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Enhanced somatosensory information decreases postural sway in older people

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ABSTRACT

The somatosensory system plays an important role in balance control and age-related declines in somatosensory function have been implicated in falls incidence. Different types of insole devices have been developed to enhance somatosensory information and improve postural stability. However, they are often too complex and expensive to integrate into daily life and textured insole surfaces may provide an inexpensive and accessible means to enhance somatosensory input. This study investigated the effects of textured insole surfaces on postural sway in ten younger and seven older participants performing standing balance tests on a force plate under three insole surface conditions: (1) barefoot; (2) with hard; and (3), soft textured insole surfaces. With each insole surface, participants were tested under two vision conditions (eyes open, closed) on two standing surfaces (firm, foam). Four 30 s trials were collected for different combinations of insole surface, standing surface and vision. Centre of pressure measurements included the range and standard deviation of anterior–posterior and medial–lateral displacement, path length and the 90% confidence elliptical area. Results revealed a significant Group*Surface*Insole interaction for five of the dependent variables. Compared to younger individuals, postural sway was greater in older people on both standing surfaces in the barefoot condition. However, both textured insole surfaces reduced postural sway for the older group especially in the eyes closed condition on a foam surface. These findings suggest that textured insole surfaces can reduce postural sway in older people, particularly during more challenging balance tasks. Textured insole surfaces may afford a low-cost means of decreasing postural sway, providing an important intervention in falls prevention.

1. Introduction

Age-related declines in sensory and motor function can result in postural instability and an increased risk of falls leading to injury, hospitalization and mortality [1]. One third of community-dwelling older people over 65 years fall at least once a year [2]. Accurate detection and integration of somatosensory information from the feet is important for balance control [3]. Degeneration of peripheral sensory receptors, exemplified in diabetic peripheral neuropathy [4], can lead to a diminished capacity to detect information from the soles of the feet during interactions with the external environment [5,6]. Diminished somatosensory function has also been identified as a significant age-related change and is believed to be a significant contributor to postural instability and falls [7]. Older participants have a lower sensitivity of the plantar surface of the foot than younger individuals [6,8], which can increase postural sway [9].

Artificially reducing somatosensory information, by cooling [10] or local anesthetic ischemia induced by hypoxic anesthesia of the feet and ankles [11], can increase postural sway. Standing on a foam surface reduces the reliability of somatosensory information and increases postural sway. These effects are exacerbated when vision is excluded and greater reliance is placed on somatosensory information [12]. The effects of standing on a foam surface have been equated to diabetic peripheral neuropathy [4,6] and more recently Patel et al. [13] reported that standing on a foam surface with eyes closed decreased the reliability of somatosensory information of feet. This observation was also supported by

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findings of Vuillerme and Pinsault [14] who recognized that somatosensory inputs from the feet were degraded by standing on a foam surface.

Previous research has provided some evidence that artificially enhancing cutaneous information can change postural sway and potentially improve postural stability [15,16]. Kavounoudias et al. [17] showed that supra-threshold vibratory stimulation of the feet during quiet stance altered postural sway; bilateral stimulation of the forefoot resulted in backward leaning. Similarly, sub-threshold mechanical vibration applied to the soles of the feet increased the detection of plantar pressure changes, with a consequent reduction in postural sway in older people [16] and peripheral neuropathy patients [18]. However, practically, vibratory devices can be expensive and complex to adopt as effective interventions to decrease postural sway. Clearly there is a need to develop and evaluate simple and inexpensive interventions that can enhance somatosensory feedback from the feet and diminish postural sway.

Recent research has suggested that passive devices may provide an inexpensive and effective alternative to decrease postural sway. Palluel et al. [19] reported reduced postural sway during quiet stance for older people while wearing sandals with firm rubber nodules. However, sandals may not be suitable footwear for all individuals and their use can be limited by environmental, work and social constraints. Furthermore, sandals and other footwear have been suggested to introduce different confounding effects due to differences in shoe design and construction [20]. Additionally, Palluel et al. [19] only evaluated postural sway on a firm surface and did not randomize the order of testing conditions, which may have introduced a learning effect into their results. Assessing postural sway while standing on a foam surface may decrease the reliability of somatosensory information from the feet and provide a more useful way to evaluate the effect of somatosensory changes on postural sway, especially without visual input. Similarly, Corbin et al. [21] reported reduced postural sway in younger participants while wearing insoles which had a textured pattern; but their effectiveness in older people was not assessed. Recently Hatton et al. [20] noticed that mediolateral sway was decreased when standing on textured surfaces in older people. However, the performance of a younger control group was not evaluated in their study.

The aim of this study was to examine the efficacy of a newly designed textured insole surface for reducing postural sway in healthy younger and older adults during standing balance. Due to aging effects on the peripheral nervous system it was expected that insole surface attenuation effects on postural sway were likely to be greater in the older groups, compared to the younger groups, especially under conditions where peripheral somatosensory information was more important in maintaining postural stability.

2. Methods

2.1. Participants

Seven elderly adults (four males and three females; mean age 72 ± 4 years; Body Mass Index (BMI) 25.6 ± 2.2 kg/m^2) and ten healthy young adults (six males and four females; mean age 27 ± 3 years; BMI 22.3 ± 2.4 kg/m^2) participated in this study. Elderly participants were randomly selected from a pre-existing database of healthy older adults who had expressed an interest in being involved in this type of research. All participants were free of significant cognitive impairment (Mini Mental State Examination total score $\geq$24) and other illnesses that may have interfered with static standing or dynamic motion.

Prior to their involvement, participants were briefed on the benefits and risks of this study and all gave written informed consent to participate in this research program. The testing procedures were approved by the Queensland University of Technology Human Research Ethics Committee.

2.2. Test protocol

To examine the influence of altering somatosensory information on postural stability, participants performed standing balance tests under three insole surface conditions: (1) barefoot; (2) hard textured insole surface (320 density ethylene-vinyl acetate); and (3) soft textured insole surface (270 density ethylene-vinyl acetate). Both insole surfaces (International Children's Orthotic Laboratory, Australia) were 1.5 mm thick and had granulations with a diameter of 5.0 mm and a height of 3.1 mm that were distributed evenly across the upper surface. The order of insole surface conditions and assessments were randomized for each participant.

For each of the insole surface conditions, participants were tested under two vision conditions (eyes open, closed) on two standing surfaces (firm, foam). During the experiments, participants stood as still as possible on a force plate (HUR Labs OY, Finland), looking straight ahead to fixate a cross positioned at eye level and 1.5 m away, with their feet 10 cm apart and their hands at their sides. Data from four 30 s trials were collected at 100 Hz.

In accordance with previous research [16,18,20,22], our study used measurements derived from the displacement of centre of pressure (COP) and included the range of anterior–posterior (AP) and medial–lateral (ML) COP displacement, AP and ML standard deviation (SD), path length (PL) and the 90% confidence elliptical area (C90 area).

2.3. Statistical analyses

A mixed model Analysis of Variance (ANOVA) with one between-participant (younger; older) and three within-participant factors, including insole surface (barefoot; hard; soft insole surface), vision (eyes open; closed) and standing surface (firm; foam) was used to compare postural control. A separate analysis examining the potential interaction of age (younger, older) and insole surface (barefoot; hard; soft insole surface) was undertaken in an 'eyes-closed' condition standing on a foam surface. Post hoc comparisons were undertaken using Fisher's Least Significant Difference (LSD) test. Statistical significance was set at the 95% confidence level ($p < 0.05$). Data were analyzed using the Statistical Package for Social Sciences (SPSS V17.0, Chicago, IL, USA).

3. Results

Clear differences in postural sway as a function of age, insole surface and standing surface were revealed by a significant Group*Surface*Insole interaction for C90 area, PL, AP and ML sway and ML SD ($p < 0.05$).

3.1. Postural sway (C90) area

The older group revealed a greater postural sway area than the younger group in the barefoot condition on firm and foam surfaces ($p < 0.05$). Both insole surfaces reduced the C90 area for the older group to an area equivalent to that observed in the younger group on the firm surface. However, when standing on the foam surface, only the soft insole surfaces reduced the C90 area of the older group to be equivalent to that observed in the younger group. Overall the measure of postural sway area revealed that only the older group benefitted from the use of different insole surfaces. No significant differences were observed for the younger participants between the barefoot, hard and soft insole surface conditions on either the firm or foam surfaces (Fig. 1).

3.2. Path length (PL)

On the firm and foam surfaces, PL for the older group was greater than the younger group under all three insole surface conditions ($p < 0.001$) (Fig. 2). There was a significant and progressive decrease in PL from the barefoot to hard to soft insole surface conditions for the older group, but only when standing on the foam surface ($p < 0.05$), and this trend was more pronounced under the eyes closed condition. The only beneficial effect for the young group, relative to the barefoot condition, was when standing on the hard insole surface on a firm surface ($p < 0.05$).

3.3. Anterior–posterior (AP) postural sway and AP SD

The older participants demonstrated increased AP sway relative to the younger group under the three insole surface conditions on the firm surface ($p < 0.05$). The older group also demonstrated

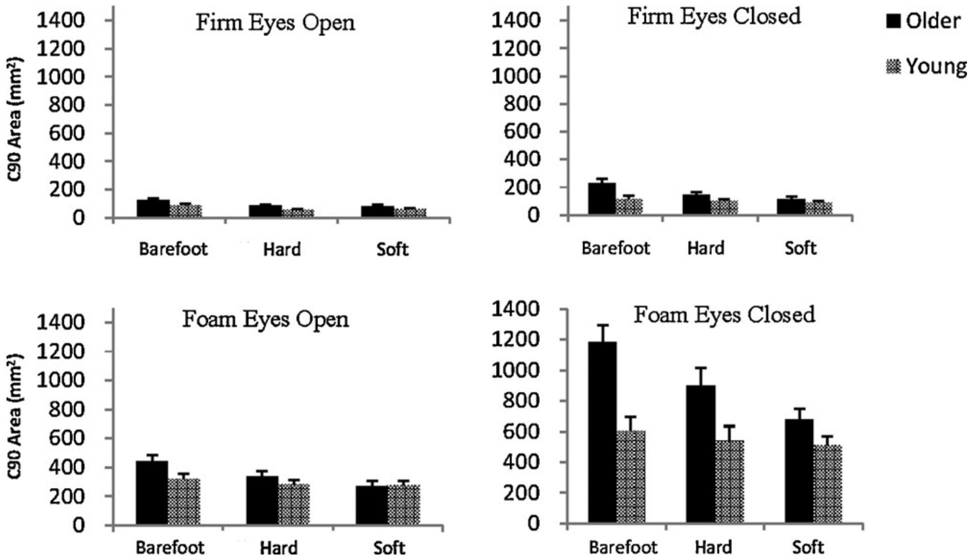

Fig. 1. Mean (+1 SD) C90 area for the older (black) and young (grey) participants during the four standing conditions.

increased AP sway on the foam surface in the barefoot and soft insole surface conditions ($p < 0.05$), but not with the hard insole surface ($p = 0.081$). Both insole surfaces significantly decreased AP sway relative to the barefoot condition for the older group when standing on the foam surface ($p < 0.05$). For the younger group, only the hard insole surface decreased AP postural sway relative to the barefoot condition when standing on the firm surface ($p < 0.05$) (Fig. 3). There were no significant differences observed in the Group*Surface*Insole interaction for AP SD.

3.4. Medial–lateral (ML) postural sway and ML SD

Both ML sway and ML SD were greater for the older group compared to the young group in the barefoot and hard insole surface conditions ($p < 0.05$), but had reduced to an equivalent level as the young group under the soft insole surface condition (Fig. 4). For the older group there was a significant reduction in ML sway from barefoot to the hard insole to the soft insole surface on both firm and foam surfaces ($p < 0.05$). For the younger group, the hard and soft insole surfaces were equally effective in decreasing ML sway relative to the barefoot condition on both surfaces. For both groups, the hard and soft insoles decreased the ML SD values more than in the barefoot condition on the firm surface ($p < 0.05$). Only the older group demonstrated reduced ML SD on the foam surface ($p < 0.001$). However, no significant changes in ML sway variability were noticed between the two textured surfaces ($p > 0.05$).

3.5. Foam eyes-closed condition

Fig. 5 depicts differences in COP for a representative older and younger participant under each insole surface condition

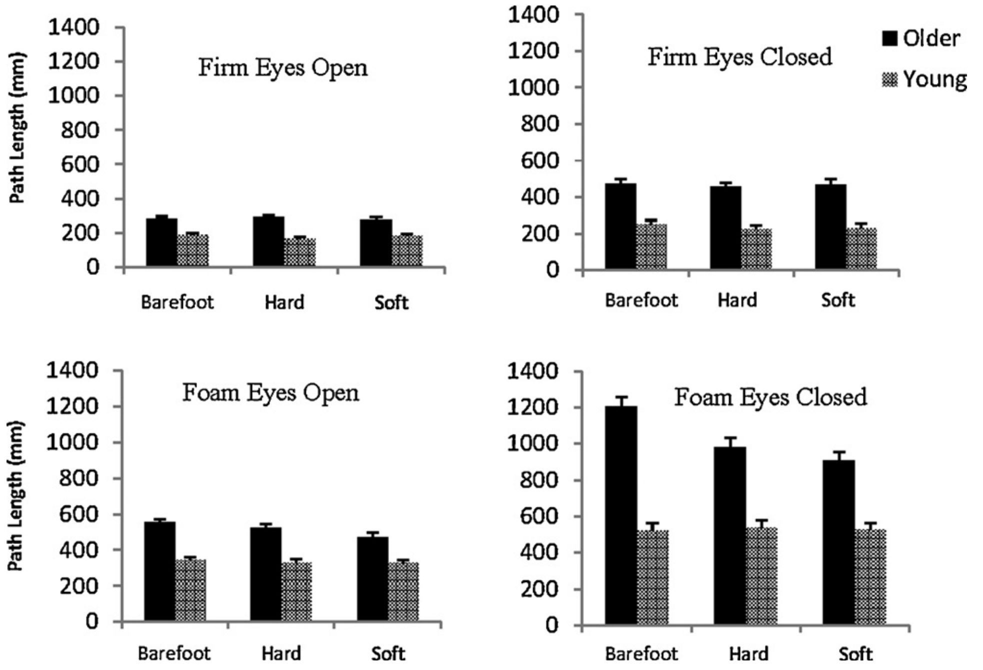

Fig. 2. Mean (+1 SD) path length for the older (black) and young (grey) participants during the four standing conditions.

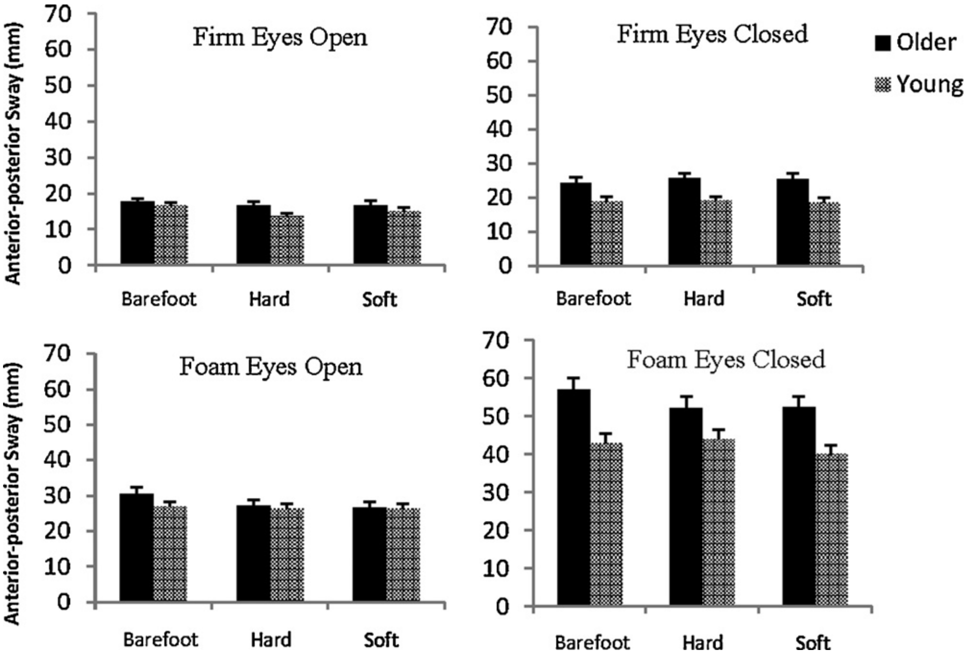

Fig. 3. Mean (+1 SD) anterior–posterior sway for the older (black) and young (grey) participants during the four standing conditions.

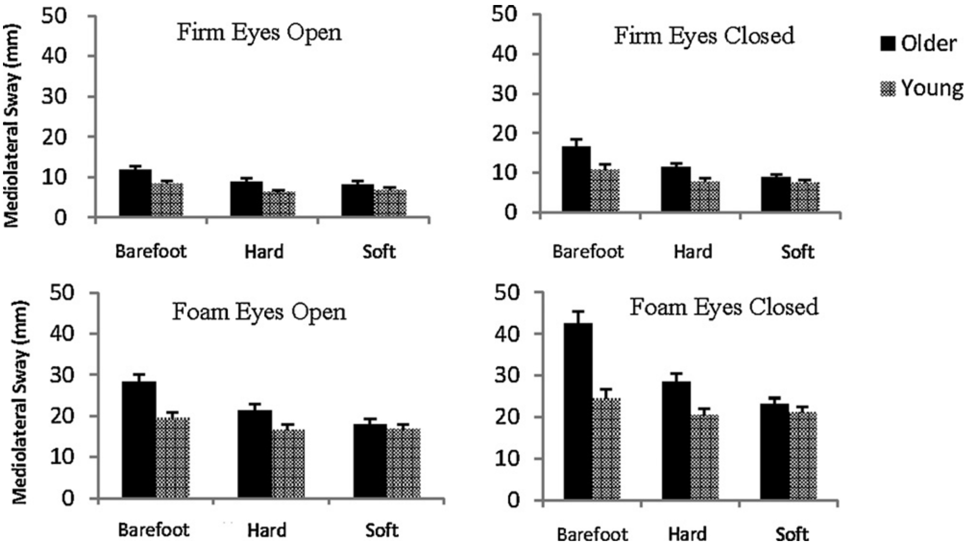

Fig. 4. Mean (+1 SD) mediolateral sway for the older (black) and young (grey) participants during the four standing conditions.

while standing on a foam surface with eyes closed. When standing on the foam surface with eyes closed, the older group showed significant reduction in ML sway, PL and C90 area from barefoot to the hard to the soft insole surface ($p < 0.05$). It was observed that ML SD values were significantly decreased by standing on both insole surfaces compared to the barefoot condition ($p < 0.001$). AP sway and PL were greater for the older participants compared to the younger group in the three insole surfaces conditions ($p < 0.05$). ML sway and C90 area were greater for the older group in the barefoot and hard insole surface conditions ($p < 0.05$), but their postural sway had reduced to an equivalent level to the young group under the soft insole surface condition. ML SD was greater for the older group in the barefoot condition ($p < 0.001$), then was reduced to a similar level as observed in the younger group in both insole surface conditions.

4. Discussion

This study examined the efficacy of inexpensive textured insole surfaces in reducing postural sway under conditions that challenged the somatosensory system in younger and older participants.

Consistent with previous research [23], the current study demonstrated that, overall, older participants displayed greater postural sway than younger participants during standing with bare feet. However, the older group demonstrated a significant and progressive decrease in postural sway from the barefoot to the hard and the soft insole surfaces. A possible mechanism is that the textured insole surfaces may have produced higher plantar pressures at the elevated parts of the textured sole, providing stronger sensory stimulation to the mechanoreceptors. Additionally, increased pressure gradients will be present between the hills

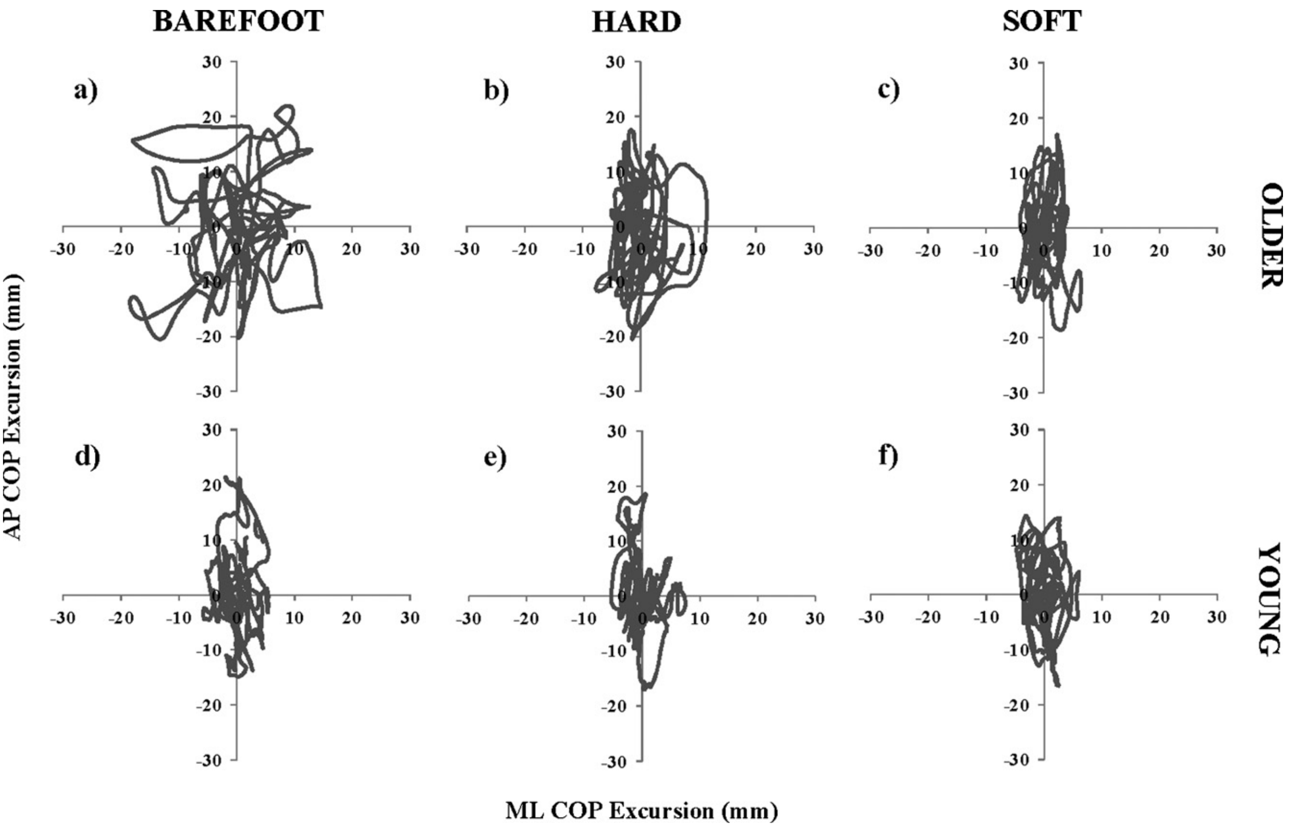

Fig. 5. Representative data for the older and young participants while standing with eyes closed on the foam surface. Data shown portray postural sway during the barefoot condition (a, d); on the hard textured surface (b, e); and on the soft textured surface (c, f).

and valleys across the textured sole pattern, creating additional stimulation to the mechanoreceptors. This effect would result in an overall increased neural feedback from the cutaneous receptors to the central nervous system [24,25] and possibly contribute to improved postural control.

Smaller improvements in postural sway were observed for the younger participants when standing on the textured surfaces. While the overall area of postural sway was unchanged by the textured insole surfaces, there were some small but significant decreases in measures of path length, AP and ML sway and ML SD. Importantly, the improvements observed in the younger participants were predominantly recorded while standing on the firm surface with the hard insole surface. The soft insole surface only reduced ML sway on both surfaces. It is unclear why the hard insole surface reduced postural sway in the younger group and not the older group, but impaired ability in the latter to scale the postural response due to age-related loss of peripheral cutaneous sensory function may have been a contributing factor [6].

In agreement with our findings, Corbin et al. [21] reported decreased postural sway during quiet stance for younger participants wearing textured insoles and Palluel et al. [19,26] reported significant reductions in ML sway for younger and older participants wearing sandals comprising textured rubber nodules. Furthermore, recent research by Hatton et al. [20] reported significant reductions in ML sway for older participants while standing on textured surfaces. Given that Maki and McIlroy [27] reported that a loss of lateral stability was closely associated with increased risk of falling, these results may indicate that reducing ML sway may be of benefit to falls prevention in older people. Taken together, these data suggest that ML sway may be an important parameter to consider when appraising the efficacy of insole interventions in improving standing balance in future research. Furthermore, the recent study by Hatton et al. [20] has indicated that standing on textured surfaces may provide different effects on postural stability compared to footwear, due to the possible confounding effects of different shoe construction characteristics.

Relative to the firm surface, the results of our study showed that postural sway was increased while standing on the foam surface and that this increase was more pronounced in older participants. However, the soft textured insole surface reduced ML sway and the C90 area for older participants to an equivalent level in the young group. This observation was particularly evident for the balance tests performed on the foam surface with eyes closed, where there was a greater reliance on somatosensory information for maintaining balance. It is well understood that standing balance depends on the integration of visual, vestibular and somatosensory inputs [28]. When standing on a foam surface, the reliability of plantar cutaneous information is decreased [13] and closing the eyes negates the contribution of the visual system to balance control. Therefore, when standing on the foam surface with eyes closed, participants could have become more dependent on their vestibular and somatosensory inputs, which may have exposed age-related sensory deficits in the older participants. The present findings suggest that textured insole surfaces may be effective in ameliorating age-related deficits in somatosensory function.

While the findings of this study demonstrated that both textured insole surfaces reduced postural sway, it is important to note that most participants anecdotally reported that the harder insoles were uncomfortable to stand on for an extended period of time. Furthermore, harder insole surfaces would most likely be more problematic for people with peripheral neuropathy, who often have ulcers and wounds on their feet. As such, it is recommended that a softer material be used for future falls prevention interventions.

Our results indicated that a simple and inexpensive textured insole surface can decrease postural sway in older people, presumably due to the enhancement of the somatosensory information received from the feet. As the changes observed in postural control may have been somewhat transient, a longitudinal study may be required to evaluate long term efficacy by fitting such textured insole surfaces into shoes. Given that postural sway is more common in clinical patient groups (e.g. people with diabetic peripheral neuropathy or Parkinson's disease), textured insole surfaces may provide potential benefits to these high risk populations. Further work involving a larger sample of older participants is also needed to confirm our findings and, given that a large percentage of falls occur during locomotion [7,29], it would be of interest to evaluate the efficacy of these textured insole surfaces on postural sway during walking.

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Conflict of interest statement

We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service and/or company that could be construed as influencing the position presented in, or the review of, the manuscript entitled "Enhanced Somatosensory Information Decreases Postural Sway in Older People".

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.gaitpost.2011.12.013.

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