Comparison of Physiological Effects Induced by Two Compression Stockings and Regular Socks During Prolonged Standing Work

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Objective: The goal of this study was to evaluate and compare lower-leg muscle fatigue, edema, and discomfort induced by the prolonged standing of security guards wearing regular socks and those wearing 15–20 or 20–30 mmHg compression stockings as intervention.

Background: Compression stockings are sometimes used by individuals standing all day at work. However, quantitative evidence showing their potential benefits for lower-leg health issues in healthy individuals during real working conditions is lacking.

Method: Forty male security employees participated in the study. All were randomly assigned to the control or one of the two intervention groups (I_{15-20} or I_{20-30}). Lower-leg muscle twitch force, volume, and discomfort ratings were measured before and after their regular 12-hr standing work shift.

Results: Significant evidence of lower-leg long-lasting muscle fatigue, edema, and discomfort was observed after standing work for guards wearing regular socks. However, no significant changes were found for guards wearing either compression stockings.

Conclusion: In healthy individuals, compression stockings seem to attenuate efficiently the tested outcomes in the lower leg resulting from prolonged standing.

Application: Occupational activities requiring prolonged standing may benefit from 15–20 or 20–30 mmHg compression stockings. As similar benefits were observed for both levels of compression, the lower level may be sufficient.

Keywords: muscle twitch force, fatigue, leg swelling, edema, discomfort

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Prolonged standing work posture is commonly observed in diverse occupations (industrial and service sectors) as indicated by work duration proportions of 47% in the European Union (Graf et al., 2015) and 55% in Canada (Tissot et al., 2005). A negative impact of prolonged standing work has been shown for musculoskeletal and cardiovascular health outcomes (Coenen et al., 2017; Halim et al., 2011; Reid et al., 2010; Waters & Dick, 2015). They include lower back pain and disorders (Gregory & Callaghan, 2008; Nelson-Wong & Callaghan, 2010; Tissot et al., 2009), lower-limb pain and discomfort (Antle et al., 2015; Garcia et al., 2017; Orlando & King, 2004), leg muscle fatigue (Garcia et al., 2015, 2016; Halim et al., 2012), lower-leg swelling/edema (Blättler et al., 2016; Garcia et al., 2016, 2018; Kraemer et al., 2000; Lin et al., 2012a, 2012b; Partsch et al., 2004; Zander et al., 2004), and varicose veins (Bahk et al., 2012; Kroeger et al., 2004; Tüchsen et al., 2005, 2000), progression of carotid artherosclerosis (Krause et al., 2000), increased risk for incident heart disease (Smith et al., 2018), and stroke (Hall et al., 2019).

Several physiological phenomena that may contribute to musculoskeletal and vascular health problems related to prolonged standing have been proposed. Muscle fatigue, commonly defined as the decrease in capacity to generate a desired force (Edwards, 1981; Taylor et al., 2006), is considered a precursor of musculoskeletal disorders with physiological/neurophysiological (Armstrong et al., 1993; Côté, 2014; Edwards, 1988; Hadrevi et al., 2019; Sejersted & Sjøgaard, 2000) and likely mechanical (Gallagher & Schall, 2017) origins. The long-lasting component of muscle fatigue, commonly referred to as low-frequency fatigue or long-lasting muscle fatigue (Edwards et al., 1977; Westerblad et al., 2000), is also induced by low-level muscle exertions (Adamo et al., 2009; Blangsted et al., 2005; Enoka & Stuart, 1992; Kim et al., 2014), may last up to 24 hr (Edwards et al., 1977) but is not subjectively perceived (Adamo et al., 2002; Garcia et al., 2015, 2018; Sejersted & Sjøgaard, 2000). This component of muscle fatigue has been evidenced in lower-leg muscles through the decrease in amplitude of the electrically induced muscle twitch force (MTF; Brownie & Martin, 2015; Garcia et al., 2015, 2016, 2018) and changes in surface electromyography (EMG; Madeleine et al., 1998) in laboratory studies requiring prolonged standing work. Considering the vascular issues, prolonged standing-induced leg edema has been associated with blood pooling in the lower limbs (Antle & Côté, 2013; Antle et al., 2018) and accumulation of fluid in response to muscle cell damage (Edwards, 1988) and muscle water (Sjøgaard et al., 1988) and systemic hemodynamic responses such as increased heart rate and blood pressure (Krause et al., 2000).

Considering the musculoskeletal and vascular burden of prolonged standing work, ergonomic interventions have been evaluated in terms of attenuation of precursors of these health issues. Several studies have recommended floor mats and shoe insoles to reduce symptoms of discomfort (Cham & Redfern, 2001; King, 2002; Lin et al., 2012b; Speed et al., 2018; Waters & Dick, 2015). However, other studies have found no influence of these two interventions on physiological outcomes including the reduction of leg swelling and muscle fatigue (Brownie & Martin, 2015; Garcia et al., 2016; Redfern & Cham, 2000; Zander et al., 2004). A growing body of literature has proposed to mitigate the negative effects of standing by incorporating seated periods (Karakolis & Callaghan, 2014) and increasing dynamic standing activities such as walking (Balasubramanian et al., 2008; Garcia et al., 2016, 2020). However, in many work environments, employees are restricted from sitting or walking and are required to work standing due to the job characteristics or a cultural tradition (Messing et al., 2015). Proposed wearable ergonomic interventions like compression stockings or hosiery could be a practical alternative in these situations.

A number of studies indicate that compression stockings reduce discomfort (Chiu & Wang, 2007; Kraemer et al., 2000) and leg edema (Blazek et al., 2013; Krijnen et al., 1997; Partsch et al., 2004) resulting from standing for 3–8 hr. However, their effectiveness is challenged by studies pointing out a significant change in subjective measures only but not in physiological or biomechanical measures (Chiu & Wang, 2007; Jungbeck et al., 2002) as reviewed by Waters and Dick (2015). Moreover, occupational applications of stockings are rather scarce and their results controversial. Physiological outcomes such as muscle fatigue have been overlooked and disagreements arise due to a variety of experimental conditions and differences in the level of compression stockings used (e.g., Maton et al., 2006; Miyamoto et al., 2011). Compression stocking may improve the venous-muscle pump (Bassez et al., 1999; Maton et al., 2006; Miyamoto et al., 2011), in that way reducing lower-leg edema and thus fluid exchange mechanisms that could contribute to muscle fatigue. Despite this interest and sport applications (e.g., Bringard et al., 2006), as far as we know, possible reduction of muscle fatigue by the use of compression stockings during prolonged standing work has not received much attention. Moreover, evaluations of muscle fatigue during standing work are generally confined to laboratory studies for practical reasons (Garcia et al., 2015, 2016) and studies in real work conditions are limited.

Another major drawback regarding compression stockings is the difficulty to recommend an adequate pressure level that would have a preventive benefit, as concluded by Waters and Dick (2015). Some benefits were observed for stockings compression ranging from 7 to 15 mmHg (Kraemer et al., 2000) and 11 to 21 mmHg (Blazek et al., 2013; Partsch et al., 2004), whereas others also found benefits in stockings with compression pressure higher than 20 mmHg (Quilici Belczak et al., 2018; Steinhilber et al., 2018) or up to 30 mmHg (Krijnen et al., 1997). However, the use of high-pressure compression stockings had led to more complaints regarding tightness and skin irritation (Kankam et al., 2018; Krijnen et al., 1997) but not for graduated compression <20 mmHg (Gianesini et al., 2020). Thus, differences between lower and higher compression pressure must be clarified before compression stocking can be proposed as a preventive method for standing work.

The primary purpose of this study was to compare with regular socks the influence of two commercial compression stockings, with mild (15–20 mmHg) and moderate (20–30 mmHg) compression respectively, on discomfort, lower-leg edema, and muscle fatigue resulting from prolonged standing work performed by male security guards. The study was designed to address the following question:

Does wearing mild and moderate compression stockings (15-20 mmHg and 20-30 mmHg) attenuate lower-leg long-lasting muscle fatigue, edema, and discomfort when compared to regular socks during 12 hr of standing work performed in real work conditions?

Furthermore, it is presumed that the effects of compression stocking may shed some light on the interaction between the accumulation of fluid and associated hydrostatic pressure and physiological mechanisms contributing to muscle fatigue.

METHOD

Participants

This study was performed at an outsourced security guard company employed by an academic institution in Ecuador. The 65 security employees were informed about the study and invited to participate through an oral presentation at a weekly staff meeting. Forty healthy male security guards, commonly assigned to work almost exclusively in a standing posture at the entrances of the institution, volunteered for the study in agreement with preset inclusion criteria. Female participants were not included due to the lack of female security guards in the chosen workforce. The participants declared to have at least 1 year work experience in a standing posture at least 4 days a week with limited walking and to be free from cardiovascular diseases, varicose veins, and any recent musculoskeletal pain or symptoms. On average, the participants' anthropometric characteristics were 35 ± 10.5 years of age, 165 ± 6.1 cm height, and 76 ± 10.9 kg weight; see Table 1 for details. All participants signed an informed consent approved by the Ethics Committee of the Universidad San Francisco de Quito. The present study complied with the tenets of the Declaration of Helsinki. All participants received a financial compensation for their involvement in the study.

Experimental Design

All participants were randomly assigned to either a control group or two intervention groups. Then it was verified that height, weight, and age were not significantly different (p = .81, p = .69, and p = .20, respectively) between groups (Table 1). The intervention groups consisted of participants assigned to use 15–20 mmHg (group: $I_{15–20}$) or 20–30 mmHg (group: $I_{20–30}$) compression stockings during their entire work shift. The control group wore their regular non-compressive socks during their shift. For

TABLE 1: Participants Demographic Data.

	Control Group	Intervention Groups	
	n = 19	n = 17	
Measurement		I15-20 n = 9	I20-30 n = 8
Height (cm)	165.83 (6.43)	165.07 (5.72)	166.57 (7.32)
Weight (kg)	76.01 (10.59)	76.88 (12.88)	73.50 (8.93)
Age (years)	34.71 (10.37)	39.33 (7.77)	32.57 (6.75)

Note. Values correspond to means (standard deviations). Differences between groups were not significant (α = .05).

all participants, the experimental day took place on the first day of return to work after a day off. The participants were asked to rest during their day off and not to do strenuous physical exercises. During the experimental day, all participants performed their main job, which consisted of guarding and controlling the entry of all individuals at an entrance of the institution. The duration of their normal work shift was 12 hr, from 6:15 am to 6:15 pm, including a 30-min lunch break at noon. While on duty, the guards are not allowed any other break but can use the restroom near each entrance as needed. Four participants (one from the control group and three from the intervention groups) withdrew from the study due to changes in their work duties in response to emergencies. The participants wore similar uniform and shoes provided by the security company. Objective and subjective measures were performed in a laboratory setting in a building located 100 and 200 meters, respectively, from the guards' assigned entrances.

For the present study, the dependent variables consisted of gastrocnemius-soleus MTF amplitude and duration, lower-leg volume, and perception of discomfort. All measurements were performed before the start of the work shift (baseline) at 5:45 am and, after 12 hr, toward the end of their work shift at 5:45 pm. Additional measurements were taken at midday (after 6 hr), for the control group where a free lunch was provided. These measurements were not obtained from the intervention groups for the following reasons: (1) to limit the amount of walking needed to reach the laboratory that could attenuate muscle fatigue (Garcia et al., 2016, 2020; Balasubramanian et al., 2008), (2) avoid removal of stockings to perform the measurement, and (3) maintain the continuity of stockings wear for the whole workday. To verify the predominantly sedentary standing work of the guards, steps were measured with a pedometer. On average, during the 12 hr of the shift, the number of steps performed by the control and intervention groups were 3568 ± 1418 SD and 2665 ± 1046 SD, respectively. These rather small numbers allow to classify the job as sedentary (Soroush et al., 2015; Tudor-Locke & Bassett, 2004). Large variations are simply due to the difference in distances between the four entrance doors controlled and the laboratory used for testing, body weight shifting while standing and steps at the entrance door to perform their work duties.

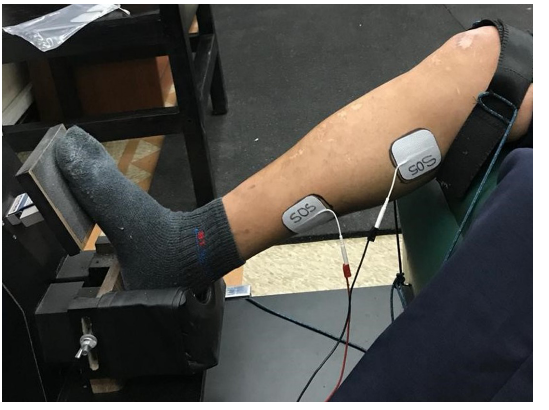

Figure 1. Muscle twitch force measurement of the gastrocnemius-soleus muscles.

Apparatus and Procedure

Muscle twitch force. The MTF measurement, which has been used and described in our previous studies (Garcia et al., 2015, 2018, 2020, 2016), consists of applying low frequency (2 Hz) electrical stimulation to the gastrocnemius and soleus muscles through two surface electrodes located over the muscles motor point area (Botter et al., 2011) and the proximal end of the Achilles tendon, respectively. The 1-ms electrical pulses were delivered with an intensity of 10–30 mA. The intensity differed between the participants in order to obtain the largest possible twitch force with a tolerable discomfort level. The MTF test was performed while the participant sat on a comfortable armchair with the left foot resting on the floor and the right foot over an inclined platform equipped with a strain gage force transducer (Figure 1). The right knee was strapped to the chair to avoid knee and upper leg movements during the stimulation (isometric twitch). The armchair was inclined backwards to obtain a relaxed seated posture with a 0° ankle dorsiflexion and 120° knee included angle. Each stimulation session lasted about 4 min, where

Figure 2. Lower-leg volumetric edema measurement.

twitch force was recorded and displayed with a custom LabView (NI) program at a sampling frequency of 1000 Hz. During the first ≈ 3 min of stimulation, a period of stimulation-induced potentiation is observed. Once the twitch force reaches a steady state (coefficient of variation of less than 3%), average values from three series of 30 twitches were computed to obtain amplitude and duration metrics of the stimulation session, as described in previous studies (Adamo et al., 2002; Garcia et al., 2015, 2016; Kim et al., 2014).

Lower-leg volume. This metric was obtained through a volumetric edema gage (ProHealthcareProducts, USA) as described in our previous studies (Garcia et al., 2018, 2020). The participants were asked to sit in an upright position and insert slowly their left lower leg in a tank filled with warm water until resting their foot on the floor with 90° knee and ankle angles. The weight of the water overflowing from the tank into a bucket (Figure 2) was recorded for each immersion. Four participants, 1 from the $I_{15\text{-}20}$ group, 1 from the $I_{20\text{-}30}$ group, and 2 from the control group, were marked as outliers (verified with the 1.5 interquartile range method Tukey's rule; Montgomery, 2013) for this measurement, due to water overflow by abrupt movements during the immersion.

Subjective evaluation. As in (Garcia et al., 2015), participants rated their perception of discomfort at the feet, ankles, lower legs, knees, upper legs/hip, lower back, and upper back on an adapted Nordic questionnaire (Kuorinka et al., 1987). Each of these body areas were highlighted on a human body sketch and connected with visual analog scales (0–10 cm), where "no discomfort" and "extreme discomfort" anchor descriptors corresponded to the left and right extremities of each scale segment. Participants were instructed to place vertical marks over the scales to indicate the discomfort level felt at the moment. The left and right body areas were grouped for the analysis, due to their high correlation (Pearson's correlation coefficient >.7).

Data Analysis

Mixed models with a variance-components covariance structure and a residual maximum likelihood estimation were used for the statistical analysis of all dependent variables through SAS Studio (SAS Institute Inc.). The mixed model for each dependent variables (MTF, lower-leg volume, and discomfort of each tested body areas) considered participants as random effects while measurement time and condition (control, $I_{15–20}$, $I_{20–30}$) were fixed effects. Least square means differences were calculated for multiple comparisons using Tukey-Kramer adjustment of *p* values due to the unbalanced design. Raw data were log transformed to fulfill the normality assumption and the significance level was set to α = .05. Partial eta-squared pseudo-effect size (η_p^2) was computed using an ad hoc method for mixed models (Tippey & Longnecker, 2016). Interpretation for η_p^2 was based on Cohen benchmarks defining small (η_p^2 = .01), medium (η_p^2 = .06), and large effects (η_p^2 = .14; Lakens, 2013). For simplification of means (*M*) and standard errors (SE)

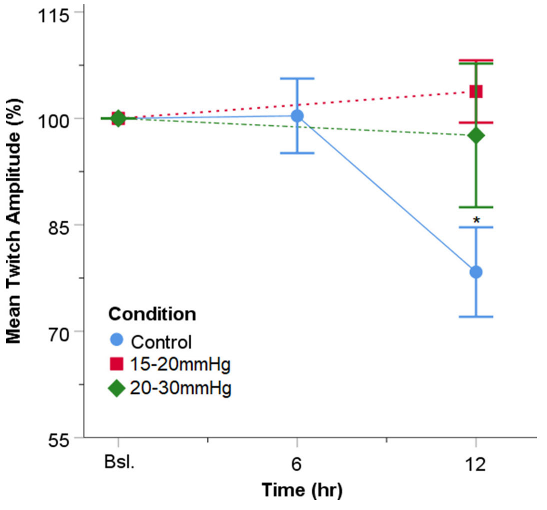

Figure 3. Muscle twitch force amplitude changes relative (%) to baseline (Bsl). Vertical bars indicate standard errors. * placed above the SE bar indicates a significant difference when compared with Bsl for the corresponding data point.

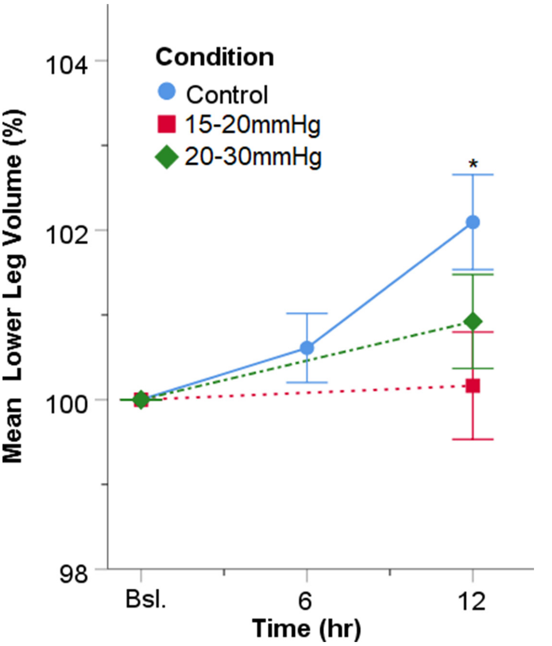

Figure 4. Lower-leg volume (%) changes relative to baseline (Bsl). Vertical bars indicate standard errors. * placed above the SE bar indicates a significant difference when compared with Bsl for the corresponding data point.

comparisons, graphic visualizations of raw data were expressed as a percentage of baseline on figures.

RESULTS

MTF

A main effect of time, $F(2,51) = 5.42$, $p = .007$, $\eta_p^2 = .05$, and a significant interaction of time with condition, $F(2,51) = 5.34$, $p = .007$, $\eta_p^2 = .09$, were found for MTF amplitude. However, condition was not significant, $F(2,51) = .45$, $p = .64$, $\eta_p^2 = .01$. For the control group, the MTF amplitude was significantly lower after 12 hr of standing work ($M = 78.34\%$, SE $= 6.31\%$; adj $p = .0002$) but not after 6 hr ($M = 100.35\%$, SE $= 5.25\%$; adj $p = .99$) when compared with baseline. For both intervention groups ($I_{15–20}$ or $I_{20–30}$), the twitch amplitude was not significantly different after 12 hr of standing work when compared with baseline (Figure 3). Moreover, the effect size of time was large ($\eta_p^2 = .27$) for the control group, but small ($\eta_p^2 = .02$) for both intervention groups. No significant differences were found for the twitch duration (time, $F(2,51) = .25$, $p = .78$; , $\eta_{p_2}^2 = .001$; condition, $F(2,51) = 2.22$, $p = .11$; $\eta_p^2 = .05$; time*condition, $F(2,51) = .75$, $p = .48$, $\eta_p^2 = .01$).

Lower-Leg Volume

A main effect of time, $F(2,42) = 6.02$, $p = .005$, $\eta_p^2 = .14$, and a significant interaction of time with condition, $F(2,42) = 3.53$, $p = .03$, $\eta_p^2 = .09$, were found for the lower-leg volume. However, condition was not significant, $F(2,42) = .05$, $p = .95$, $\eta_p^2 = .001$. For the control group, lower-leg volume was significantly higher after 12 hr of standing work ($M = 102.09\%$, SE $= .56\%$; adj $p = .0005$, $\eta_p^2 = .07$) but not after 6 hr ($M = 100.61\%$, SE $= .41\%$; adj $p = .86$, $\eta_p^2 = .32$) when compared with baseline. For the intervention groups ($I_{15–20}$ or $I_{20–30}$), the lower-leg volume was not significantly different after 12 hr of standing work when compared with baseline (Figure 4). However, the effect size for time was much larger for the $I_{20\text{-}30}$ group ($\eta_p^2 = .15$) than for the $I_{15\text{-}20}$ ($\eta_p^2 = .003$).

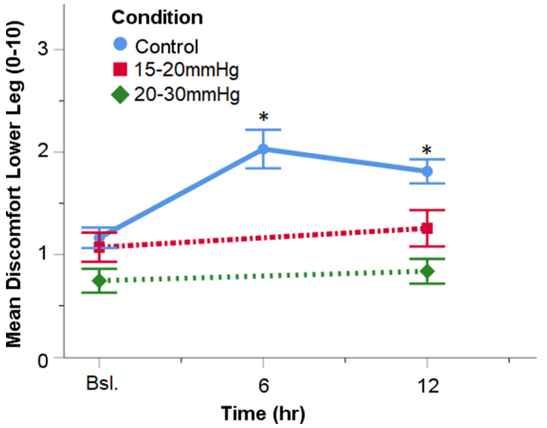

Figure 5. Lower-leg discomfort ratings (0–10). Vertical bars indicate standard errors. * placed above the *SE* bar indicates a significant difference when compared with Bsl for the corresponding data point.

Subjective Evaluation of Discomfort

A main effect of time was found for discomfort ratings of the feet ($F(2,139) = 4.51$, $p = .01$, $\eta_p^2 = .05$) and the lower leg ($F(2,139) = 6.43$, $p = .002$, $\eta_p^2 = .07$). A main effect of condition was found only for the lower leg ($F(2,139) = 3.50$, $p = .03$, $\eta_p^2 = .04$). The interaction of condition with time was significant only for the lower leg ($F(2,139) = 11.66$, $p < .0001$, $\eta_p^2 = .12$) and knees ($F(2,139) = 4.43$, $p = .01$, $\eta_p^2 = .02$). Discomfort ratings of the feet, lower leg, and knees areas were significantly higher ($p < .008$) after 12 hr of standing work when compared with baseline for the control group, but not for the interventions groups. Moreover, for the control group, discomfort ratings for the feet and lower leg area were significantly higher after 6 hr of work ($p < .04$) when compared with baseline (Figure 5). No significant differences were observed for the upper back, lower back, upper legs/hip, and ankles for any group, after 6 or 12 hr of standing work.

DISCUSSION

Compared with regular socks, the intervention method aimed at decreasing the negative effects of standing work on lower-leg muscle fatigue, edema, and discomfort consisted of using stockings with 15–20 or 20–30 mmHg of compression, respectively. All tested indicators of detrimental effects of prolonged standing converge to indicate the benefits of compression stockings by reduction of lower-leg muscle fatigue and body segments discomfort as well as reduction of lower-leg edema. Furthermore, it appears that the efficiency (in term of muscle fatigue and leg volume control) of the lower and higher compression stocking tested is similar.

Prolonged Standing With Regular Socks

At the end of the 12-hr day of standing work, lower-leg muscle fatigue (indicated by a lower MTF magnitude), edema (indicated by a higher volume), and discomfort (indicated by higher ratings) were significant in the control group, who wore regular socks. These expected effects conform to previous results showing that prolonged standing induce long-lasting muscle fatigue (Garcia et al., 2015, 2016, 2018; Wall et al., 2020), edema (Antle & Côté, 2013; Antle et al., 2018; Garcia et al., 2018; Hansen et al., 1998; Wall et al., 2020; Zander et al., 2004), and discomfort (Garcia et al., 2015, 2018; Antle & Côté, 2013, Drury et al., 2008). However, in this field study, lower-leg muscle fatigue and edema were not yet significant after 6 hr of standing work, when wearing regular socks, while these effects were seen to appear within 3 hr of static standing work at an office workstation (Antle & Côté, 2013; Garcia et al., 2015, 2016, 2018; Wall et al., 2020). Moreover, when standing at an office workstation, lower-leg muscle fatigue was strongly present after 3 hr of light manual work (Garcia et al., 2015, 2016, 2018) regardless of age, gender, and habituation to standing work (Garcia et al., 2015; Wall et al., 2020); hence, these factors are not considered in the present work. As opposed to an office workstation context in which displacements are strongly limited by the computer task requirements, the guards posted at entrance gates had no other constraint than not to lean against structures. Thus, they frequently made a few steps to perform their controlling task, change posture, or simply move within the perimeter of their assigned gate. To a lesser extent, but similarly to walking that reduces the development of lower-leg muscle fatigue when compared with standing (Balasubramanian et al., 2008, 2009; Garcia et al., 2016; Wall et al., 2020), these limited movements provided dynamic disruptions that contributed toward slowing down muscle fatigue development (Farina et al., 2008; Westad et al., 2003) and prevented an exacerbation that could have resulted from the very long work duration of a 12-hr workday. Indeed, the level of muscle fatigue is similar or even less pronounced between this type of work after 12 hr and static standing work after 5 hr, as observed in Garcia et al. (2015, 2016). Furthermore, when compared with previous results showing a 1%–2% increase in lower-leg volume after 5 hr (Garcia et al., 2018), the small increase of about ½% after 6 hr of standing work with bouts of dynamic actions, is in favor of our assumption as it likely stems from the same origin, which can be associated with the activation of blood flow, dissipation of fluid, and muscle oxygenation observed in dynamic leg activities or walking (Carvalho et al., 2015; Garcia et al., 2018; Noddeland & Winkel, 1988; Sheriff, 2005; Stick et al., 1992). During the guard's standing work, significant lower-leg discomfort was reported after 6 and 12 hr, which is an indicator of the development of muscle fatigue and edema as observed in previous studies (Antle, Vézina, et al., 2013, Antle et al., 2018; Tüchsen et al., 2000, 2005). Finally, the number of steps being on average greater for the control group (showing muscle fatigue) than the intervention groups (not showing fatigue) suggests that the influence of distances between the testing and gate location cannot be considered as a confounding factor.

Prolonged Standing With Compression Stockings

The utilization of compression stockings appears to successfully attenuate the development of lower-leg muscle fatigue, edema, and discomfort despite a very long standing workday. The reduction of edema was anticipated from consistent previous results (Blazek et al., 2013; Mosti et al., 2012; Quilici Belczak et al., 2012). This reduction has been attributed to the increase in intramuscular hydrostatic pressure contributing to an increase in blood flow velocity (Ibegbuna et al., 2003; Maton et al., 2006), a reduction of venous blood pooling assisting the muscle pump (Kraemer et al., 2000), and the stiffening of tissues "improving the efficacy of the muscle pump" during dynamic activities and thus fluid outflow by venous absorption (Maton et al., 2006). In the present case, although limited, the activities correspond to steps and movements indicated above and may act in synergy with the compression stockings (Quilici Belczak et al., 2012).

The wear of compression stockings in sport activities such as running and cycling has been advocated to reduce muscle fatigue (Miyamoto & Kawakami, 2014; Miyamoto et al., 2011). However, muscle contractions differ significantly between sport activities and standing work and so do the muscle fatigue mechanisms, which are task dependent (see for review Enoka & Stuart, 1992) and thus revealed only by adapted methods. Furthermore, the effect of compression stockings on muscle fatigue is also dependent on the compression level (Miyamoto et al., 2011). Hence, the effects on muscle fatigue may appear controversial or inconsistent. For example, whereas Maton et al. (2006) did not find the benefit of 15–20 mmHg compression stockings (as tested here) on muscle fatigue or fatigue recovery in responses to sustained 50% MVC static contractions, Miyamoto et al. (2011) observed some alleviation of muscle fatigue by compression stockings 20–30 mmHg but not by stockings 15–20 mm Hg on twitch ankle torque induced by electrical stimulation. In addition, Miyamoto and Kawakami (2014) found that 15–20 mmHg compression stockings can reduce thigh muscle fatigue during submaximal running exercise. However, these studies did not quantify edema. Our results defer to some extent, as both levels of compression contribute to the prevention of muscle fatigue and the development of edema.

Hence, the concurrence of these two phenomena suggests an interaction between vascular and muscle fatigue mechanisms. The respective roles of K + ions and blood flow in the prevention or provocation of muscle fatigue resulting from low level sustained or intermittent exertions have been described (Sejersted & Sjøgaard, 2000; Sjøgaard et al., 1988). Here, when compared with the control condition, the absence of muscle fatigue in compression stockings conditions suggest that K + homeostasis is preserved, as illustrated by Sjøgaard et al. (1988). The balance of K + loss and gain between the muscle and the circulation system (Sejersted & Sjøgaard, 2000) is maintained by the improvement of blood flow (increase in flow speed and improved efficiency of the muscle pump) via the synergistic effects of compression stockings induced intramuscular pressure (Ibegbuna et al., 2003; Maton et al., 2006) and the sporadic bouts of muscle contractions. This perspective is also supported by the results of Kraemer et al. (2000) obtained after 8 hr of standing, which showed a higher plasma volume shift of water and an absence of increase in creatine kinase (a marker of muscle tissue damage) with compression stockings when compared with the control condition of standing without compression stockings. Furthermore, the absence of muscle fatigue post work, and thus fatigue of long duration, also suggests the maintenance of Ca^{++} homeostasis as its disruption was shown to produce a failure of the “excitation-contraction coupling” associated with long-lasting muscle fatigue (Chin et al., 1997; Garcia et al., 2018; Ortenblad et al., 2000; Sejersted & Sjøgaard, 2000). In sum, better blood flow prevents the development of muscle fatigue mechanisms and the accumulation of fluid.

Both types of compression stockings have a positive effect on discomfort. This perception, which is associated with muscle fatigue (at least during and immediately after a fatiguing task) and edema (Antle, Vézina, et al., 2013; Garcia et al., 2018) is not changing when wearing the compression stockings. Therefore, the absence of increase in discomfort observed in the intervention groups is most likely due to the absence of associated physiological changes, which are indicated above. Neither of the compression levels presented an advantage over the other in terms of measures performed according to the statistical results. However, since the effect size for lower leg volume is large for 20-30 mmHg compression stockings after 12 hr of standing work, this compression level may be less beneficial than 15-20 mmHg under the tested conditions. Future studies may investigate the potential difference between these compression stockings for larger sample sizes. It may be emphasized that participants commonly mentioned that the 15–20 mmHg compression stocking was easier to put on. Finally, the absence of upper body discomfort was an expected outcome since work tasks consisted of only very light manual work in a mostly neutral upper body posture.

Study Limitations

The present study is limited to simple prolonged standing work, which did not involve walking, material handling, or other tasks that may be present in different standing jobs. Although the results were obtained with a large cohort of habituated-to-standing-work participants in real work condition, only healthy male participants were considered in this study due to the lack of female security guards in the considered population. Females working in a prolonged standing job and workers with preexisting varicose veins insufficiency, or history of deep vein thrombosis or pulmonary embolisms, should be considered in future studies. Only two types of compression stockings were considered in this study; other compression levels may need to be tested to generalize the results and a balance repeated measure design which includes different measurement days over the week may provide further insights into the benefits. Although not systematically addressed in the questionnaire, some participants indicated more feet sweating with the compression stocking than their usual socks. This issue may need to be investigated further in regard to the type of material that could be used to minimize/prevent sweating.

CONCLUSIONS

Lower-leg muscle fatigue, edema, and discomfort were negatively affected after a 12-hr standing work shift performed by security guards in real work conditions when wearing normal socks. However, these outcomes were much less frequently observed when the guards wore 15–20 and 20–30 mmHg compression stockings. Lower-leg muscle fatigue and edema appear to be prevented to a larger extent by these levels of compression, even for very long standing workdays. Overall, neither compression stocking level tested in this study seems to present a significant benefit over the other. Lower-leg discomfort related with prolonged standing work seems to be interconnected with physiological changes like edema.

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KEY POINTS

- Physiological measures were significantly altered after 12 hr of standing work when wearing regular socks but not with compression stockings.
- Both 15–20 and 20–30 mmHg compression stockings presented a significant benefit in term muscle fatigue, edema, and discomfort reduction when compared to regular socks.
- Compression stockings seem to address the mechanisms responsible for long-lasting muscle fatigue and edema, which are most likely contributing to MSDs and vascular problems.

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SUPPLEMENTAL MATERIAL

The online supplemental material is available with the manuscript on the *HF* website.

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