Influence of unstable footwear on lower leg muscle activity, volume change and subjective discomfort during...

Article *in* Applied ergonomics · March 2016

DOI: 10.1016/j.apergo.2015.09.003

Teimour Allahyari
Urmia University of Medical Sciences

mahmood. R Azghani
Sahand University of Technology

Hamid reza Khalkhali
Urmia University of Medical Sciences

Applied Ergonomics 53 (2016) 95–102

Contents lists available at ScienceDirect

Applied Ergonomics

journal homepage: www.elsevier.com/locate/apergo

Influence of unstable footwear on lower leg muscle activity, volume change and subjective discomfort during prolonged standing

Zanyar Karimi [a], Teimour Allahyari [a, *], Mahmood Reza Azghani [b], Hamidreza Khalkhali [c]

[a] Department of Occupational Health, School of Health, Urmia University of Medical Sciences, Urmia, Iran
[b] Department of Biomechanics, Faculty of Mechanical Engineering, Sahand University of Technology, Tabriz, Iran
[c] Department of Epidemiology and Biostatistics, School of Health, Urmia University of Medical Sciences, Urmia, Iran

ARTICLE INFO

Article history:
Received 8 March 2015
Received in revised form
7 September 2015
Accepted 9 September 2015
Available online xxx

Keywords:
Unstable footwear
Discomfort
Prolonged standing
Muscle activity
Leg volume

ABSTRACT

Purpose: The present study was an attempt to investigate the effect of unstable footwear on lower leg muscle activity, volume change and subjective discomfort during prolonged standing.
Methods: Ten healthy subjects were recruited to stand for 2 h in three footwear conditions: barefoot, flat-bottomed shoe and unstable shoe. During standing, lower leg discomfort and EMG activity of medial gastrocnemius (MG) and tibialis anterior (TA) muscles were continuously monitored. Changes in lower leg volume over standing time also were measured.
Results: Lower leg discomfort rating reduced significantly while subjects standing on unstable shoe compared to the flat-bottomed shoe and barefoot condition. For lower leg volume, less changes also were observed with unstable shoe. The activity level and variation of right MG muscle was greater with unstable shoe compared to the other footwear conditions; however regarding the left MG muscle, significant difference was found between unstable shoe and flat-bottomed shoe only for activity level. Furthermore no significant differences were observed for the activity level and variation of TA muscles (right/left) among all footwear conditions.
Conclusions: The findings suggested that prolonged standing with unstable footwear produces changes in lower leg muscles activity and leads to less volume changes. Perceived discomfort also was lower for this type of footwear and this might mean that unstable footwear can be used as ergonomic solution for employees whose work requires prolonged standing.

1. Introduction

Standing for prolonged periods of time is essential in many occupations, including health care workers, supermarket workers, school teachers, and inspection and assembly workers. Numerous studies found that prolonged standing leads to various health problems such as lower extremity fatigue, pain, swelling and discomfort, venous blood pooling, low-back pain, and whole-body fatigue (Cham and Redfern, 1999; King, 2002; Lin et al., 2012b; Madeleine et al., 1997; Reid et al., 2010; Thomas and Dick, 2014; Zander et al., 2004; Zhang et al., 1991). Fatigue of leg muscles and pooling of blood in the legs are two suspected mechanisms for development of discomfort in the lower extremity during standing (Zander et al., 2004). Venous pooling as a result of a lack of contract-relax leg muscle activity, leads to foot and lower leg swelling and increased hydrostatic venous pressure, which may explain the increased reports of discomfort and pain (Antle and Cote, 2013). So that in previous studies, increase in lower limb volume (particularly lower leg and foot) has been reported as an indicator of insufficient blood return (Hansen et al., 1998; Zander et al., 2004). In addition, the reduced blood supply on gravity-loaded muscles accelerates muscle fatigue and pain due to an accumulation of metabolites in muscles (Balasubramanian et al., 2009). A recent research has suggested that the main cause of standing-related lower limb discomfort is more vascular in origin (Antle and Cote, 2013).

The impact of standing related discomforts on health insurance, absenteeism, productivity and well-being is substantial (King, 2002). Therefore, one of the priorities in many countries is prevention of musculoskeletal problems which are associated with prolonged standing in the workplace. Various ergonomic solutions to reduce these problems have been proposed in the literature,

* Corresponding author.
E-mail address: Allahyari@umsu.ac.ir (T. Allahyari).

http://dx.doi.org/10.1016/j.apergo.2015.09.003
0003-6870/

including anti-fatigue mats, shoe inserts, footrest, sit/stand chairs, and footwear (Chiu and Wang, 2007; Hughes et al., 2011; Thomas and Dick, 2014). More physical variation is commonly suggested to be an effective intervention against musculoskeletal disorders in jobs with low-level, long-lasting loads or repetitive operations (Mathiassen, 2006). Therefore, the main goal of the above-mentioned interventions, is to change the static standing into a more dynamic standing situation (active standing). Active standing is classified as the use of an unstable standing surface which requires the subject to engage in more body movement (lower limb in particular) to maintain an upright standing posture. A more dynamic situation during standing can lead to an increase in the muscle activity level; Furthermore it can increase the variation in the muscle activity, which might be useful for blood circulation and reduction of discomfort (Srinivasan and Mathiassen, 2012; Balasubramanian et al., 2008, 2009).

However, among these ergonomic interventions, footwear characteristics and their ability to create a more active posture during prolonged standing has not received much attention. According to recent studies, one of the significant characteristics of footwear, which might influence muscular activity pattern and haemodynamic response in lower extremities, is the rocker shape of sole design that produces instability during standing and walking (Nigg et al., 2012; Sousa et al., 2012). Several scientific studies have investigated the impact of unstable footwear (shoe with a rocker sole) on biomechanical objective measures during walking so far. These studies support the general concept that unstable footwear have positive effects on gait kinematic, kinetic, and muscular activity (Demura and Demura, 2012; Hutchins et al., 2009; Nigg et al., 2012, 2006; Romkes et al., 2006; Sobhani et al., 2013; Stewart et al., 2007; Taniguchi et al., 2012). With regard to standing, previous studies in the laboratory settings commonly evaluated the effects of unstable footwear on subjective and objective measures, including perceived instability, center of pressure (CoP) excursion, plantar pressure distribution, muscular activity, and physiological responses during maximum of 1-min standing in first use of unstable shoe (shoe with a rounded sole design in the anterior–posterior direction) (Buchecker et al., 2012; Plom et al., 2014; Stewart et al., 2007) or in before and after accommodation periods (use the unstable shoe for 2–10 weeks) (Nigg et al., 2006; Sousa et al., 2012; Landry et al., 2010). To date, some benefits have been introduced for unstable footwear during short time standing, including increase in the activity of lower limb muscles and improvement in some physiological variables such as energy expenditure, reflex excitability and venous return (Maffiuletti, 2012). However, for prolonged and continuous standing the potential influence of unstable footwear on standing discomforts, muscle activity level and venous return over standing time has not been investigated. Furthermore, the effect of unstable footwear on the variation of muscle activity during prolonged standing has been overlooked in the past.

It was hypothesized that the unstable footwear would significantly decrease perceived discomfort and volume change caused by increased lower leg muscle activity level and variation, compared to the stable footwear condition. Therefore, the main purpose of this study was to investigate the influence of unstable footwear on lower leg muscle activity (level and variation), volume change and subjective discomfort during a 2-h simulated continuous standing in the laboratory settings.

2. Methods

2.1. Subjects

Ten paid healthy males, with a mean age of 25.3 ± 1.49 years, an average body height of 1.77 ± 0.02 m, and average body weight of 74.8 ± 2.69 kg, participated in this experiment. The participants were student at Urmia University of Medical Sciences and none of them was engaged in a work which requires prolonged standing. To evaluate a single shoe size, the primary criterion for subject selection in this study was that subjects normally wear shoes with the size of 42 during their daily activity. None of the selected participants had a lower extremity injury/deformity, physical disability, or discomfort problem. All the volunteers also read and signed an informed consent form before participation.

2.2. Instruments

The electromyographic (EMG) signal of the medial gastrocnemius (MG) and tibialis anterior (TA) muscles, bilaterally, were monitored 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 center-to-center inter electrode distance was two cm. EMG signals during quiet standing show excellent repeatability (Lehman, 2002). A Gulick measuring tape was used to objectively measure lower leg circumference. To decrease the error caused by traction and compression of soft tissues, this tape measure had a tension meter at one end, ensuring that each measurement is being taken under the same pressure (Lin et al., 2012b; Zander et al., 2004). A reliable test should be characterized by a high reliability coefficient in combination with a low relative precision. For the studies which have been done with a spring tape measure, high reliability coefficient measurements of 0.97 for the calf and 0.98 for the ankle of healthy subjects and low relative precision of 6.36% for the calf and 12.49% for the ankle have been reported (Labs et al., 2000). Assessment of lower leg region discomfort was also performed using a 100 mm (mm) visual analog scale (VAS; 0, no discomfort; 100, worst discomfort imaginable). The reliability and validity of the VAS has been well documented (Revill et al., 1976; Summers, 2001).

2.3. Footwear

Both types of applied footwear in this experiment were manufactured specifically for the purpose of this study by a certified orthopedic shoe technician in a medical shoe construction center. The upper part of both shoes was made using the same last with a soft natural leather. In the normal shoe, the outsole was manufactured by ethyl-vinyl-acetate (EVA) foam with a flat design. Regarding the unstable shoe, the outsole was also constructed from EVA foam that was characterized by a rounded sole design in the anterior–posterior direction with the purpose of making the shoe unstable (Fig. 1).

2.4. Experimental design

The study used a within-subject experimental design in which participants took part in trying all the three footwear conditions: barefoot, flat-bottomed shoe and unstable shoe. The order of each condition was randomized by participants selecting a condition

Fig. 1. Unstable footwear (left) and flat-bottomed footwear (right) used in the study.

from a black bag. Each subject performed a 2-h simulated standing test in the laboratory for each footwear condition in a certain time of the day (morning) and with one week interval between each test session. The dependent variables were measures of perceived discomfort, muscle activity and volume change in lower leg region during the standing period with different footwear condition.

2.5. Procedures

The participants were first introduced to the purpose and procedure of this experiment. In the beginning of each test session participants were instructed to sit on a chair with their legs outstretched on another chair. The location of circumferences measurement, for the purpose of calculating lower leg volume, was marked by a colored pen, starting at the lateral malleolus of the ankle, and then progressed proximally in 4-cm segments along the longitudinal axis to 20-cm proximal to the lateral malleolus, where the calf has maximum circumference (totally six point) (Zander et al., 2004). Participants were asked not to erase the markings. The circumferences of lower leg were measured in cm scale for right and left legs in the beginning of each session and after standing for 2 h.

In the next stage, for EMG recording, the participants' lower legs for electrodes placement were prepared by shaving the skin surface of the interest muscle belly area; removing dead cells with alcohol; and removing non-conductor elements between electrode and muscle with abrasive pad. The application of surface electrodes followed the recommendations of SENIAM (Hermens et al., 2000, 1999). For tibialis anterior muscles, the surface electrode were placed at approximately 20% of the distance from the tibial tuberosity to the inter-malleoli line, starting from the tuberosity of the tibia. For medial gastrocnemius muscles, the surface electrode were placed at approximately 25% of the distance from the medial side of the popliteus cavity to the calcaneal tubercle. The reference electrode was placed at the medial malleolus. To avoid movement and to ensure homogeneous and constant pressure, the electrodes were fixed to the skin with adhesive tape.

Participants performed maximal voluntary contractions (MVC) tests with specific positions before each experiment. For MVC of gastrocnemius muscle, they performed single leg toe standing with provided balanced support and strong manual resistance was given downward at the shoulders. In presence of the resistance, where subject could stand on tip toes, maximal plantar flexion was obtained. Moreover, for tibialis anterior muscle participants in standing position did ankle dorsiflexion and manual resistance was given downward at the foot. Again, despite the resistance, where subject could do dorsiflexion to midrange, maximal dorsiflexion was obtained. All MVC tests were performed by an experimenter and was attempted to apply same manual resistance according to each participant in each session. 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.

Finally, participants entered into the prolonged standing task in which they were required to stand in a confined working area (0.50 _ 0.5 m) for 2 h while completing a series of assembly (sorting objects) and mental (completing puzzle) tasks on the work surface which was positioned in front of the participants and adjusted to a height of 5 cm below elbow height for each participant (Fig. 2). These tasks were chosen to simulate basic occupational activities often performed during prolonged standing. In assembly task, three different sizes of bolts were removed 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 min. 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 min of standing test. The order to perform any of these tasks was optional. During the 2-h standing period, the participants were prohibited from stepping 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. During standing period the participants were required to rate their level of perceived discomfort in lower leg region (for both right and left legs together) using a 100 (mm) visual analog scale. Ratings of discomfort were conducted at the start of the 2-h standing period and every 30 min until the end of the collection period (total of five discomfort ratings). EMG data were collected continuously for the 2-h standing in 15-min blocks for all the muscles in the quiet bipedal anatomical standing position (nine of 30-s EMG recording for each muscle).

Fig. 2. Subjects standing for 2 h in each of footwear conditions while completing light assembly and mental tasks.

2.6. Data processing

In this experiment, lower leg volume calculations, based on measured circumferences, were done using the following formula:

$$V = \frac{\sum(X^2 + Y^2 + XY)}{3\pi}$$

Where V is limb volume, X is the circumference at one point on the limb, and Y is the circumference at a point 4 cm proximal to X. After calculation of the pretest (V_1) and posttest (V_2) lower leg volume in each session, the percentage of volume changes, were also calculated:

$\Delta V\% = \{(V_2 - V_1)/V_1 \times 100\}$

EMG recordings of right/left MG and TA muscles in 15-min blocks during the standing trials (nine of 30-s recording for each muscle) were analyzed using Matlab software (Matlab R 2009, version 7.8.0.347, The Mathworks, Inc., Natick, USA). Root mean square (RMS) of EMG signal was considered as the most reliable parameter in the time domain (Balasubramanian et al., 2009). Analysis of root mean square (RMS) of EMG signal was done for raw data. The mean and coefficient of variance (CV) of normalized RMS of EMG signals during each 30-second recording was calculated for each muscle. To normalize raw data, the MVC data for each muscle was used. Mean and CV of normalized RMS were used to indicate changes in level and variation of muscle activity, respectively.

2.7. Statistical analysis

SPSS version 19.0 (SPSS, Inc. 2010) was used for all statistical analyses. First, descriptive statistics were run for all of the variables. Then, two-factor repeated measures analysis of variance (ANOVA) was performed to analyze the effect of footwear conditions and standing time on lower leg muscles activity and subjective discomfort responses, separately. For lower leg volume changes, only footwear condition effect was analyzed. 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.

3. Results

3.1. Influence of unstable footwear on subjective discomfort

Fig. 3 illustrates the Changes in mean values of subjective lower leg discomfort ratings during standing period for three footwear conditions. According to the results of ANOVA, which summarized in Table 1, subjective rating of lower leg discomfort was significantly influenced by time, footwear conditions and interaction between them. The level of lower leg discomfort rating increased for three footwear conditions during the 2-h standing. Multiple-range tests using the least significant difference (LSD) results indicated that discomfort rating during prolonged standing for barefoot condition was higher than standing with flat-bottomed ($p = 0.001$) and unstable shoes ($p = 0.000$). Lower discomfort rating among footwear conditions, was also related to unstable shoe ($p = 0.000$).

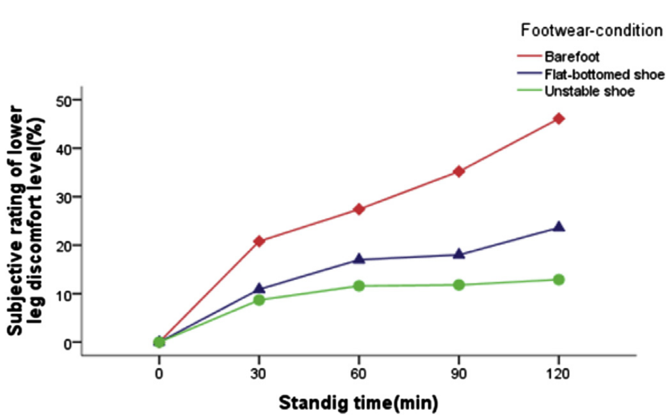

Fig. 3. Changes in mean values of subjective lower leg discomfort ratings for three different footwear conditions.

3.2. Influence of unstable footwear on lower leg volume change

Table 2 presents the mean and standard deviations for lower leg volume (right and left legs) measured before and after experimental sessions. Furthermore lower leg volume changes (increased volume) and percentage of these changes in proportion to pretest volume are also presented (Table 2). Under all three footwear conditions the mean scores of lower leg volume, for both legs, increased from pretest to posttest following the 2-h standing. To evaluate the effects of footwear conditions on lower leg volume during standing period, percentage of changes value that normalized to resting or pretest leg volume was analyzed. The repeated-measures ANOVA results revealed that footwear conditions influenced this value for right and left legs after 2 h of standing (Table 1). LSD's multiple-range test results showed that percentage of volume changes was reduced by unstable shoe in relation to barefoot condition for right ($p = 0.024$) and left legs ($p = 0.02$). There was no significant difference for percentage of volume changes between unstable and flat-bottomed shoes, or between barefoot condition and flat-bottomed shoe in both legs ($p > 0.05$).

3.3. Influence of unstable footwear on muscle activity level and variation

Fig. 4 shows the mean activity level (%MVC) for lower leg muscles which their EMG signals were recorded in 15-min blocks during a 2-h prolonged standing with different footwear conditions. Based on the repeated-measures ANOVA results (Table 1), level of activity for right and left MG muscles significantly influenced by footwear conditions. LSD's multiple-range test results revealed that right MG activity level during standing time for unstable shoe was higher than barefoot condition ($p = 0.032$) and flat-bottomed shoe ($p = 0.000$). For left MG muscle, standing with flat-bottomed shoe caused lower activity level than standing while barefoot ($p = 0.05$) or wearing unstable shoe ($p = 0.011$). No significant difference in the activity level was found for right and left TA among all footwear conditions ($p > 0.05$).

With regard to muscle activity variation during standing period, Fig. 5 shows CV of recorded EMG signals for lower leg muscles. ANOVA results (Table 1) showed only right MG muscle activity variation significantly influenced by footwear conditions. LSD's multiple-range test results indicated that standing with unstable shoe caused higher variation in the right MG muscle activity compared to barefoot condition ($p = 0.022$) and flat-bottomed shoe ($p = 0.034$). No significant difference in the activity variation was found for left MG and both right and left TA muscles among all footwear conditions ($p > 0.05$).

4. Discussion

Continuous standing for 2 h in this study lead to development of discomfort and increased volume in the lower leg (both right and left legs) region for all footwear conditions, especially while standing barefoot on hard floor (Fig. 3, Table 2). These findings are in line with the previous studies results which indicated standing for prolonged periods of time (2 h or more) causes development of lower limb discomfort and increase in the foot and calf volume (Cham and Redfern, 1999; Hansen et al., 1998; King, 2002; Madeleine et al., 1997). That's why in the most working environments, where employees are required to perform their duties and tasks in upright postures for prolonged periods of time, to reduce the standing related discomforts, ergonomic interventions such as footwear modification and promotion may be effective and helpful (Chiu and Wang, 2007; Lin et al., 2012b). Therefore, in this experimental study one of the most important footwear characteristics,

Table 1
Summary of repeated measures analysis of variance (ANOVA).

Measure	Footwear condition		Time		Time × footwear condition	
	F	P	F	P	F	P
Subjective rating of lower leg discomfort	29.36	0.000*	50.92	0.000*	22.89	0.000*
Percentage of lower leg volume change:						
Right leg	4.42	0.027*	–	–	–	–
Left leg	4.33	0.029*	–	–	–	–
EMG(RMS, Mean)						
Right MG	8.67	0.002*	1.39	0.21	0.37	0.98
Right TA	1.06	0.36	0.04	1.00	0.04	1.00
Left MG	3.66	0.046*	0.78	0.62	0.07	1.00
Left TA	1.47	0.25	0.19	0.99	0.17	1.00
EMG(RMS, CV)						
Right MG	4.38	0.028*	0.70	0.69	0.88	0.58
Right TA	3.49	0.053	0.84	0.56	1.14	0.32
Left MG	0.93	0.41	1.88	0.07	1.21	0.26
Left TA	1.59	0.23	0.88	0.53	0.30	0.99

*$p < 0.05$.

Table 2
Pretest and posttest mean scores and standard deviations of lower leg volume (cm^3) in the right and left legs for three different footwear conditions.

Footwear conditions	Pretest mean (SD)		Posttest mean (SD)		Change mean (SD)		Change (%) mean (SD)	
	Right	Left	Right	Left	Right	Left	Right	Left
Barefoot	991.88 (76.48)	996.81 (87.38)	1037.18 (75.76)	1041.66 (86.27)	45.30 (7.87)	44.84 (6.37)	4.60 (0.95)[a]	4.53 (0.83)[b]
Flat-bottomed shoe	993.36 (92.89)	996.52 (88.94)	1035.11 (94.83)	1038.57 (91.50)	42.58 (5.51)	42.04 (6.86)	4.30 (0.59)	4.27 (0.69)
Unstable shoe	991.02 (97.72)	997.07 (94.21)	1028.44 (97.61)	1036.35 (93.90)	37.42 (3.23)	39.28 (3.05)	3.81 (0.51)[a]	3.99 (0.50)[b]

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

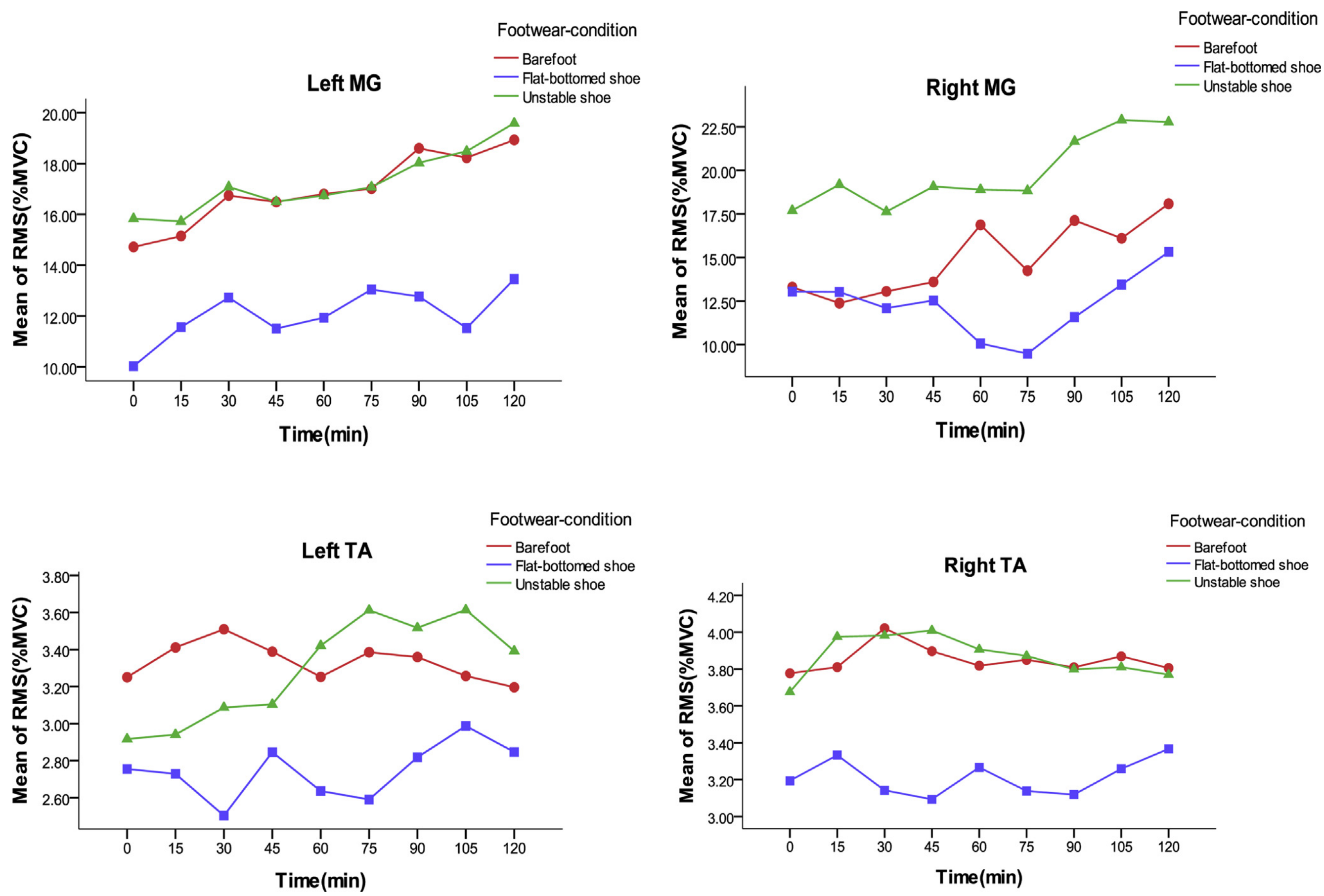

Fig. 4. Lower leg muscles activity level (%MVC) for three different footwear conditions during standing period. TA: Tibialis Anterior, MG: Medial Gastrocnemius.

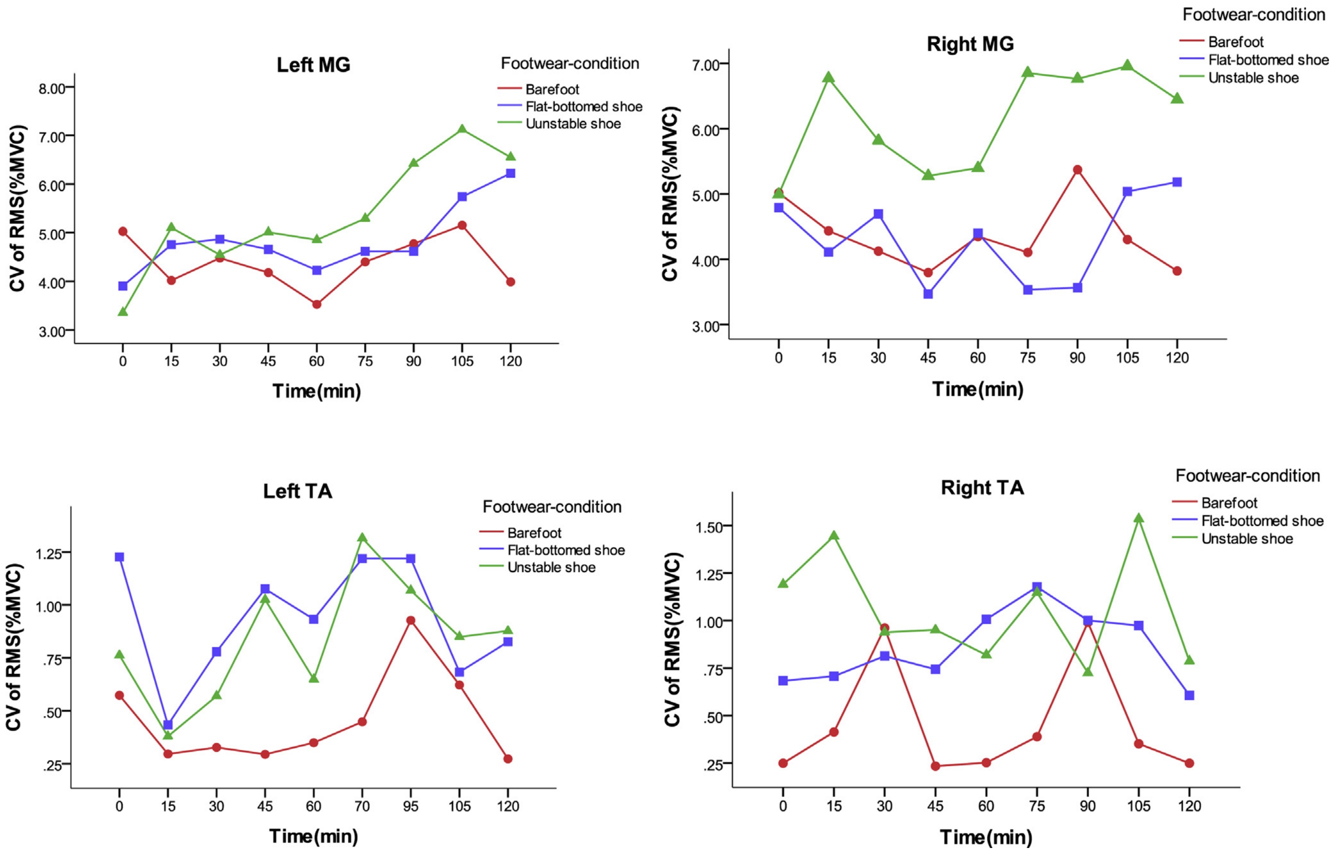

Fig. 5. Lower leg muscles activity variation (%MVC) for three different footwear conditions during standing period. TA: Tibialis Anterior, MG: Medial Gastrocnemius, CV: Coefficient of variance.

that is the sole design in relation to degree of stability (stable flat-design or unstable rocker-design), was evaluated for prolonged standing among healthy subjects. During standing period in this study, wearing the shoe (unstable or flat-bottomed) compared to barefoot condition reduced lower leg discomfort ratings. These findings are consistent with previous studies (Lin et al., 2012b; Zhang et al., 1991). An important finding in this study was that, the lower discomfort rating was seen while subjects standing on unstable shoe and this can be an advantage for this type of footwear.

With regard to the importance of footwear for prolonged standing, results obtained by Hansen et al. (1998) showed that for both 2-h standing and standing/walking work among all shoe (soft and hard)/floor (soft and hard) conditions the largest oedema-preventing effect occurs with the combination of soft shoe and hard floor. Therefore, proper footwear is one of the effective measures for controlling lower leg oedema during prolonged standing. Based on the findings of this study regarding lower leg volume changes, in relation to barefoot condition, only standing with unstable shoe lead to significant less volume changes, and no significant differences were found between the two shoe conditions or between flat-bottomed shoe and barefoot condition (Tables 1 and 2). These results suggest that venous return was better only in standing on unstable shoe compared to barefoot condition. In explaining why significant difference was not found between two shoe conditions, it should be mentioned that swelling of the legs or increase in legs volume may not give a full picture of what is happening vascularly. Therefore, future studies might track more accurate measures such as blood pressure, oxygen saturation and cutaneous blood flow to show the vascular changes between shoe conditions during prolonged standing. However, the positive effect of unstable shoe on venous return was also confirmed by Sousa et al. (2012) study results. In this study evaluation was performed in just 30-s bipedal quiet standing before and after 8-weeks use of unstable shoe. The findings suggested that wearing an unstable shoe leads to increased venous return and this increase was maintains after 8 weeks of using the unstable shoe.

According to Nigg et al. (2012), the concept behind unstable shoes can be summarized as follows: 'Unstable shoes are built to provide a training device that uses instability as a mechanism to train the neuromuscular control and/or to strengthen muscles in the human locomotor system'. Based on this concept, the effects of unstable shoe depend on the instability which is produced by this type of shoe. For prolonged standing, the produced instability can lead to a more active standing. Accordingly, active standing can lead to an increase in the postural activity. Increased activity of the postural control system increases the activity in the muscles that contribute to postural control, especially muscles that active in the co-called ankle strategy of postural control (lower leg muscles in particular) (Buchecker et al., 2012; Landry et al., 2010; Nigg et al., 2006; Sousa et al., 2012). Finally, these increased activity of lower leg muscles can lead to change the static standing into a more active standing which can useful for venous return (Lin et al., 2012a).

Lower leg muscles activity that monitored in this study with EMG signal recording over the 2-h standing period in 15-min blocks, showed higher level of activity for both right and left MG muscles during which subjects wearing unstable shoe compared to flat-bottomed shoe and for right and left TA muscles; however increase in activity showed for unstable shoe but no significant differences were found between two footwear conditions (Fig. 4, Table 1). Increased EMG activities for TA and MG muscles during standing in the unstable shoe compared to a standard control shoe, also reported by Nigg et al. (2006) and Buchecker et al. (2012) while the only significant difference found for the TA in both studies. According to Fig. 2 right MG also has higher activity level in standing with unstable shoe than barefoot condition, whereas right TA, left MG and left TA muscles were shown similar activity pattern in both standing with unstable shoe and barefoot condition. The results of Sousa et al. (2012) study also showed that using an unstable shoe (versus barefoot) among all monitored muscles just leads to increased MG activity.

Recently, it has been suggested that posture and load variation during static or repetitive works is beneficial to health and well-being (Mathiassen, 2006; Srinivasan and Mathiassen, 2012). For occupations exhibiting long-term, low-level exposures such as prolonged and continuous standing, increased variation may more effectively be obtained through increased activity than through rest. Therefore, along with increased activity of lower leg muscles, increase in activity variation, can be more helpful in pumping function of these muscles. With regard to variation in muscle activity, the results of this study showed that, although standing with unstable shoe leads to higher activity variation in most of the monitored muscles, the significant difference between two footwear conditions was only found for right MG muscle (Fig. 5, Table 1). These findings are in line with other studies in which they suggested that dynamic standing or more variation in lower limb movements and muscles activity leads to less discomfort and swelling in the lower extremities during prolonged standing (Balasubramanian et al., 2008, 2009; Lin et al., 2012a).

Based on the findings of the present study, flat-bottomed shoe compared to barefoot condition reduced the activity level of monitored muscles especially in MG muscles, whereas wearing the unstable shoe caused maintenance or increase in the activity level of these muscles (Fig. 4, Table 1). This feature of unstable footwear, in addition to improving the variation of lower leg muscle activity can lead to less volume changes and this signifies a better blood circulation. Finally the increase in venous return or less volume changes in lower leg region might explain the lower discomfort rating in this study which was observed when subjects standing on unstable footwear.

It is important to note that, although MG activity level with the barefoot condition did not differ so much compared to the unstable measurements, lover leg volume changes were greater in this condition compared to both footwear conditions. Based on the results obtained in this study, the detailed explanation for this difference cannot be found, but it can probably be due to the difference in the type of muscle contraction or differences in postural control strategies while standing barefoot compared to standing with unstable shoe. However, further investigations are recommended to find the definitive and accurate answer to this question. Another significant point which is worth mentioning here is the difference between right and left legs in the muscle activity level and variation. The origin of this difference, in which higher level and variation of activity was seen just for right MG muscle in standing with unstable shoe compared to other conditions and not found for left MG muscle, probably return to the difference between participants in the strategy of standing. Eighty percent of the participants said that their right leg is the dominant leg. Therefore, subjects tended to lean more on the right leg while standing and this possibly caused higher value for muscle activity parameters in the right leg.

In summary, the results of this study indicated that a 2-h standing on unstable footwear can be comfortable than standing with a stable footwear or barefoot condition; however the most beneficial degree of instability, effectiveness of unstable footwear for maximum time of continuous standing (4 or 8-h), their advantages in relation to other ergonomic aids (such as mats), and identifying the precise mechanisms of muscular activities and postural movements which lead to lower discomfort rating are subjects that needs more investigations.

5. Conclusions

The findings of this study demonstrated that during a 2-h continuous standing, unstable footwear significantly reduced the discomfort rating in lower leg region compared to flat-bottomed footwear and barefoot conditions. In addition, this type of footwear had positive effect on lower leg muscles EMG, especially lead to increased EMG activity level and variation in MG muscles and this could be helpful for venous return in lower leg region, Therefore smaller volume changes were observed while subjects standing on unstable footwear. In summary, based on the findings which was limited to 2 h of standing, unstable footwear can be used as ergonomic solution for employees whose work requires standing for prolonged periods of time. This intervention should be trialed in real work environments and industrial situations, and impact of other outcomes (walking stability, safety issues with slip/trip/fall) will need to be reviewed in future works.

Acknowledgment

This study was fully supported by Urmia University of Medical Sciences with project number (1393-04-34-1338). Acknowledgements are due to vice chancellery for research, Urmia University of Medical Sciences for funding this project.

References

Antle, D.M., Cote, J.N., 2013. Relationships between lower limb and trunk discomfort and vascular, muscular and kinetic outcomes during stationary standing work. Gait Posture 37, 615–619.
Balasubramanian, V., Adalarasu, K., Regulapati, R., 2008. Comparing stationary standing with an intermittent walking posture during assembly operations. Hum. Factors Ergon. Manuf. Serv. Ind. 18, 666–677.
Balasubramanian, V., Adalarasu, K., Regulapati, R., 2009. Comparing dynamic and stationary standing postures in an assembly task. Int. J. Ind. Ergon. 39, 649–654.
Buchecker, M., Pfusterschmied, J., Moser, S., Muller, E., 2012. The effect of different Masai Barefoot Technology (MBT) shoe models on postural balance, lower limb muscle activity and instability assessment. Footwear Sci. 4, 93–100.
Cham, R., Redfern, M.S., 1999. The influence of flooring on subjective standing comfort and fatigue. In: Proceedings of the Human Factors and Ergonomics Society Annual Meeting. SAGE Publications, pp. 737–741.
Chiu, M.-C., Wang, M.-J.J., 2007. Professional footwear evaluation for clinical nurses. Appl. Ergon. 38, 133–141.
Demura, T., Demura, S.-I., 2012. The effects of shoes with a rounded soft sole in the anterior–posterior direction on leg joint angle and muscle activity. Foot 22, 150–155.
Hansen, L., Winkel, J., Jørgensen, K., 1998. Significance of mat and shoe softness during prolonged work in upright position: based on measurements of low back muscle EMG, foot volume changes, discomfort and ground force reactions. Appl. Ergon. 29, 217–224.
Hermens, H.J., Freriks, B., Disselhorst-Klug, C., Rau, G., 2000. Development of recommendations for SEMG sensors and sensor placement procedures. J. Electromyogr. Kinesiol. 10, 361–374.
Hermens, H.J., Freriks, B., Merletti, R., Stegeman, D., Blok, J., Rau, G., Disselhorst-Klug, C., Hägg, G., 1999. European Recommendations for Surface Electromyography, 8. Roessingh Research and Development, pp. 13–54.
Hughes, N.L., Nelson, A., Matz, M.W., Lloyd, J., 2011. AORN Ergonomic Tool 4: solutions for prolonged standing in perioperative settings. AORN J. 93, 767–774.
Hutchins, S., Bowker, P., Geary, N., Richards, J., 2009. The biomechanics and clinical efficacy of footwear adapted with rocker profiles—evidence in the literature. Foot 19, 165–170.
King, P.M., 2002. A comparison of the effects of floor mats and shoe in-soles on standing fatigue. Appl. Ergon. 33, 477–484.
Labs, K.H., Tschoepl, M., Gamba, G., Aschwanden, M., Jaeger, K.A., 2000. The reliability of leg circumference assessment: a comparison of spring tape measurements and optoelectronic volumetry. Vasc. Med. 5, 69–74.
Landry, S.C., Nigg, B.M., Tecante, K.E., 2010. Standing in an unstable shoe increases postural sway and muscle activity of selected smaller extrinsic foot muscles. Gait Posture 32, 215–219.
Lehman, G.J., 2002. Clinical considerations in the use of surface electromyography:

three experimental studies. J. Manip. Physiol. Ther. 25, 293–299.
Lin, Y.-H., Chen, C.-Y., Cho, M.-H., 2012a. Effectiveness of leg movement in reducing leg swelling and discomfort in lower extremities. Appl. Ergon. 43, 1033–1037.
Lin, Y.-H., Chen, C.-Y., Cho, M.-H., 2012b. Influence of shoe/floor conditions on lower leg circumference and subjective discomfort during prolonged standing. Appl. Ergon. 43, 965–970.
Madeleine, P., Voigt, M., Arendt-Nielsen, L., 1997. Subjective, physiological and biomechanical responses to prolonged manual work performed standing on hard and soft surfaces. Eur. J. Appl. Physiol. Occup. Physiol. 77, 1–9.
Maffiuletti, N.A., 2012. Increased lower limb muscle activity induced by wearing MBT shoes: physiological benefits and potential concerns. Footwear Sci. 4, 123–129.
Mathiassen, S.E., 2006. Diversity and variation in biomechanical exposure: what is it, and why would we like to know? Appl. Ergon. 37, 419–427.
Nigg, B., Federolf, P.A., Von Tscharner, V., Nigg, S., 2012. Unstable shoes: functional concepts and scientific evidence. Footwear Sci. 4, 73–82.
Nigg, B., Hintzen, S., Ferber, R., 2006. Effect of an unstable shoe construction on lower extremity gait characteristics. Clin. Biomech. 21, 82–88.
Plom, W., Strike, S., Taylor, M., 2014. The effect of different unstable footwear constructions on centre of pressure motion during standing. Gait Posture 40, 305–309.
Reid, C.R., Bush, P.M., Karwowski, W., Durrani, S.K., 2010. Occupational postural activity and lower extremity discomfort: a review. Int. J. Ind. Ergon. 40, 247–256.
Revill, S., Robinson, J., Rosen, M., Hogg, M., 1976. The reliability of a linear analogue for evaluating pain. Anaesthesia 31, 1191–1198.
Romkes, J., Rudmann, C., Brunner, R., 2006. Changes in gait and EMG when walking with the Masai Barefoot Technique. Clin. Biomech. 21, 75–81.
Sobhani, S., Hijmans, J., Van den Heuvel, E., Zwerver, J., Dekker, R., Postema, K., 2013. Biomechanics of slow running and walking with a rocker shoe. Gait Posture 38, 998–1004.
Sousa, A., Tavares, J.M.R., Macedo, R., Rodrigues, A.M., Santos, R., 2012. Influence of wearing an unstable shoe on thigh and leg muscle activity and venous response in upright standing. Appl. Ergon. 43, 933–939.
Srinivasan, D., Mathiassen, S.E., 2012. Motor variability in occupational health and performance. Clin. Biomech. 27, 979–993.
Stewart, L., Gibson, J., Thomson, C.E., 2007. In-shoe pressure distribution in “unstable”(MBT) shoes and flat-bottomed training shoes: a comparative study. Gait Posture 25, 648–651.
Summers, S., 2001. Evidence-based practice part 2: reliability and validity of selected acute pain instruments. J. PeriAnesthesia Nurs. 16, 35–40.
Taniguchi, M., Tateuchi, H., Takeoka, T., Ichihashi, N., 2012. Kinematic and kinetic characteristics of Masai Barefoot Technology footwear. Gait Posture 35, 567–572.
Thomas, R., Dick, Robert B., 2015. Evidence of health risks associated with prolonged standing at work and intervention effectiveness. Rehabil. Nurs 40.3, 148–165.
Zander, J.E., King, P.M., Ezenwa, B.N., 2004. Influence of flooring conditions on lower leg volume following prolonged standing. Int. J. Ind. Ergon. 34, 279–288.
Zhang, L., Drury, C.G., Woolley, S.M., 1991. Constrained standing: evaluating the foot/floor interface. Ergonomics 34, 175–192.