



Effects of indoor slippers on plantar pressure and lower limb EMG activity in older women

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ABSTRACT

Open-toe mule slippers are popular footwear worn at home especially by older women. However, their biomechanical effects are still poorly understood. The objective of this study is to therefore evaluate the physical properties of two typical types of open-toe mule slippers and the changes in plantar pressure and lower limb muscle activity of older women when wearing these slippers. Five walking trials have been carried out by ten healthy women. The results indicate that compared to barefoot, wearing slippers results in significant increases in the contact area of the mid-foot regions which lead to plantar pressure redistribution from metatarsal heads 2–3 and the lateral heel to the midfoot regions. However, there is no significant difference in the selected muscle activity across all conditions. The findings enhance our understanding of slipper features associated with changes in biomechanical measures thereby providing the basis of slipper designs for better foot protection and comfort.

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1. Introduction

Footwear is intended to provide comfort for wearers and offer the first line of protection to the feet. The design features and fit not only contribute to changes in the plantar pressure and dynamic balance during walking, but also influence the development of children's feet. Improper footwear has been linked to foot pain and deformity, and even risk of falls in older people (Helfand, 2003; Janisse, 1995; Menant et al., 2008). Past studies on shoe features have indicated that midsole material hardness, height of the heel collar and outer sole slip resistance are important variables that affect the balance control and postural stability during outdoor walking (Hornbrook et al., 1991; Perry et al., 2007). It is also suggested that wearing footwear that is light in weight and offers minimal support such as flip flops or sandals affects the arch development in children (Carl and Barrett, 2008; Chard et al., 2013; Choi et al., 2013). There is a lower prevalence of flat-feet and a higher rate of normal arches among habitually unshod children compared to habitually shod children (Sachithanandam and Joseph, 1995). Nevertheless, prolonged use of less supportive footwear such as thong style flip-flops that are typically

constructed from a rubber template and loosely secured to the feet has been linked to heel pain and other conditions, such as overuse injuries of the tibialis anterior and toes in young adults (Chard et al., 2013; Zhang et al., 2013). Due to their flexible thin sole and lack of support, flip-flops also cause an altered gait and unusual stresses as compared to walking in barefoot and/or traditional closed-toe footwear (Shroyer et al., 2010).

Due to age-related deterioration of somatosensory feedback and problems with cutaneous mechanoreceptors in the sole of the feet of the elderly, postural stability tends to be affected by the hardness of the footwear sole materials as more rigid soles suggest greater postural stability. While thick and soft soles tend to better accommodate foot posture in older people, they may impair stability by reducing foot position awareness and mechanical stability, thus leading to a high risk of imbalance and falls (Menz et al., 2006; Menant et al., 2008; Qu, 2015). Inappropriate footwear can therefore cause discomfort, foot pain, tissue injury and ulceration due to high plantar pressure, which in turn, may cause gait and balance disturbances, which are predispositions of falls in older people (Mickle et al., 2010). On the other hand, footwear for the elderly must be appropriate for the location and activity being undertaken, which would assist the force transfer of the foot during the gait cycle and during stance and even accommodating foot deformities to reduce pain and discomfort (Helfand, 2003). To enhance comfort, footwear worn indoors tends to be softer and less supportive than

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those worn outdoors. Despite the fact that footwear can provide support for the lower extremity muscles and foot protection from injuries (Menant et al., 2008; Murley et al., 2009; Perry et al., 2007), many older people may prefer walking barefoot or in socks for comfort at the risk of a ten-fold increase in falling (Koepsell et al., 2004; Menant et al., 2008; Mickle et al., 2010). However, up to now, there has been a scarcity of scientific work which can offer solutions to older people for comfortable and safe footwear that can be worn at home. Biomechanical studies on indoor footwear of different design features compared to barefoot walking are very scarce.

As compared with thong style footwear, open-toe slip-on mule slippers (i.e. one strap across the distal-dorsal foot) are a popular type of household footwear because of their convenience and comfort, which is especially true for older women. They are primarily flat in shape and made of leather, foam rubber, textiles, plastic or leather and are loosely secured to the feet. However, their lack of fixation and rigidity fail to control heel motion and maintain postural stability. Further evaluation of footwear characteristics for older people has also indicated that due to age-related loss of muscle strength and alteration of muscle activity, inappropriate footwear which leads to increased muscle activity patterns elicits greater metabolic cost, and potentially increases the risks of fatigue and fall (Candow and Chilibeck, 2005; Hortobágyi et al., 2011; Marques et al., 2013; Mickle et al., 2010). To the best of our knowledge, there is a lack of investigation on the effects of indoor slippers on plantar pressure and lower limb muscle activity in older people. Previous studies on flip flops or sandals (Price et al., 2013, 2014) have mainly focused on gait modification and the joint range of motion in young adults. These studies have discussed lower limb muscle activity, but the influence of footwear features and material properties on muscle activity and plantar pressure has not been investigated. An understanding of the impact of footwear on plantar pressure and the lower limb muscle activity is very important in terms of the consideration of material and design of indoor slippers for older people. Hence, the purpose of this study is to evaluate the effects of two typical types of open-toe slip-on mule slippers with different material properties on plantar pressure and the lower limb muscle activity of older women when they are walking as compared to a barefoot condition.

We hypothesize that the design features of slippers and their material properties are associated with changes in plantar pressure patterns and level of muscle activity as compared to the barefoot condition during walking. Walking in slippers made of either soft or hard footbed material would yield different values of plantar pressure and muscle activity as compared with the barefoot condition. Soft footbed material with higher compressibility would allow better pressure-attenuating capability but also require higher muscle activity to maintain postural stability as compared to more rigid footbed materials.

2. Methods

2.1. Participants

A total of ten healthy females between 60 and 67 years of age (mean: 62.85; SD: 2.81) are recruited for this study. Their body mass index (BMI) ranges from 20.41 to 28.62 kg/m² (mean: 23.40; SD: 2.67). Their foot lengths range from 212 mm to 241 mm. A physiotherapist performed foot and gait assessments to check the feet for good foot sensitivity and normal gait. Participants with a history of major foot deformity or pain as well as neurological problems in the lower limbs were excluded. All of the participants were asked to provide written informed consent before the study.

2.2. Footwear

Three experimental conditions were used, including barefoot and the donning of two types of slippers. The selected slippers are those that are commonly worn by local older women at home (Fig. 1). Both types of slippers are open-toe and secured to the feet with a strap across the dorsal forefoot. Material physical property testing was carried out on the footbed of each slipper. Their key dimensions and physical properties with specified test standards are listed in Table 1.

2.3. Experimental protocol

In this study, the participants wear two types of indoor slippers with different physical characteristics in the wear trials. The participants were asked to walk at a speed that they felt was comfortable along a linoleum-covered concrete walkway that was 8-meters in length. The walking speed was measured by using an automatic timing gate that uses infrared (Brower Timing Systems, Utah, USA; 0.01 s precision) and standardized between the walking trials of each subject. The order of the three experimental conditions (barefoot, and wearing Soft and Hard Slippers) was counter-balanced to minimize potential order effects. The self-selected speed was predetermined by asking subjects to walk at their natural pace over a distance of 12 m and the duration for each trial was determined with two timing gates placed at 2 m and 10 m. The self-selected speed was calculated by dividing the distance walked (8 m) by the time to cover this distance (s). A total of 10 trials were used for the calculation of the self-selected speed of each participant. The mean walking speed was 3.35 km/h (SD: 1.5), which ranged from 2.64 to 4.39 km/h. The walking trials that exceeded 5% of the predetermined self-selected speed were rejected to minimize the effect of different walking speeds on plantar pressure (Burnfield et al., 2004). For each test condition, the participants were given a five-minute acclimatization period to walk along the pathway to adapt to the surroundings and footwear conditions, and instructed to complete 5 valid walking trials. The plantar pressure and surface electromyography (sEMG) data were simultaneously collected and the data for each subject were collected on the same day. After finishing the trial for each footwear condition, a visual analogue scale (VAS) questionnaire on their perceived comfort was immediately administered. Then the participants were given a five-minute rest with the slippers off to reduce potential muscle fatigue effects (Cram et al., 1998).

2.4. Plantar pressure distribution measurement

The plantar pressure was measured with an in-shoe Pedar[®] system (Novel GmbH, Munich, Germany) at a sampling rate of 50 Hz. This system comprises a matrix of 99 capacitance-based sensors in 2-mm thick flexible pressure-sensing insoles. A proper size of the pressure-sensing insoles was used to accommodate the different foot sizes of the participants. The barefoot condition was simulated by securing pressure-sensing insoles onto the bottom of the feet of the subject, and then they put on standard cotton socks that are 1.4-mm in thickness to secure the insoles (Bacarin et al., 2009; Burnfield et al., 2004). For the conditions in which the slippers were worn, pressure-sensing insoles were placed between the feet and slippers. The Novel Multimask software (Novel GmbH, Munich, Germany) was used to divide the plantar foot into 9 anatomical regions: the hallux, lesser toes, 1st metatarsal head (Mth1), 2nd to 3rd metatarsal heads (Mth23), 4th to 5th metatarsal heads (Mth45), medial and lateral arches, and medial and lateral heels. For each region, the data on the peak pressure (PP), pressure-time integral (PTI) and contact area were collected by the Novel

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