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

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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,

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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.