonstrated no significant effects on the force output, overall work, and maximum numbers of repetitions performed with the Tru-squat.

In a later study, Doan et al. [4] evaluated a new generation of compressive material that was thicker and more elastic than previous fabrics. Their countermovement jump test results showed that the maximal jump height of the athletes in the compressive garment condition was significantly higher than that in the control condition by 2.4 cm ($p < 0.05$). They also noted a significantly lower squat depth with the compression garment than with the control condition, which may indicate a larger impulse during the later stretch period of the CMJ. However, the mechanism by which compressive garments enhance performance via the influences on the function and activity of neuromuscular system remains to be elucidated. Moreover, a considerable amount of studies failed to observe similar positive effects of compression garments probably because of the different locomotor movements that were tested in different experiments and the different materials and compressive levels of compression garments [7,18]. Therefore, further investigations are still warranted.

However, it is noted that local compression substantially affected the pattern of muscle involvement (amplitude and frequency) during prolonged muscle action. Specifically, during the entire 25 repetitions of knee extension at 60 and 300°/s, the EMG amplitude exhibited a compression-related decrease, that is, EMG_{RMS} significantly declined (Fig. 1) with applied local compression. Therefore, regardless of the velocity of concentric contraction, local elastic compression affected the long-term contraction responses and motor unit recruitment of the thigh muscles. In conjunction with the results of increased EMG frequency (Fig. 2) and decreased work fatigue (Table 1), local compression may, to a certain extent, exert a better positive effect on muscle fatigue than control condition. This finding agrees with a recent finding that compression helps in the recovery of mechanisms that may be involved in physiological and psychological responses [20].

Generally, soft tissue vibrations are important for the energetics of locomotion because muscle activity is required to dampen these vibrations [21]. Previous research also mentioned that compression garments reduced soft tissue vibrations during movement [4,18]. However, the exact mechanisms by which compression garments save energy and improve sport through the damping of soft tissue vibrations remain unknown. A recent investigation has revealed that compression apparel decreased muscle pre- and post-activation during running [22]. This observation agrees with the present results. Considering the findings of force output and work fatigue in maximal isokinetic concentric contraction, we inferred that local compression can reduce unnecessary muscle activity and recruit less motor units to maintain similar power output. These effects can potentially relive muscle fatigue in long-term exercise. However, further studies on the influence of compressive on biological feedback and neuromuscular behaviour are still required because of the restriction of isokinetic movements compared with dynamic activities.

As with all studies, the current investigation is not without limitations. First, the intra-class correlation coefficient and the standard error of measurement were not calculated to further determine the EMG reliability of each condition. This lack of measurement errors of the EMG needs to be taken into account when considering the present findings and their contributions. Additionally, it should be noted that we have only concentrated on 25 maximal concentric isokinetic muscle actions. More repetitions and contraction types in different levels of muscular forces should be involved in future research.

In summary, external leg compression did not immediately improve the muscle force of the quadriceps in healthy subjects during isokinetic knee extension movements. However, wearing compression garments reduced the EMG amplitude of the thigh muscles and increased the EMG frequency during isokinetic movements at both 60 and 300°/s. Hence, increased external pressure is associated with changes in EMG time and frequency domain behavior. These effects can improve muscle endurance and fatigue resistance during prolonged muscle actions.

Acknowledgments

This work was supported by the NNSFC (11302131), the Innovation Fund of Shanghai Municipal Education Commission (14YZ125), and the Innovation Fund in Graduate Education of Shanghai University of Sport (yjscx2016).

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