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Lower leg swelling and muscle co-contraction during prolonged standing: an unstable footwear evaluation

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The purpose of this study was to investigate the lower leg swelling and muscle co-contraction during prolonged standing with the focus on unstable footwear effects. The EMG signals of medial gastrocnemius and tibialis anterior muscles (bilaterally) were continuously recorded to quantify their co-contraction index (CCI) in 10 healthy asymptomatic subjects during two hours of standing in three footwear conditions including barefoot, stable shoe and unstable shoe. Lower leg circumference changes (swelling) were also monitored over the standing time. During two hours of standing remarkable reduction in lower leg circumference changes and significant reduced CCI level for both legs were observed only for unstable shoe compared to barefoot condition. However, bilaterally, no significant differences were found for both measures between barefoot condition and stable shoe or between two shoe conditions (stable and unstable). The unstable shoe produced changes in activity pattern of lower leg muscles which seems to be advantageous for venous pump mechanism during prolonged standing. These findings suggest that unstable footwear can be used as ergonomic intervention for prolonged standing during work or daily activities.

Keywords: prolonged standing; muscle co-contraction; lower leg swelling; unstable footwear; EMG

1. Introduction

Various occupations such as manufacturing, food service, aviation, and health care industries and also many daily activities require a prolonged standing posture which is accompanied with low-level of displacement. Standing for long hours has been associated with various health problems, particularly low back pain and lower extremity discomforts (Waters & Dick, 2015). Regarding lower limbs, the most significant outcome is the lower leg and foot swelling due to reduced blood circulation and blood pooling. These can immediately cause pain/discomfort and also in the long run can lead to other chronic venous insufficiency such as varicose vein (Antle & Côté, 2013; Bahk, Kim, Jung-Choi, Jung, & Lee, 2012). In this sense, increase in lower leg and foot volume has been reported as an indicator of insufficient blood return (Hansen, Winkel, & Jørgensen, 1998; Zander, King, & Ezenwa, 2004).

Substantial increase in hydrostatic pressure, distention of thin-walled vein, and disturbed venous valves function are the main reasons for greater peripheral venous pump activity during standing (Katz, Comerota, Kerr, & Caputo, 1994; Stick, Grau, & Witzleb, 1989). Considering lower limb muscles, pumping activity of calf muscles is the most significant one to blood return from legs (Williams, Ayekoloye, Moore, & Davies, 2014). Venous pump mechanism functions through the process of alternating lower leg muscles contraction, particularly non-isometric one (Zander et al., 2004). However, this type of muscle contraction can be seen more in dynamic situations compared to prolonged static standing in which continuous isometric contraction prevails (Balasubramanian, Adalarasu, & Regulapati, 2009; Lin, Chen, & Cho, 2012a). In addition, because of postural control and balance processes during static standing, synergies between antagonist muscles such as simple patterns of reciprocal activation, co-contraction (simultaneous contraction of agonist and antagonist muscles crossing a joint), and complex triphasic activation patterns can prevail (Donath, Kurz, Roth, Zahner, & Faude, 2015; Sousa, Silva, & Tavares, 2012; Warnica, Weaver, Prentice, & Laing, 2014). Now, is there any relationship between these synergies and venous pump mechanism during standing?

The primary purpose of muscle co-contraction is to reinforce ligament function in maintenance of joint stability. Accordingly, stabilizing function of lower leg muscles co-contraction has been observed during weight acceptance phase of gait and short-term standing test (Di Nardo, Mengarelli, Maranesi, Burattini, & Fioretti, 2015; Nagai et al.,

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2011; Peterson & Martin, 2010). Generally, typical/relaxed standing is associated with spontaneous sway pattern which consists of continuous small body deviations countered by corrective torques (inverted pendulum model) (Sousa, Silva et al., 2012). Moreover, to maintain balance during quiet/still standing, among all effective factors it has been suggested that active ankle stiffness plays a significant role which is typically generated through increased co-contraction of antagonistic muscles crossing the ankle joint (Reynolds, 2010; Warnica et al., 2014). Therefore, due to static stability challenge during prolonged standing (the nature of standing is more quiet/still than relaxed), possible increase in lower leg muscles co-contraction leads to reduction in alternating contractions and this issue cannot be useful for venous return.

The impact of standing-related problems on health insurance, absenteeism, productivity, and well-being is substantial (King, 2002); therefore, to reduce these problems various ergonomic solutions have been proposed including posture changes (leg movement), sit/stand chair, anti-fatigue mats, and footwear modifications (Aghazadeh et al., 2015; Balasubramanian et al., 2009; Chiu & Wang, 2007; King, 2002; Lin, Chen, & Cho, 2012b; Sousa, Tavares, Macedo, Rodrigues, & Santos, 2012; Waters & Dick, 2015). Since more physical variation is suggested to jobs with low-level, long-lasting loads or repetitive operations (Mathiassen, 2006), the main goal of these interventions is mostly to change static standing into a more dynamic standing situation. The key factor in creating a dynamic or active standing is changing the muscular activity characteristics (Srinivasan & Mathiassen, 2012), particularly in the lower leg region, toward a more alternating and dynamic or non-isometric contractions (Balasubramanian et al., 2009; Lin et al., 2012a; Wiggermann & Keyserling, 2012).

One of the above-mentioned ergonomic interventions, which can be applicable in both working environment and everyday life, is footwear. A recently introduced type of footwear which can help in changing the muscular activity and affording a more active standing is the unstable shoe (shoe with a rounded sole design in the anterior–posterior direction) (Nigg, Federolf, Von Tscharner, & Nigg, 2012). Increased lower leg muscles activity level and improvement in venous return have been reported for standing with unstable shoe (Karimi, Allahyari, Azghani, & Khalkhali, 2016; Sousa, Tavares, et al., 2012). Furthermore, in our previous study we also found higher activity variation for some of lower leg muscles during prolonged standing with unstable shoe (Karimi et al., 2016). Besides, according to the posture studies, it has been indicated that during first use of unstable shoe the postural control system relies mostly on reflex feedback rather than ankle stiffness increase strategy, which means decrease in the co-contraction level of lower leg muscles (Sousa, Macedo, Santos, & Tavares, 2013; Sousa & Tavares, 2014). On the other hand, after prolonged wearing of unstable shoe (eight weeks), with the same evaluation method (short-term standing test), the reducing effects of unstable shoe on lower leg muscle co-contraction were not reported (Sousa et al., 2016; Sousa, Silva, Macedo, Santos, & Tavares, 2014). However, previous studies have not investigated the relationship between muscle activation synergies (such as co-contraction) and hemodynamic responses during static standing challenges under the effects of unstable shoe.

Although higher co-contraction has been shown during quiet/still standing tests, it is unknown whether increased lower leg muscle co-contraction during static standing challenges is predictive of increased leg swelling. In addition, short-term standing test may not give a comprehensive conclusion regarding the effects of unstable footwear on lower leg muscle co-contraction and its relationship with leg swelling during prolonged and continuous standing. Findings of the current study may provide insight into unstable footwear influence on lower leg muscle activation synergies during static standing challenges and also how these relate to the leg swelling. Therefore, the main purpose of this study is to investigate the changes of lower leg swelling and muscle co-contraction simultaneously under the influence of different footwear conditions (stable/unstable) during a two-hour simulated continuous standing in the laboratory conditions. The authors hypothesized that increase in muscle co-contraction would be accompanied by increased lower leg swelling. Furthermore, it was hypothesized that unstable footwear compared to stable footwear condition would decrease both lower leg swelling and muscle co-contraction during prolonged standing.

2. Material and methods

2.1. *Participants*

Ten healthy males were recruited for this experiment from a university student population (age mean = 25.3 years, SD = 1.49, height mean = 1.77 m, SD = 0.02, body mass mean = 74.8 kg, SD = 2.69). None of the subjects were engaged in work that requires prolonged standing and all of them were free from any lower limb problems (disorder, discomfort, pain). To evaluate a single shoe size, during selection process of subjects, wearing the shoe with size of 42 by the participants in their daily activities was the primary criterion. All the volunteers read and signed an informed consent form before participation.

2.2. *Instrumentations*

Electromyographic (EMG) data of the medial gastrocnemius (MG) and tibialis anterior (TA) muscles were collected bilaterally using four circular Ag/AgCl bipolar surface electrodes (SX230, Biometrics Ltd., Gwent, UK) which were connected to the DataLINK system (DLK900, Biometrics Ltd., Gwent, UK). The diameter of each electrode was 1 cm and the centre-to-centre inter electrode distance was 2 cm. EMG signals show excellent repeatability during quiet standing (Lehman, 2002). A Gulik measuring tape was used to assess lower leg swelling through measuring the circumference of this region. The Gulick tape has a constant tension of 1 N when measuring the leg circumference, ensuring that each measurement is being taken under the same pressure and also decreases the error caused by traction and compression of soft tissues (Lin et al., 2012b; Zander et al., 2004).

2.3. Footwear

Unstable and stable (flat-bottomed) footwear, which were used in this experiment, were manufactured by a certified orthopaedic shoe technician in a medical shoe construction centre. The materials used for construction of footwear were the same in both upper (soft natural leather) and lower (ethyl-vinyl-acetate (EVA) foam) shoe parts. The only difference between two shoes was the outsole design which for unstable shoe it was characterized by a rounded sole design in the anterior–posterior direction and a flat design for stable shoe. (Figure 1)

2.4. Experimental design and protocol

The current study used a within-subject experimental design in which each participant completed a two-hour simulated continuous standing test session in the laboratory for each of three footwear conditions including barefoot, stable shoe, and unstable shoe (three sessions for each participant with one trial in each session, totally 30 trials). The order of each condition was randomized by participants selecting a condition from a black bag. All standing tests were performed in a certain time of the day (morning) and with one week interval between each test session. The dependent variables were measures of muscles co-contraction and swelling in lower leg region during standing period with different footwear conditions.

Before starting the first session, the purpose and procedure of this experiment were introduced to each participant. In the beginning of each test session, the midpoint of lower leg was marked by a coloured pen as the location for circumference measurement. Participants were asked not to erase the markings. The circumference of lower leg was measured in centimetre scale for right and left legs in the beginning of each session and after standing for two hours (Lin et al., 2012b).

In the next stage, lower legs of participants were prepared for surface EMG electrode placement. Skin surface of the belly area of the interested muscles was shaved and the dead cells and non-conductor elements were removed by alcohol and abrasive pad, respectively. For the application of surface electrodes the recommendations of SENIAM were followed (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000). The electrodes then were applied over two bilateral muscle groups: TA (in 20% of the distance from the tibial tuberosity to the inter-malleoli line) and MG (in 25% of the distance from the medial side of the popliteus cavity to the calcaneal tubercle). The reference electrode was placed on the medial malleolus. To avoid movement and to ensure homogeneous and constant pressure, the electrodes were fixed to the skin using adhesive tape. After electrode placement, to obtain maximal voluntary contractions (MVC) the following positions were used: plantar flexion through single leg toe standing with provided balanced support (strong manual resistance was given downward at the shoulders) for gastrocnemius muscle, and ankle dorsiflexion while standing (manual resistance was given downward at the foot) for TA muscle. The raw EMG signals were acquired at a sample rate of 1000 Hz, pre-amplified at the electrode site, and also were amplified using a single differential amplifier with an input impedance of 1000 MΩ, a common mode rejection ratio of 110 dB, and a gain of 1000. The signals were filtered with a bandwidth of 15–500 Hz.

Then, the participants entered into the prolonged standing task as its experimental set-up is shown in Figure 2. The work surface was positioned in front of the participants and adjusted to a height of 5 cm below elbow height for each participant. Participants were required to stand in a confined working area (0.5 _ 0.5 m) for two hours required not to step out of the test area. However, they were allowed to adjust their posture within this space and rest their forearms on the worktable without supporting their body weight.

Two different tasks (assembly and mental task) were chosen to simulate light occupational activities often performed

Figure 1. Unstable (left) and stable (right) footwear used in the study.

Figure 2. Subjects standing for two hours in each of footwear conditions while completing light assembly and mental tasks.

during prolonged standing. In assembly task, three different sizes of bolts were taken from three boxes which were positioned on the right side of the working table and then were screwed on special plate which was placed on the left side of the working table. The completion of each size lasted 30 minutes. For mental task, the puzzle pieces, which were in a box in front of the participants, were taken by the participants and placed on a special frame that was positioned near to the box. These tasks were done by the participants in each 30 minutes of standing test. The order to perform any of these tasks was optional. EMG data were collected continuously for the two-hour standing in 15-minute blocks for all the muscles in the quiet bipedal anatomical standing position (nine 30-second EMG recording for each muscle).

2.5. *Data processing*

With regard to lower leg midpoint circumferences the following formula was used to determine the percentage of circumference changes as an indicator of swelling:

$$\%\Delta C = \frac{C_2 - C_1}{C_1} \times 100$$

where C_1 is the initial circumference (in cm) and C_2 is the circumference (in cm) at the end of standing period (two hours).

Raw EMG signals were analysed using Matlab software (Matlab R 2009, version 7.8.0.347, The Mathworks, Inc., Natick, MA, USA). Root mean square (RMS) of EMG signals was considered as the most reliable parameter in the time domain (Balasubramanian et al., 2009). For both MG and TA muscles (right/left), RMS data of nine 30-second recording signals (as RMS_j), resting EMG signals (as $\mathrm{RMS}_{\mathrm{rest}}$), and MVC signals (as $\mathrm{RMS}_{\mathrm{MVC}}$) were computed separately. Then, to normalize RMS data based on the MVC signals the following equation was applied as one of the best methods to normalize EMG signals in healthy people (Sousa & Tavares, 2012):

Normalized RMS (NRMS) relation

$$\mathrm{NRMS}_j = \frac{\mathrm{RMS}_j - \mathrm{RMS}_{\mathrm{rest}}}{\mathrm{RMS}_{\mathrm{MVC}} - \mathrm{RMS}_{\mathrm{rest}}} \qquad (1)$$

Finally, to compute the co-contraction index (CCI), which provides a quantitative measure of the degree of co-contraction for a pair of lower leg antagonist (TA/MG) muscles, the following equation was used:

CCI computation relation

$$\mathrm{CCI} = \sum_{i=1}^{N} \left(\frac{\mathrm{NRMS}_{\mathrm{Low}\ i}}{\mathrm{NRMS}_{\mathrm{High}\ i}} \right) \left(\mathrm{NRMS}_{\mathrm{Low}\ i} + \mathrm{NRMS}_{\mathrm{High}\ i} \right) \qquad (2)$$

where N is the number of data points. $\mathrm{NRMS}_{\mathrm{Low}}$ i and $\mathrm{NRMS}_{\mathrm{High}}$ i were selected from all NRMS data of two muscle groups (TA/GM). In each time, one of these muscles had the relative minimum value ($\mathrm{NRMS}_{\mathrm{Low}}$) and the other had the relative maximum value ($\mathrm{NRMS}_{\mathrm{High}}$) NRMS. For both right and left lower legs nine CCIs were obtained separately.

2.6. *Statistical analysis*

First, descriptive statistics were run for all of the variables. Then, changes in EMG data (CCI) and lower leg swelling (ΔC%) were assessed separately using repeated measures analysis of variance (ANOVA) with two within-subject factors (footwear condition and standing time) for EMG (CCI) data and one factor (footwear condition) for lower leg swelling (ΔC%). Pairwise comparison with the least significant difference (LSD) was made when *post hoc* multiple-range tests were required. The alpha level of equal to or less than 0.05 was accepted as significant for all statistical tests. Moreover, considering relatively small sample size (10 subjects), effect sizes were reported using partial eta-squared (η_p^2). All statistical analyses were performed through SPSS version 19.0 (SPSS, Inc. 2010).

3. Results

3.1. Lower leg swelling: unstable footwear effects

Table 1 lists the mean and standard deviations for right and left lower legs circumference measures (pretest/posttest circumferences, circumference changes, and percentage of changes in proportion to the pretest circumference). After the standing time, bilaterally, increase in lower leg circumference was observed in all footwear conditions. To compare the effects of footwear conditions, the percentage of changes value which was normalized to pretest circumference was analysed. According to the results of repeated measures ANOVA, which are summarized in Table 2, the footwear conditions influenced this value for right and left legs after two hours of standing. Multiple range tests using the LSD results indicated that percentage of circumference changes was reduced by unstable shoe in relation to barefoot condition for right ($p = 0.004$) and left legs ($p = 0.043$). There was no significant difference for percentage of circumference changes between unstable and stable shoes, or between barefoot condition and stable shoe in both legs ($p > 0.05$).

3.2. Lower leg muscles co-contraction: unstable footwear effects

Figure 3 illustrates the mean CCI level for antagonist lower leg muscles (right and left MG/TA pairs) which their EMG signals were recorded in 15-minute blocks during a two-hour prolonged standing with different footwear conditions. The repeated measures ANOVA results revealed that level of CCI for right and left MG/TA muscles pair was significantly influenced by footwear conditions (Table 2). LSD's multiple-range test results showed that for both right and left legs, standing with unstable shoe caused lower CCI level of MG/TA muscles pair than standing while barefoot (right: $p = 0/013$) (left: $p = 0/041$). No significant difference in the CCI level was found for MG/TA muscles pair between unstable and stable shoes, or between barefoot condition and stable shoe in both legs ($p > 0.05$).

4. Discussion

The present study was designed to quantify the lower leg swelling and muscle co-contraction during continuous standing for two hours with three different footwear conditions including barefoot, stable shoe, and unstable shoe. With regard to the lower leg circumference changes (swelling) as the most undesirable outcome of prolonged standing (Antle & Côté, 2013), the findings of this study revealed that among all footwear conditions the lowest changes or swelling were in the standing with unstable shoe, but the significant differences for both right and left legs were only found compared to barefoot condition (Tables 1 and 2). These findings are in line with Sousa, Tavares, et al. (2012) study showing improved venous blood return from the legs following long-term use of

Table 1. Means and standard deviations of lower leg circumferences (cm) for three different footwear conditions.

	Pretest mean (SD)		Posttest mean (SD)		Change mean (SD)		Change (%) mean (SD)	
Footwear conditions	Right	Left	Right	Left	Right	Left	Right	Left
Barefoot	26.80 (1.64)	27.06 (1.47)	27.64 (1.53)	27.92 (1.42)	0.84 (0.22)	0.86 (0.33)	3.17 (0.96)[a]	3.20 (1.38)[b]
Stable shoe	27.33 (1.39)	27.21 (1.28)	28.04 (1.39)	28.02 (1.35)	0.71 (0.13)	0.81 (0.26)	2.60 (0.51)	2.97 (0.97)
Unstable shoe	27.21 (1.60)	27.07 (1.76)	27.80 (1.53)	27.67 (1.67)	0.59 (0.16)	0.60 (0.15)	2.18 (0.65)[a]	2.20 (0.70)[b]

[a]Significant deference for right leg.
[b]Significant deference for left leg.

Table 2. Summary of repeated measures analysis of variance (ANOVA).

	Footwear condition			Time			Time × footwear condition		
Measure	F	P	ES	F	P	ES	F	P	ES
Percentage of lower leg circumference change:									
Right leg	7.33	0.006*	0.44	–	–	–	–	–	–
Left leg	3.49	0.048*	0.27	–	–	–	–	–	–
EMG(CCI, mean)									
Right MG/TA	3.91	0.036*	0.32	0.19	0.99	.026	0.13	1.00	.015
Left MG/TA	3.63	0.044*	0.28	0.18	0.99	.021	0.14	1.00	.016

Note: ES: effect size.
$^{*}p < 0.05$.

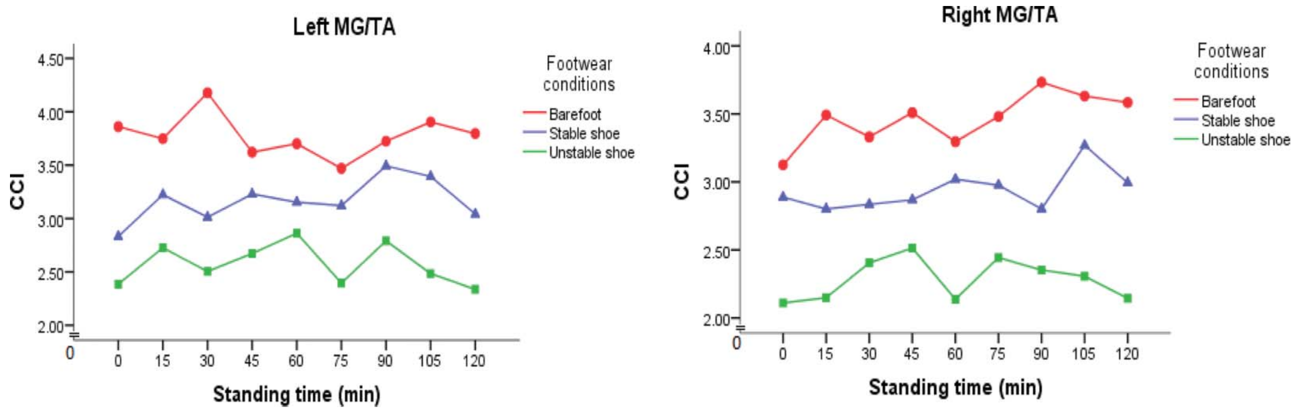

Figure 3. Lower leg muscles mean CCI level for three different footwear conditions during standing period. TA: tibialis anterior, MG: medial gastrocnemius.

unstable shoes. Furthermore, the findings are also in line with the authors' recent research demonstrating smaller lower leg volume changes during continuous prolonged standing challenge with this type of shoe compared to a barefoot condition (Karimi et al., 2016).

The main difference between unstable shoe and other two footwear conditions (barefoot and stable shoe) is the degree of surface stability under the feet which decreased more for unstable shoe compared to other footwear conditions through the rocker sole design (Nigg et al., 2012). Decreased stability can lead to more body swaying (Plom, Strike, & Taylor, 2014) and consequently can cause more muscle activity in different body parts, specifically those muscles engaged in ankle strategy of postural control (lower leg muscles in particular) (Buchecker, Pfusterschmied, Moser, & Müller, 2012; Nigg, Hintzen, & Ferber, 2006; Sousa, Tavares, et al., 2012). Increased activity of lower leg muscles leads to the change of static standing into a more dynamic standing which can be useful for venous return and reduction in lower leg circumference (Lin et al., 2012a). In this regard, the positive effects of unstable shoe on isolated activation pattern of some lower leg muscles were also confirmed by the authors' previous study results (Karimi et al., 2016). The findings have suggested that standing with unstable shoe leads to increased muscle activity level and variation in a two-hour prolonged standing test. Therefore, destabilizing the standing surface can be an effective factor to create such changes in the isolated muscle activation pattern during prolonged standing. But regarding activation synergies between different lower leg muscles such as co-contraction that might be prevailing during static standing, which changes are beneficial?

Assuming that relaxed stance condition is representative of normal standing in everyday life and also in occupations which require standing posture, with increased time of standing, the relaxed standing can change into a still standing condition. This can be accompanied by different postural control strategy with regards to muscle activation pattern in ankle region, commonly in the form of increased antagonist muscles co-contraction level for voluntary maintenance of standing postural balance (Reynolds, 2010; Warnica et al., 2014). In general, muscle co-contraction is one of the most important activation patterns to produce greater stability in the joints through the concurrent contraction of agonist/antagonist muscles pair with minor or no joint movement and thereby any significant change in the muscle length (Di Nardo et al., 2015; Nagai et al., 2011). In this regard, prolonged standing condition with low-level of body movements such as barefoot standing on ceramic surface can lead to still standing with greater level of lower leg muscle co-contraction. The underlying assumption to change the standing type (relaxed to still) is the high stability during long time of barefoot standing which can lead to further encouragement of the person to maintain balance. Increase in muscle co-contraction can be seen as increased concurrent static contraction in the lower leg muscles (such as MG/TA pair). Therefore, the aim of any intervention to prolonged static standing based on a recent recommendation, 'more posture and load variation during static or repetitive works is beneficial to health and wellbeing' (Mathiassen, 2006; Srinivasan & Mathiassen, 2012), should be focused on increased alternating (dynamic) muscle contraction which is accompanied by the low-level of lower leg muscles co-contraction.

Regarding antagonist lower leg muscles co-contraction which was monitored in this study with EMG signal recording over a two-hour standing period in 15-minute blocks, results showed significant lower level of CCI for both right and left MG/TA pairs during standing with unstable shoe compared to standing barefoot (Table 2 and Figure 3). In this regard, the studies conducted by Andreia S.P. Sousa et al. have shown that there is a significant reduction in the lower leg antagonist muscle co-contraction (MG/TA) during short-term quite standing test with unstable shoe compared to standing barefoot (Sousa et al., 2013). However, after long-term use of unstable shoe (eight weeks) this reduction in the level of lower leg muscle co-contraction during similar standing test condition was not reported (Sousa et al., 2014, 2016). In addition to these reports, the present study results demonstrated that standing for long periods of time with unstable shoe can maintain the lower level of muscle co-contraction in the MG/TA antagonist pair steadily. Furthermore, as mentioned earlier, increased activity of lower leg muscles was reported in previous studies during standing test with unstable shoe (Buchecker et al., 2012; Karimi et al., 2016; Nigg et al., 2006; Sousa, Tavares, et al., 2012). Combining the results, it can be suggested that standing with unstable shoe compared to barefoot standing increases muscle activity in the form of dynamic contraction and this type of activity can be useful for venous pump mechanism.

It is worth mentioning that comparison between two shoe conditions revealed that although the level of CCI was lower for standing with unstable shoe, but no significant differences were found compared to stable shoe. Furthermore, no significant differences were observed for the right and left CCI level between stable shoe and barefoot condition (Table 2 and Figure 3). In addition to these results, comparison of lower leg circumference changes between stable and unstable shoes and, between stable shoe and barefoot condition also showed no significant differences for both of right and left legs in this study (Table 1 and 2). In interpreting of these results, it should be noted that the outsole of stable shoe which was constructed by EVA foam, although more stable than unstable shoe because of flat design, is slightly more unstable than standing barefoot on ceramic surface because of material softness. Therefore, the outcome measures (lower leg circumference changes and CCI level) in the standing with the stable shoe can be slightly smaller than standing barefoot. However, this instability compared to one that provided by unstable shoe has not significant effect on reduction of lower leg circumference changes and CCI level which were seen in standing barefoot.

Considering the results of this study altogether, in relation to barefoot condition, prolonged standing with unstable shoe compared to stable shoe can lead to significant reduction in the lower leg muscle co-contraction and circumference changes bilaterally. However, there are some limitations to the present study that must be considered in future investigations. The results of the present study can be further confirmed through greater study population and also evaluation of unstable shoe over the longer time of standing in the real work environment. Monitoring other lower limb muscles activation patterns and recording the centre of pressure excursion are useful measures that can be applied in future studies for better interpretation of results. Finally, swelling of the legs may not give a full picture of what is happening vascularly, therefore more accurate measures (oxygen saturation and cutaneous blood flow) are recommended to quantify lower leg swelling in next studies.

5. Conclusion

In summary, based on the findings of this study which was limited to two hours of standing test, footwear condition in the form of unstable shoe can lead to significant changes in outcome measures (lower leg swelling and muscles co-contraction) which were recorded during standing barefoot on ceramic surface. But such significant effects were not observed for stable shoe. Considering the positive effects of unstable shoe in relation to reduced lower leg swelling and muscle co-contraction, application of this type of footwear as ergonomic solution is recommended for people whose work or daily activities require prolonged standing. However, the use of this intervention in real work environment and even during everyday activities (focus on prolonged standing) should be more reviewed in future works through more comprehensive assessments.

Disclosure statement

The authors declare that they have no conflict of interest.

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