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Topic choice: Aging

Influence of textured indoor footwear on posture stability of older women based on center-of-pressure measurements

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Abstract

Objective: The objective of this study is to evaluate the efficacy of indoor footwear with a textured surface to improve control of balance and reduce excessive plantar pressure in older women.

Background: Balance instability is a common condition in older people. Textured insoles with protrusions on the entire insole have been examined for enhancing somatosensory feedback in the elderly in order to improve control over balance. However, these insoles have significant challenges in distributing the plantar pressure. Textured insoles with tailored protrusions should be therefore investigated for the same purpose but provide better plantar pressure distribution.

Method: A total of 24 older women have undergone both static standing and walking tests with the use of the in-shoe Pedar® system.

Results: The results indicate that wearing textured indoor footwear provides a significant reduction in postural sway, particularly in the medial–lateral direction during walking. As compared to walking barefoot, the center of pressure trajectory when wearing the textured indoor footwear remains supported with less variance among the steps, which is statistically significant in the medial–lateral direction. A significant reduction in the peak pressure is found in the forefoot and rearfoot regions as the plantar pressure is redistributed to the midfoot regions.

Conclusion: The textured surface of the insole improves balance control of older women and effectively reduces foot pressure at high pressure areas.

Application: The findings enhance current understanding on textured footwear as a form of intervention associated with changes in functional impairments, therefore providing basis for footwear design in balance control.

Keywords: Age; Textured indoor footwear; Center of pressure; Postural stability; Women

Précis: A textured insole with specific types of protrusions helps to improve postural stability and redistribute plantar pressure in the elderly in both static and dynamic activities.

1. Introduction

Postural control is a fundamental component of daily human activities, which involves motor, sensory (visual, vestibular, and somatosensory) and nervous system functions (Duarte & Freitas, 2010; Mesquita, de Carvalho, Freire, Neto, & Zângaro, 2015). To maintain balance during walking, information from three aspects, including the eyes, vestibular system and sole of the feet, is normally used (Christovão et al., 2013). However, control over posture declines with age due to deterioration of plantar sensitivity, and loss of vestibular system function, vision and muscle strength. Elderly people therefore often have a slower walking speed, shorter and wider stride length, as well as shorter swing phase time and lower joint range of motion during gait (Devita & Hortobagyi, 2000; Stief et al., 2016). In comparison to young adults, they also have greater body sway even in a simple upright posture so that neuromuscular adjustments are constantly needed to keep the center of pressure (COP) within the stability limits of the supporting base (Parreira et al., 2013).

As feet are an important source of afferent feedback for balance and locomotion, many footwear intervention studies have attempted to explore the effects of shoes or insoles on postural stability by artificially enhancing cutaneous information (Palluel, Nougier, & Olivier, 2008; Priplata et al., 2002; Qiu et al., 2012; Wang & Yang, 2012; Wu et al., 2007). To improve the postural stability of the elderly, Wang and Yang (2012) constructed vibrating insoles that provide temporary stimuli at an appropriate amplitude. The results showed that vibrating the plantar soles leads to increased postural response, which is more obvious in the anterior-posterior (AP) direction. However, vibratory devices are expensive, complex and difficult to use as an effective intervention in the mass market to reduce postural sway. As a means to stimulate plantar sensory nerves, protrusions placed at the edge of an insole and/or massaging knobs throughout the insole surface have shown to improve postural stability. Textured insoles with an array of spikes made with semi-rigid PVC at a low cost have been also used to enhance the somatosensory feedback of the feet of the elderly to reduce postural sway during quiet standing and maintain better stability, where a significant reduction was found in the surface area of the COP as well as the AP and medial–lateral (ML) root mean square (RMS; Palluel et al., 2008).

Significant differences in the velocity and surface area of the COP were also found in the young subjects during standing (Corbin, Hart, Palmieri-Smith, Ingersoll, & Hertel, 2007). Qiu et al. (2012) compared the effects of soft and hard textured insoles made of EVA on COP measurements for both young (mean age 27 ± 3 years) and elderly adults (mean age 72 ± 4 years) by using a force plate. Both types of insoles were found to reduce the postural sway of older people, especially when the subjects had their eyes closed and were standing on a foam surface. Nonetheless, the results from these studies are conflicting. Wilson, Rome, Hodgson, and Ball (2008) argued that wearing textured insoles has no significant effects on the range of AP or ML sway in healthy middle-age females in the static position. Experimental studies have also been done to evaluate the influence of a full textured insole made of Evalite Pyramid EVA (Shore A50) for improving the postural control of older people (Hatton, Dixon, Rome, Newton, & Martin, 2012). However, no significant immediate improvement was found in any of the COP parameters in quiet standing and gait measurements with the use of the GAITRite (a pressure sensitive walkway) except for gait velocity, and step and stride lengths. To date, the efficacy of full textured insoles on postural balance, especially in walking, has not been verified. The material properties of the textured insoles entirely covered with protrusions for enhancing the cutaneous response of the sole of the feet have not been reported in detail. Although the hard textured insoles (constructed with EVA) in Qiu et al. (2012) with granulations that are evenly distributed across the entire surface of the insole help to reduce the postural sway of older people during standing to a certain extent, they might cause issues in distributing the plantar pressure because they reduce the surface contact area, thus leading to discomfort during wear, especially in areas of high pressure. Therefore, protrusions on insoles made of an appropriate type of material are important for improving the comfort and practical use of footwear.

Current designs of textured insoles mainly have protrusions that cover the entire surface of the insoles, which evenly stimulate the sole of the feet. However, a previous study by Zehr et al. (2014) found that significant dynamic changes in reflex amplitudes, kinematics, and foot sole pressures are caused by site-specific stimulation. The stimulation of discrete locations on the sole of the feet could lead to “sensory steering” and might improve balance as well as locomotion through the modulation of limb loading and the placement of the feet (Zehr et al., 2014). To date, few studies have explored the effects of site-specific stimulation on balance by using textured insoles. Therefore, insoles with specific placement of protrusions are important for enhancing the stability of the elderly through site-specific stimulation. Arch support can be incorporated into the insoles with specific placement of the protrusions to further promote better balance. A properly shaped arch support has been found to offer good cushioning as well as adequate support of the body, which would help to prevent hyperpronation of the forefoot as well as shift the load and pressure under the areas of the heel and metatarsal to the midfoot area, thus reducing the pain of the lower extremities and contributing to better walking stability (Chen, Ju, & Tang, 2003; Mulford, Taggart, Nivens, & Payrie, 2008). It is considered that such footwear-generated biomechanical manipulation could lead to adjustments in body movement and redistribution of plantar pressure which would allow the user to develop suitable motor skill strategies that improve stability during locomotion in response to the lack of stability and control over balance.

To evaluate the effects of the different interventions and/or treatments and their performance efficiency in controlling balance, posturography is commonly used as a method to assess balance problems. The COP of the feet on the ground and the displacement of the COP in either static or dynamic conditions are recorded to assess postural sway. Previous studies have suggested certain measures of the COP to assess the risk of falls, and have even attempted to directly differentiate between faller and non-faller groups to predict falls (Laughton et al., 2003; Prieto, Myklebust, Hoffmann, Lovett, & Myklebust, 1996; Qiu & Xiong, 2015). Moghadam et al. (2011) and Prieto et al. (1996) found that the mean velocity of the COP is the most critical measure for assessing the postural steadiness and risk of falls related to age-group differences. However, few studies have included the velocity of the COP to study textured insoles. During double-limb standing tests, Hatton et al. (2012) reported larger COP velocity but not significant COP velocity in older fallers who had their eyes closed when wearing the textured insoles during double limb standing. The velocity of the COP as a balance parameter should be therefore further considered when assessing textured insoles for balance. In view of dynamic balance, walking stability can also be measured based on the abnormal trajectory of the COP during the stance phase, which is also known as a process for balance control by measuring the tilting movements of the foot (Hoogvliet, vanDuyl, de Bakker, Mulder, & Stam, 1997). Walking in spike insoles/sandals for 5 mins influences the plantar cutaneous information from the sole of the feet, which lead to improvements in the AP and ML planes for balance in the elderly and indicate a shift in the COP (Palluel, Nougier, & Olivier, 2008). The extra inversion or eversion movements of the foot at different activity levels can lead to deviations in the COP (Gefen, Megido-Ravid, Itzchak, & Arcan, 2002). Thus, COP measurements as well as the COP trajectory are particularly relevant for the biomechanical study of balance and postural control (Winter, Prince, Frank, Powell, & Zabjek, 1996). However, the effects of textured insoles on balance performance during dynamic activities based on COP parameters have not been fully reported in the field.

Therefore, the aim of this study is to examine the effects of specific site stimulation by using textured insoles with specific types of protrusions at the boundaries of the metatarsal heads and lateral heel areas as well as arch support on the COP trajectory and plantar pressure distribution in older women. It is hypothesized that indoor footwear with insoles that have a unique textured surface can help to improve their balance control and optimize the overall control of plantar pressure during walking. The findings of this study are important for designing ergonomic indoor footwear for older people that enhance their balance control.

2. Method

2.1 Participants

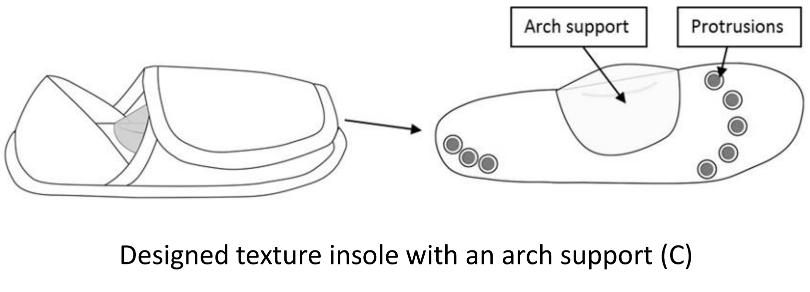
Twenty-four older women between the ages of 60–73 years old (*M*: 65; *SD*: 3.6) have been recruited for this study. The inclusion criteria are women who are 60 or older, able to walk independently across a distance of at least 6 m without a walking aid, have hallux valgus with an angle that is less than 30 degrees, free of neurological conditions and musculoskeletal problems that might affect balance, and no history of foot injuries during the past two years. The body mass index of these women ranges from 15.2 to 32.2 kg/m^2 (*M*: 22 ; *SD*: 3.2). Their foot size is 35 to 40 (European). Written informed consent is provided to all the participants before participating in the study. The experiment is approved by the

Human Subjects Ethics Sub-Committee at The Hong Kong Polytechnic University prior to beginning the study.

2.2 Indoor Footwear Conditions

All of the participants are examined under three experimental foot conditions in this study, which are barefoot (Condition A), wearing the control (Footwear Condition B without socks), and wearing the designed textured insole with an arch support (Footwear Condition C without socks) (see Figure 1). The raised nodules and arch support in the texture insoles were made of silicone (KE-1300T, Shin-Etsu Chemical Co, Ltd.). The experimental parameters with specific test standards are listed in Table 1. Eight protrusions of the same size were placed around the boundaries of the metatarsal heads and on the toe crest (five protrusions) as well as the boundaries of the lateral side of the heel of each foot (three protrusions). This design is based on the work in Maki, Perry, Norrie and McLlroy (1999) in which a continuously raised ridge was formed and extended around the perimeter of the plantar surface of the foot (from the metatarsal heads to the heel) to improve sensation and enhance particular types of stabilizing reactions caused by unpredictable postural perturbations.

Control (B)



Designed texture insole with an arch support (C)

Figure 1: Experimental indoor footwear

Table 1: Experimental parameters

	Indoor footwear (B)	Terry fabric	Protrusions – Footwear Condition C
Size (diameter,mm)	N/A	N/A	15
Thickness (mm)	13.43	4.50	5.00
Density (g/cm^3)	N/A	0.12	1.12
Weight Range (g)	71.33-82.49	N/A	0.78
Coefficient of friction	0.67	N/A	N/A
Bending stiffness (N·mm)	643.80	N/A	N/A
Hardness (Shore A) ASTM D2240	26	N/A	8
Force Reduction ASTM D 2632 (%)	61.56	N/A	96.98
Compression ASTM D575-9 (kPa)	14,018	N/A	1,007

2.3 Experimental Protocol

The experiment was conducted in a laboratory. The participants were required to perform both static standing and dynamic walking in the tests for all three footwear conditions, see Figure 2. All of the measures were taken with the eyes of the subjects open. To minimize possible order effects, the sequence of the footwear conditions was randomized. For the static standing test (3 footwear conditions X 3 recordings), the participants were asked to go through all three footwear conditions and stand in their standard posture with their hands at their side. Their feet had to be spaced 17 cm apart between the midpoints of the left and right heel counters, with the toes pointing at an angle of 14 degrees for 30 seconds (McIlroy & Maki, 1997), while looking at a red sticker dot that was placed 2 m away from where they were standing at eye level. Only the timeframe between 5 and 25 seconds is analyzed in this study. Each condition was recorded three times. Before the recording started, the subjects were given 30 seconds to adjust to the fit of the footwear after changing to a new condition in a standing position. They were allowed to rest for 1 min after every 3 recordings. For the dynamic walking test (3 foot/footwear conditions X 3 recordings), the participants were required to walk along a 7-meter concrete walkway at a self selected speed for all of the walking trials. An automatic timing gate (Brower Timing Systems, Utah, USA) that uses infrared and has 0.01 s precision was used to measure the speed of walking so as to ensure the walking speed of each subject was consistent across different footwear conditions. To establish the self selected speed, they were asked to walk in barefoot over a distance of 11 m at their natural pace. Two timing gates were placed at the 2 m and 9 m to determine the duration for each trial. A total of 10 trials were carried out to obtain the speed of walking of each participant, which was calculated based on the division of the distance walked (7 m) by the time needed to cover this distance (s). To minimize the effect on the plantar pressure due to the different walking speeds, the walking trials were rejected if it exceeded 5% of the predetermined self-selected speed (Burnfield, Few, Mohamed, & Perry, 2004). For each test condition, acclimatization (2 walking trials) was first given to the participants to walk along the pathway so as to adapt to the footwear conditions and the environment as well as to adjust the strap of the footwear, and then complete 3 valid walking trials under instruction. The participants were given 3 minutes for a short rest after completing each condition. In barefoot condition, the pressure-sensing insoles is secured onto the plantar of the feet of the subjects by using standard cotton socks (1.4-mm in thickness) (Bacarin, Sacco, & Hennig, 2009; Burnfield et al., 2004). The overall rated subjective comfort for Footwear Condition C in comparison to their own indoor shoes was provided by the participants after they finished the walking test (see Figure 3).The data for each participant were collected within two hours.

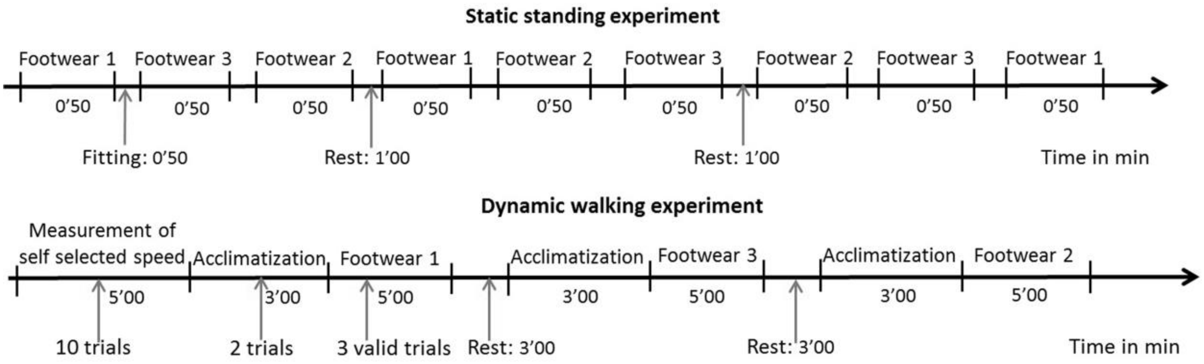


Figure 2: Experimental procedures for static standing and dynamic walking tests

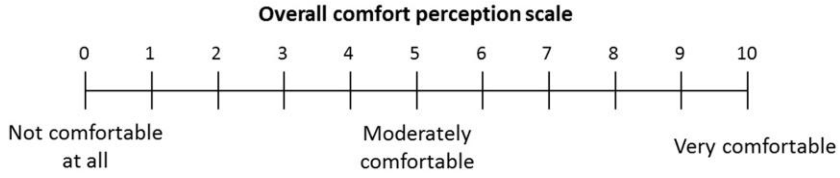


Figure 3: Rating scale for subjective comfort

2.4 Equipment

The COP and the plantar pressure distribution were recorded with the in-shoe Pedar® system (Novel GmbH, Munich, Germany) and the sampling rate is set at 50 Hz. This system consists of a pair of flexible pressure-sensing insoles, which have 99 capacitance-based sensors that are 1.9-mm in thickness. Pressure-sensing insoles in different sizes were available to accommodate the participants with different foot sizes. The location of the in-shoe COP is recorded by the software as X–Y coordinates, which relatives to the origin and is lied at the most medial and posterior points of the insole (Debbi et al., 2012).

2.5 Data analysis

The COP measures are: range of COPx (ML direction) and COPy (AP direction), mean COPx and COPy, mean *SD* of COPx and COPy, and mean velocity of COPx and COPy, except for the 95% confidence ellipse area, which was only assessed for the static standing test. To assess the changes in the ML direction during dynamic walking, the RMS of the residual of each COPx to its mean curve was calculated with Matlab R2008a. First, all of the steps were normalized from 0 to 100% in the stance phase. A mean curve was then fitted to the COPx of all selected steps in each condition for each subject, where the residual of each data point is the distance between the data point to the fitted curve. All of the COP measurements were calculated by using equations from previous studies (Jiang, Yang, Shieh, Fan, & Peng, 2013; Raymakers, Samson, & Verhaar, 2005; Rugelj, Gomiscek, & Sevsek, 2014). In order to analyze the pressure distribution, the plantar foot was divided into 4 anatomical regions: the toes, forefoot, midfoot and rearfoot (Luximon, Cong, Luximon, & Zhang, 2015). For each region, three variables of plantar pressure were measured: the mean of the peak pressure (MPP), contact area (CA) and pressure-time integral (PTI), and the Novel software was used for statistical analysis. To eliminate the influence of acceleration and deceleration during gait initiation and termination of each walking trial, the first and last two steps were excluded (Arts & Bus, 2011; Bonanno, Landorf, & Menz, 2011). Only the data of the right foot were analyzed.

2.6 Statistical analysis

The data were analyzed by using the Statistical Package for the Social Sciences (SPSS) Version 19.0 (SPSS Inc., Chicago, IL). Reliability tests were used to assess the consistency of the data from three repeated trials. One-way repeated measures ANOVA (within-subjects effect) was used to test for the statistical significant differences of the different indoor footwear conditions on the COP parameters and plantar pressure in the older women. In order to compare the main effects among each condition, Bonferroni-adjusted post hoc tests were conducted subsequently. The level of significance was set at .05.

3. Results

3.1 Static standing test

The results of the COP parameters collected during both static standing and dynamic walking are presented in Table 2. A reliability test was carried out and acceptable values (over 0.7) were found for all of the COP parameters as well as plantar pressure variables (Qiu & Xiong, 2015). Table 2 shows that there are no significant differences across all of the COP parameters among the three conditions for static standing. In comparison to Condition A and Footwear Condition B, the subjects showed better stability in the ML direction with Footwear Condition C. However, the mean of the COPy between Condition A and Footwear Condition C was found to be close to significance, which might indicate that the subjects have less stability in the AP direction with Footwear Condition C in comparison to Condition A, which is the barefoot condition.

Table 2: COP parameters of three experimental conditions

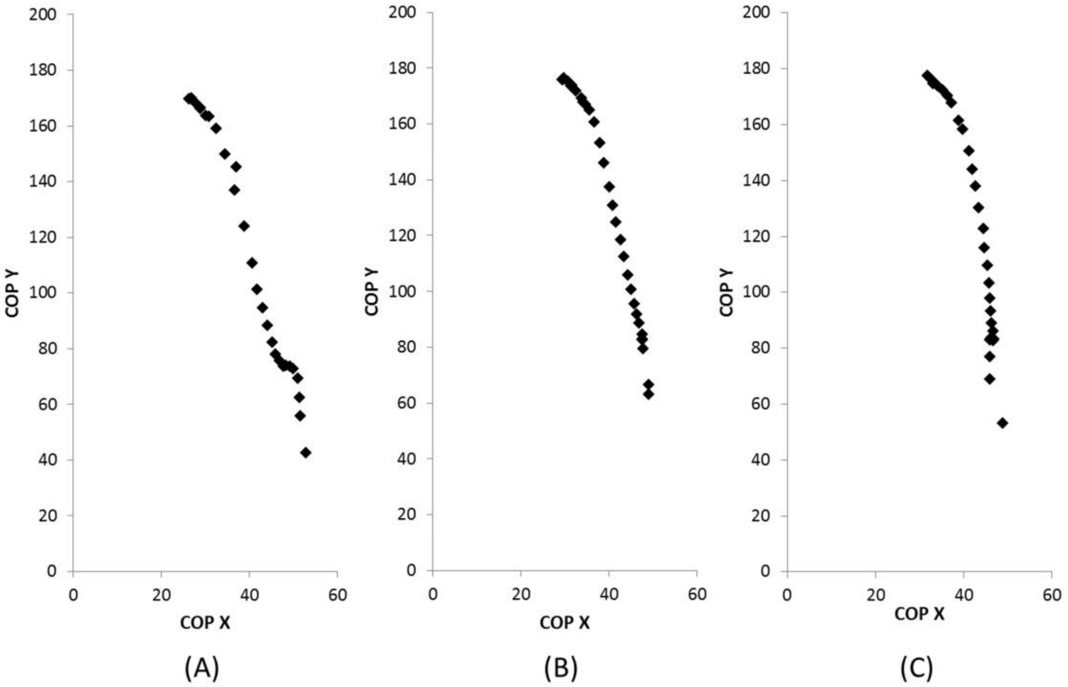
Main effect	A	B	C	P-value		
				Footwear Conditions		
	Mean (SD)	Mean (SD)	Mean (SD)	A & B	A & C	B & C
Static Standing Test						
Range of COPx (mm)	2.98 (1.66)	2.54 (0.83)	2.53 (0.72)	0.856	0.738	1.000
Range of COPy (mm)	19.64 (7.62)	18.93 (5.76)	18.94 (5.78)	1.000	1.000	1.000
Mean COPx (mm)	41.22 (3.78)	41.59 (2.93)	40.95 (2.64)	1.000	1.000	0.207
Mean COPy (mm)	89.75 (13.87)	91.60 (12.31)	93.15 (12.55)	0.290	0.056	0.393
Mean S.D. COPx	0.56 (0.30)	0.45 (0.17)	0.45 (0.14)	0.184	0.160	1.000

Mean S.D. COPy	3.95 (1.49)	3.62 (1.26)	3.82 (1.26)	0.467	1.000	0.951
Mean velocity of COPx (mm/s)	10.43 (2.68)	11.29 (2.93)	11.24 (2.55)	0.170	0.446	1.000
Mean velocity of COPy (mm/s)	38.66 (11.42)	42.45 (13.66)	42.62 (15.24)	0.385	0.758	1.000
95% Ellipse Area (mm^2)	21.38 (17.73)	17.79 (11.71)	17.72 (8.75)	0.754	0.941	1.000
Dynamic Walking Test						
Range of COPx (mm)	**23.06 (4.57)**	**20.28 (3.75)**	**19.74 (4.26)**	**0.013**	**0.007**	1.000
Range of COPy (mm)	144.49 (13.94)	140.98 (13.43)	142.90 (14.50)	0.411	1.000	0.901
Mean COPx (mm)	**43.32 (3.26)**	**41.74 (2.97)**	**40.96 (3.13)**	**0.007**	**0.004**	0.229
Mean COPy (mm)	**114.82 (8.35)**	**122.39 (8.91)**	**124.87 (8.94)**	**0.000**	**0.000**	0.211
Mean S.D. COPx	**7.43 (1.69)**	**6.36 (1.12)**	**5.69 (1.28)**	**0.006**	**0.000**	**0.007**
Mean S.D. COPy	49.10 (5.39)	48.71 (4.77)	47.65 (5.90)	1.000	0.322	0.567
Mean velocity of COPx (mm/s)	**53.46 (9.59)**	48.69 (8.58)	**47.24 (10.43)**	0.125	**0.030**	1.000
Mean velocity of COPy (mm/s)	246.05 (45.20)	252.80 (24.17)	252.63 (31.60)	1.000	1.000	1.000
RMS COPx	**3.77 (1.32)**	3.26 (1.09)	**3.03 (0.97)**	0.103	**0.014**	0.387

Note: Bold values show significance at $P<0.05$

3.2 Dynamic walking test

The mean walking speed during dynamic walking was 3.19 km/h (*SD*: 0.49), which ranged from 2.37 to 4.54 km/h. Footwear Conditions B and C provide a significant reduction in the range and mean of COPx and a significant increase in the mean of COPy when compared to Condition A, see Table 2. Footwear Condition C, in particular, also resulted in a significant reduction in the mean SD, the mean velocity and the RMS of COPx when compared to the other foot conditions. According to Figure 4, the COP trajectory of the subjects in Footwear Condition C is similar to that in Condition A, but with a significantly smaller range of movement in the ML direction. The lowest COP trajectory was found for Footwear Condition B, which may indicate an effect on propulsion during walking**.** Figure 5 shows a typical example of the variability of the COPx under each condition. Footwear Condition C has a flat and concentrated fitted curve along the ML direction, with the smallest RMS value of the COPx, which indicates that there is little variance amongst the steps taken when compared to the other foot conditions (Figure 5(C)). The highest COPx values are found for Condition A during loading response (0-20% of the stance phase) and mid-stance (20-70% of the stance phase). A slightly upward shift to the right after heel strike can be observed for Condition A followed with a decline towards the end of loading response for all footwear conditions, while Condition A shows a more steep decline in comparison to the other footwear conditions (Figure 5(A)). At push-off (about 80-90% of the stance phase), the lowest COPx values are found for all footwear conditions, in which the COP is found around the metatarsal heads. The mean subjective comfort for Footwear Condition C is 7.29 (S.D. 1.66), which indicates that the overall comfort of Footwear Condition C is not only acceptable but is quite comfortable.



(A) (B) (C)

Figure 4: Example of COP trajectory during dynamic walking in three footwear conditions

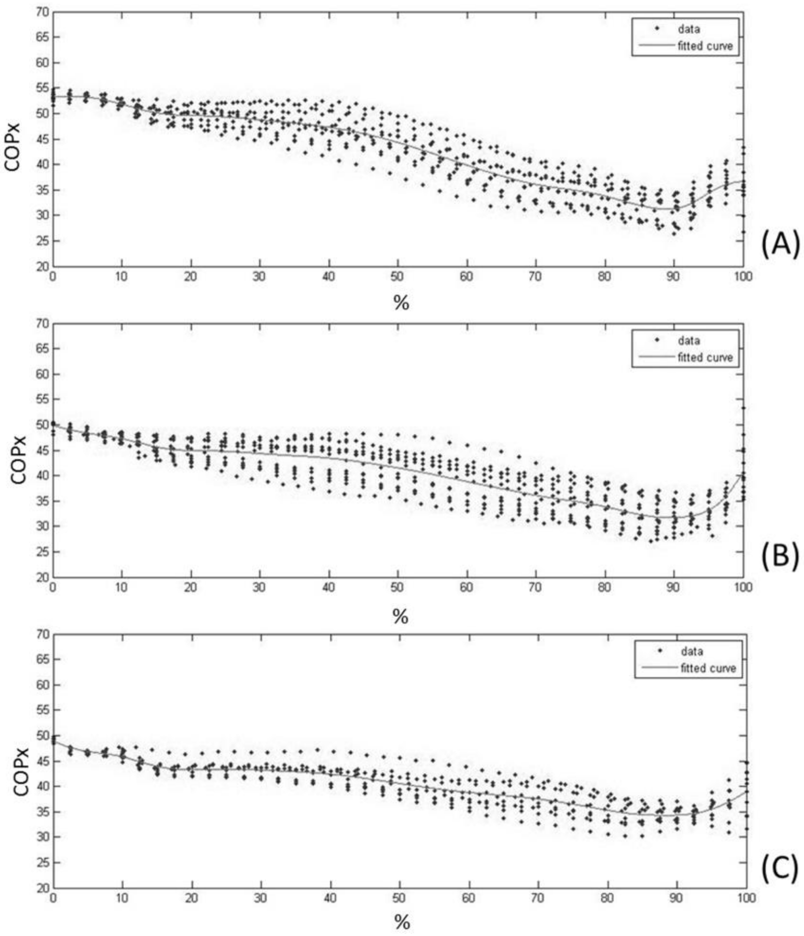
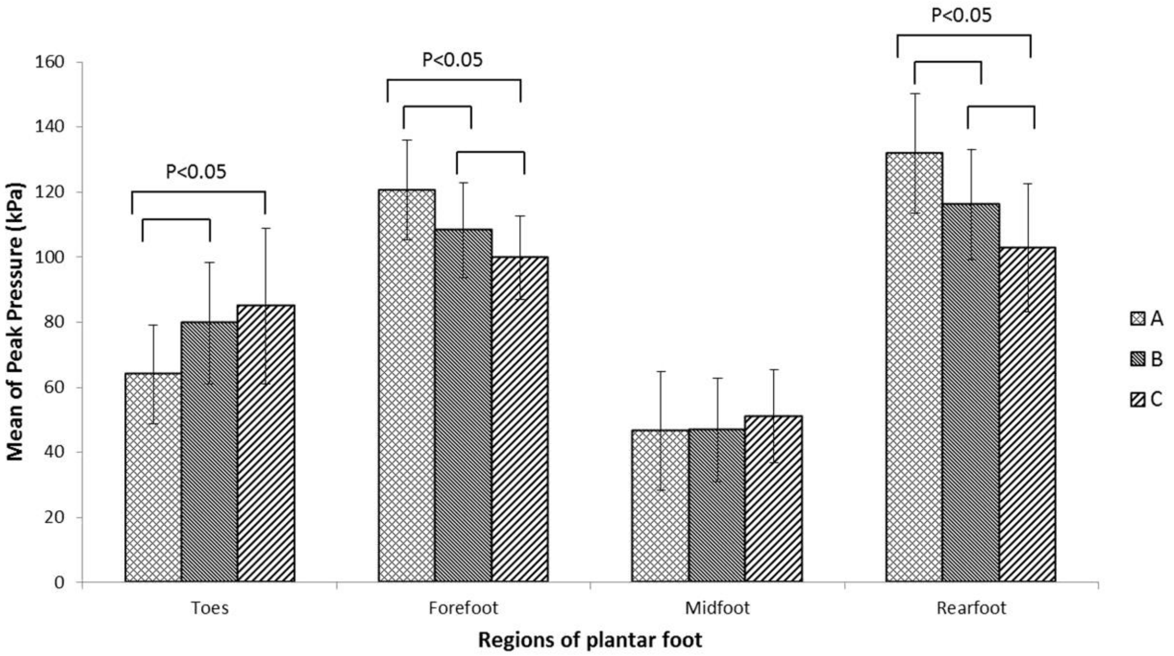


Figure 5: Example of COPx distributions and fitted smoothing spline curves across entire stance phase during dynamic walking in three footwear conditions

3.3 Plantar Pressure Distribution

As shown in Figure 6, the subjects show a significant increase in the MPP in the toe region when wearing shoes, while a significant reduction is found in the forefoot and rearfoot regions, especially for Footwear Condition C. A significant increase is also found for PTI in Footwear Conditions B and C in the toe and midfoot regions, while a significant reduction is found in the forefoot and rearfoot regions. The lowest PTI is in the forefoot region for Footwear Condition C. Footwear Condition C also causes a significant increase in the CA of all the plantar regions when compared to Conditions A and Footwear Condition B (see Figures 6 and 7).


P<0.05
P<0.05
P<0.05
Mean of Peak Pressure (kPa)
0
20
40
60
80
100
120
140
160
Toes
Forefoot
Midfoot
Rearfoot
Regions of plantar foot
▨A
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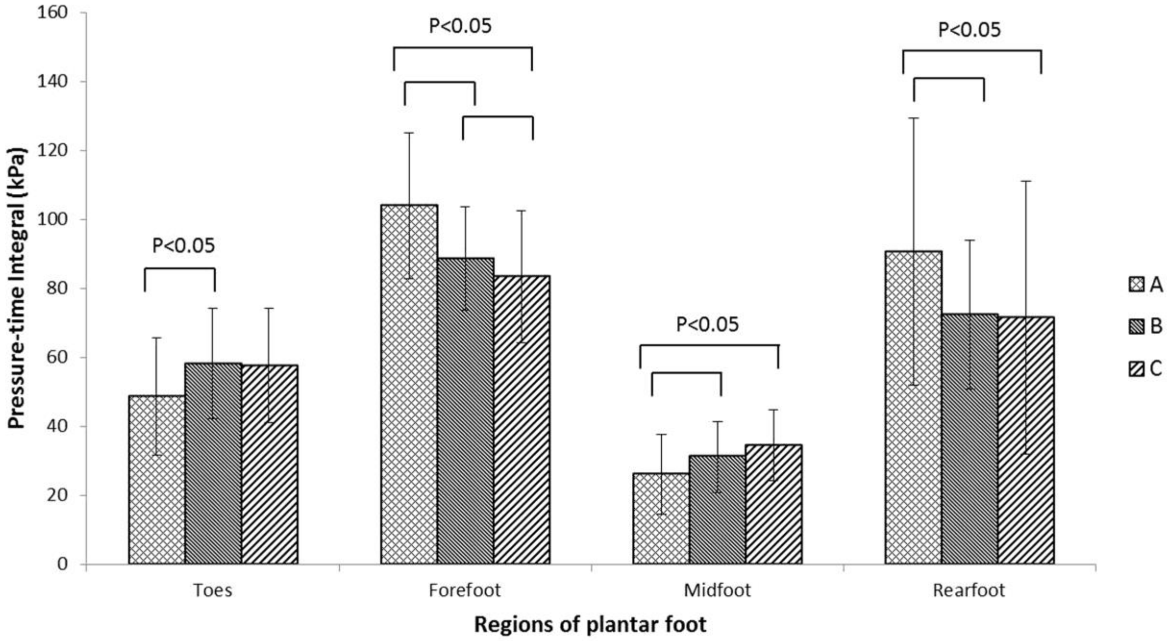
P<0.05
P<0.05
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Pressure-time Integral (kPa)
0
20
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Toes
Forefoot
Midfoot
Rearfoot
Regions of plantar foot
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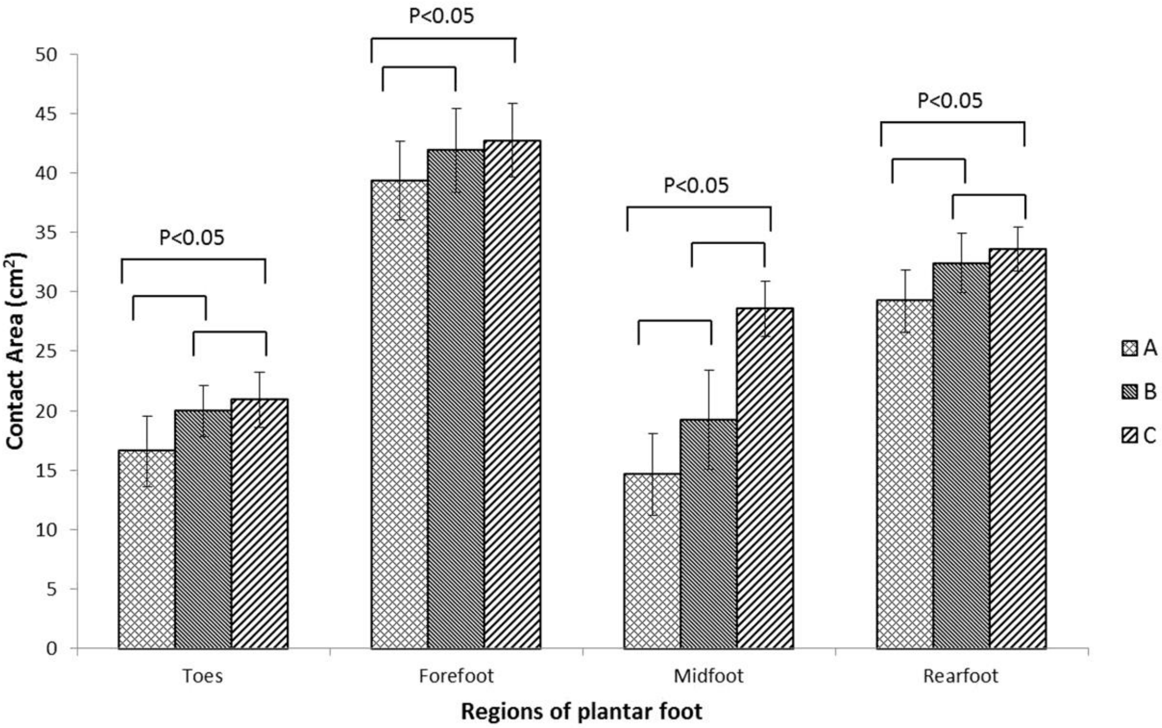

Figure 6: Mean values (S.D.) of three variables of plantar pressure during dynamic walking

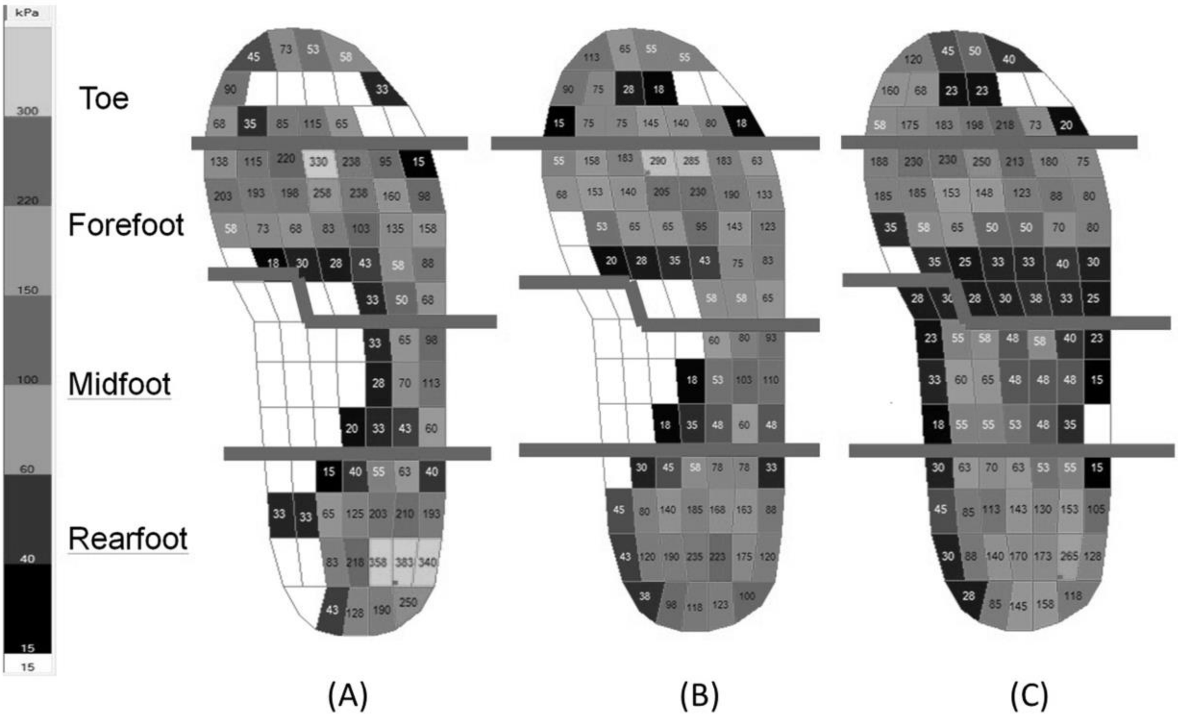

Figure 7: Example of plantar pressure distribution (peak pressure) during dynamic walking in three conditions

4. Discussion

The purpose of this study is to investigate the effects of a designed textured insole which is placed in indoor footwear on standing and walking stability as well as plantar pressure distribution. In comparison to Condition A, the subjects showed improved postural stability when wearing the footwear with the textured insole (Footwear Condition C) in the ML direction for both the static standing and dynamic walking tests. These results are consistent with those of previous studies (Corbin et al., 2007; Qiu et al., 2012). According to Palluel et al. (2008), elderly people who wear textured insoles that are covered entirely with spike protrusions show greater improvement in stability during standing as opposed to walking. However, after wearing the textured insoles (Footwear Condition C) in this study, the subjects are able to show a more pronounced improvement in stability during walking as opposed to only standing. This might be because the textured insoles evenly stimulate the entire sole of the foot which results in better balance control during static standing. However, the areas of the loss of sensitivity of the plantar of the foot are not the same, as the elderly are found to have less sensitivity in the forefoot and rearfoot regions as opposed to the midfoot regions (Machado et al., 2016). Therefore, more stimulation might be required for specific foot sites for better stability during dynamic movement or walking. The eight protrusions on the surface of the textured insole in this study could induce more plantar pressure onto specific sites of the sole of the feet and provide greater sensory stimulation to the mechanoreceptors of these sites. The response of the mechanoreceptors to mechanical stimuli (such as indentation and stretching of the skin) can provide information on the texture and allow detection of the roughness and textured patterns for spacing and orientation (Gardner, Martin, & Jessell, 1991). Additionally, pressure gradients induced by the specified textured sole pattern might increase and also stimulate the mechanoreceptors. The stimulation induced by the protrusions on the lateral side of the plantar foot increased the load medially on the sole of the foot. The result is a shift in weight to ensure an even load on the foot in response to the uneven surface and for better balance (Zehr et al., 2014). As a result, the overall neural feedback from the cutaneous receptors which is transferred to the central nervous system would increase and possibly lead to more improvement of postural control, especially in dynamic walking (Hidaka, Nozaki, & Yamamoto, 2000; Manjarrez, Rojas-Piloni, Mendez, & Flores, 2003).

The roles of the feet include the support of the body, distribution of plantar pressure, absorption of impacts and adjustment for postural stability during walking (Christovão et al., 2013). Adjustments made for postural stability include straightening of the spinal column, verticalization of the sacrum and flexion of the knee and hip can be reflected and measured from abnormal deviations in the COP trajectory (Gefen et al., 2002; Han, Paik, & Im, 1999). In this study, the mean, magnitude and velocity of the COPx significantly increase in Condition A in comparison to Footwear Condition C during walking. Larger mean and excursion of the COP, and more rapid rate of change in movement in the COPx direction may indicate that the elderly experiences a larger COP medial shift and propulsion occurs over the medial metatarsal and toe regions, which results in less stability in barefoot (Chiu, Wu, Chang, & Wu, 2013). Greater effort and more intensive body sways are then required to correct the COP so as to maintain body balance. The specific placement of protrusions in Footwear Condition C helps to reduce deviations in the COP (the mean and S.D. of the COP), which suggests that the foot and ankle are more stable during the loading response phase of the gait cycle (Chiu, Wu, Chang, & Wu, 2013). Consistent with the results of Palluel et al. (2008), protrusions with a unique pattern also result in a significant reduction in the RMS of the COPx during walking, which indicates that specific site stimulation could also provide similar effects as textured insoles that are entirely covered with protrusions but with higher perceived comfort.

The elderly usually suffer from age-associated impairment in terms of lateral stability and loss of control in lateral balance. The aging effects on balance might be accentuated in the ML direction. Previous falls and the future risk of falls of the elderly are usually associated and predicted with measures of ML sway/amplitude (Machado et al. 2016; Rogers & Mille, 2003). Therefore, the COPx can be regarded as a vital factor for assessing stability. During walking, the displacement of the COPx (in the ML direction) is greater in Condition A in comparison to all shod conditions, especially in Footwear Condition C. The mean curve of the COP in the ML direction during the stance phase plotted in this study helps to determine walking stability by showing the pattern of the progression of COPx and the intra-subject variance of COPx among strides. The mean curve of the COP for Condition A shows more fluctuations and a relatively greater decline towards the end of loading response, which might indicate that the COP has shifted to the medial side at push-off, and the foot becomes more unstable and tends to exert greater effort to "correct" the COP back to a neutral position during loading response along the ML direction. The possible reasons for the lower displacement and fewer fluctuations of the COPx in Footwear Condition C are because the sole of the footwear might have reduced the medial rolling of the foot and therefore the displacement of the COP in the medial direction (Zhang, Paquette, & Zhang, 2013). The protrusions placed on specific locations of the lateral side of the foot might have also contributed to enhancing plantar sensation which would allow better balance control in the ML direction under the acute effect of the disturbance.

The pressure under the areas of heel and midfoot is mainly influenced by weight bearing at heel strike and midstance, whereas pressure in the toes and forefoot is largely affected by flexibility, and strength and recruitment of muscle (Kimmeskamp & Hennig, 2001). It was observed in Condition A that less force and pressure were exerted by the elderly onto the medial side of the foot, such as the medial arch and medial calcaneus. This indicates that the bearing weight of older people during normal walking appeared on the lateral side of the foot which results in less propulsion in the heel-touch to the toe-off phases. As refer to the clinical field, the lateralization of pressure under the foot and reduction in propulsion found in older people may affect the their walking ability, thus causing difficulties in balance control, forward thrusting, and terrain adapting. Better redistribution in weight bearing and significant reduction in foot peak pressure were found in Footwear Condition C. The use of designed texture insoles does not lead to excessive plantar pressure on the foot during normal walking, which may help to relieve the heavy loads and pressure imposed onto the foot and prevent pressure ulcers (Hessert et al., 2005). A previous study by Kato, Takada, Kawamura, Hotta and Torii (1996) showed that the peak pressure of the entire foot could reduce by 56.3 percent and the contact area could increase by 62.7 percent when using a customized molded polyurethane insole (Kato et al., 1996). As compared to Condition A, a properly shaped arch support and protrusions used in a textured insole would also lead to a reduction in the peak pressure of the forefoot by 17.2% and the heel by 22.1%, which redistribute the pressure to the midfoot area (Chen, Ju, & Tang, 2003). Moreover, a larger CA over the entire foot of 26.0% in this study, especially in the midfoot which increased by 95.0%, also helps to provide more foot support, thus enabling walking stability (Luximon, Cong, Luximon, & Zhang, 2015).

Nevertheless, this is a preliminary study with some limitations. First, the relatively small sample size may limit the generalizability of the results. A multivariate analysis of variance could be a more stringent statistical test for a study with a small sample size. A self selected speed for walking is chosen in this study, which may introduce variability to the data and may even affect the results to a certain extent. For example, increasing the speed of walking could lead to higher pressure and the COP may shift medially. Structural characteristics of the foot, such as the arch type, may also affect plantar pressure distribution. Pressure tends to concentrate beneath the forefoot and the heel of a more rigid high-arched foot, with little pressure found beneath the midfoot. However, the effects of and relationship between arch type and plantar pressure have not been analyzed in this study. Future research can consider studying the effects of various types of indoor footwear on the COP based on foot segments and gait cycle.

5. Conclusion

Indoor footwear plays an important role in preventing falls of older people at home, especially with an appropriate design and components. The findings from this study show that textured insoles can improve the balance control of older women in both standing and walking, especially in the ML direction. The COP trajectory when the indoor footwear is worn with the designed textured insole during walking allows a natural balance to emerge just like being barefoot, but has resulted in significantly smaller range of changes in the ML direction. The findings of this study may have important practical implications with regard to the development of novel footwear designs that improve balance control and reduce the risk of falling in older adults.

Key points:

- The effects of textured insoles with designs on balance performance during static and dynamic activities based on COP measures have been reported in this study.
- The designed textured surface of the insole is found to significantly reduce plantar pressure in the forefoot and the heel areas, as well as improve the balance control of the elderly, especially in the ML direction during walking.
- The current findings enhance understanding on intervention with textured footwear which will contribute to footwear designs that improve the postural stability of older adults.

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