Clinical Section / Original Paper

Gerontology

Gerontology
DOI: 10.1159/000448892

Received: June 21, 2016
Accepted: August 4, 2016
Published online: September 3, 2016

Effects of Indoor Footwear on Balance and Gait Patterns in Community-Dwelling Older Women

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Key Words
Ageing · Accidental falls · Postural balance · Footwear

Abstract
Background: Footwear worn indoors is generally less supportive than outdoor footwear and may increase the risk of falls. ***Objective:*** To evaluate balance ability and gait patterns in older women while wearing different styles of indoor footwear: a backless slipper and an enclosed slipper designed to optimise balance. ***Methods:*** Older women (n = 30) aged 65–83 years (mean 74.4, SD 5.6) performed a series of laboratory tests of balance ability (postural sway, limits of stability, and tandem walking, measured with the NeuroCom® Balance Master) and gait patterns (walking speed, cadence, and step length, measured with the GAITRite® walkway) while wearing (1) socks, (2) backless slippers with a soft sole, and (3) enclosed slippers with a firm sole and Velcro® fastening. Perceptions of the footwear were also documented using a structured questionnaire. ***Results:*** Significant overall effects of footwear were observed for postural sway, the limits of stability test (directional control), the tandem walk test (step width and end sway), and temporospatial gait patterns (walking speed, cadence, and step length). No footwear effects were observed for maximum excursion when performing the limits of stability test or for speed when performing the tandem walk test. Post hoc tests indicated that performances were best while wearing the enclosed slippers, intermediate with socks, and worst with backless slippers. The enclosed slippers were perceived to be more attractive, comfortable, and well fitted, but heavier than the backless slippers. Most participants (n = 23; 77%) reported that they would consider wearing the enclosed slippers to reduce their risk of falling. ***Conclusion:*** Indoor footwear with an enclosed heel, Velcro® fastening, and a firm sole optimises balance and gait compared to backless slippers, and is therefore recommended to reduce the risk of falling.

Introduction

Falls in older people are a major public health problem, with 1 in 3 people in the community aged over 65 years falling each year [1, 2]. Up to 15% of falls result in serious injury such as head trauma, fractures, disloca-

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tions, and lacerations [3], making falls the leading cause of injury-related hospitalisation and mortality in older people [4]. Although falls are complex and multifactorial, several studies have shown that footwear influences balance and may therefore play a role in increasing the risk of falls in this age group [5, 6]. Specifically, footwear with elevated or narrow heels, soft midsoles, and lack of fixation is considered to be detrimental [5, 6].

A key limitation of the available literature in this area is that relatively few studies have addressed the effect of indoor footwear on balance. This is a significant limitation for two main reasons. Firstly, half of all falls occur inside the home, and older people who fall indoors are more likely to be female, older, less physically active and to have poorer general health [7]. Secondly, indoor footwear tends to be less supportive than outdoor footwear, is infrequently replaced, and is selected primarily for comfort [8]. The most frequently worn indoor footwear is slippers, which often comprise design features considered detrimental to balance, including lack of fixation, thick, soft midsoles, and smooth outsoles [8–11]. Indeed, several studies have shown that wearing slippers is a risk factor for falls [12, 13] and fall-related injury [14–17] in older people.

In response to these findings, several authors have suggested that older people should wear more supportive footwear inside the home [17, 18]; thus there is a need to develop indoor footwear that is both comfortable and safe for older people at risk of falling. Therefore, the primary aim of this study was to assess balance and gait patterns in older women when wearing socks alone, backless slippers, and enclosed slippers designed to optimise balance. The secondary aim was to evaluate participants' perceptions of the two slippers. We hypothesised that balance and gait patterns would be optimal when wearing the enclosed slippers, intermediate in socks alone, and worst in the backless slippers, but that the backless slippers would be considered more comfortable.

Methods

Participants

The sample size for the study was determined a priori, assuming an effect size of 20%, power of 0.80, and an alpha level of 0.05. For the balance tests, standard deviation (SD) data from Suttanon et al. [19, 20] indicated that a minimum of 25 participants would be required, while for the gait parameters, SD data from Hollman et al. [21] indicated that at least 13 participants would be required. Therefore, to ensure that the study was sufficiently powered to detect differences in each of these measures, we recruited 30 participants.

Participants were recruited by (1) conducting a mail-out using a database of people attending a university health sciences clinic for podiatry treatment, and (2) displaying a poster in a nearby retirement village. To be included in the study, participants were required to be female, aged over 65 years, living independently in the community, able to walk household distances without a walking aid, and able to understand English in written and verbal form. Participants were deemed ineligible if they had cognitive impairment (defined as a score of <7 on the Short Portable Mental Status Questionnaire [22]), a neurodegenerative condition such as Parkinson's disease, lower limb amputation, or foot and ankle surgery in the previous 3 months.

Ethics approval was granted from the La Trobe University Faculty of Health Sciences Human Ethics Committee (reference FHEC14/254), and written informed consent was obtained from all participants prior to the study.

Questionnaire and Clinical Assessment

A self-completion questionnaire was administered which included basic participant, demographic, and medical history data (age, a checklist of common medical conditions, and medication usage), the falls history for the previous 12 months, fear of falling (using the Falls Efficacy Scale International [23]), general health (using the Short Form-12 Version 2 survey [24]), and physical activity (using the Incidental and Planned Exercise Questionnaire [25]). A brief foot assessment was also undertaken to document the presence of keratotic lesions and lesser toe deformity [26], and the presence and severity of hallux valgus was documented using the Manchester Scale [27].

Falls Risk Assessment

Risk of falling was evaluated using the validated QuickScreen© tool, which consists of eight measures: (1) previous falls, (2) total medications, (3) use of psychoactive medications, (4) visual acuity (using a 10% low-contrast letter chart), (5) touch sensation (using a Semmes-Weinstein-type pressure aesthesiometer applied to the lateral malleolus), (6) the sit-to-stand test (using a 43-cm-high chair without armrests, 5 times, as fast as possible with arms folded), (7) the near tandem stand test (eyes closed, with feet separated laterally by 2.5 cm and the heel of the front foot 2.5 cm anterior to the great toe of the back foot), and (8) the alternate step test (alternatively placing the whole left and right feet as fast as possible onto a 19-cm-high and 40-cm-deep step 8 times). Each of these measures was dichotomised using established cut points, and an overall falls risk score was calculated [28].

Balance Assessment

Balance was assessed using the NeuroCom® Balance Master long plate sampling at 100 Hz (Natus Medical Inc., Pleasanton, Calif., USA), which has been shown to have high retest reliability in older people [19]. Three tests were used. First, postural sway was measured in degrees per second (°/s) from 3 trials of 20 s duration. Second, the limits of stability test, which quantifies the maximum distance the participant can intentionally displace and maintain the stability of their centre of gravity, was performed with participants leaning in eight directions at 45-degree intervals represented by targets on a computer monitor. The participants were instructed to keep their feet on the ground and use their body to lean towards each target. Maximum excursion (expressed as a percentage of each participant's limits of stability, determined by their height) and direc-

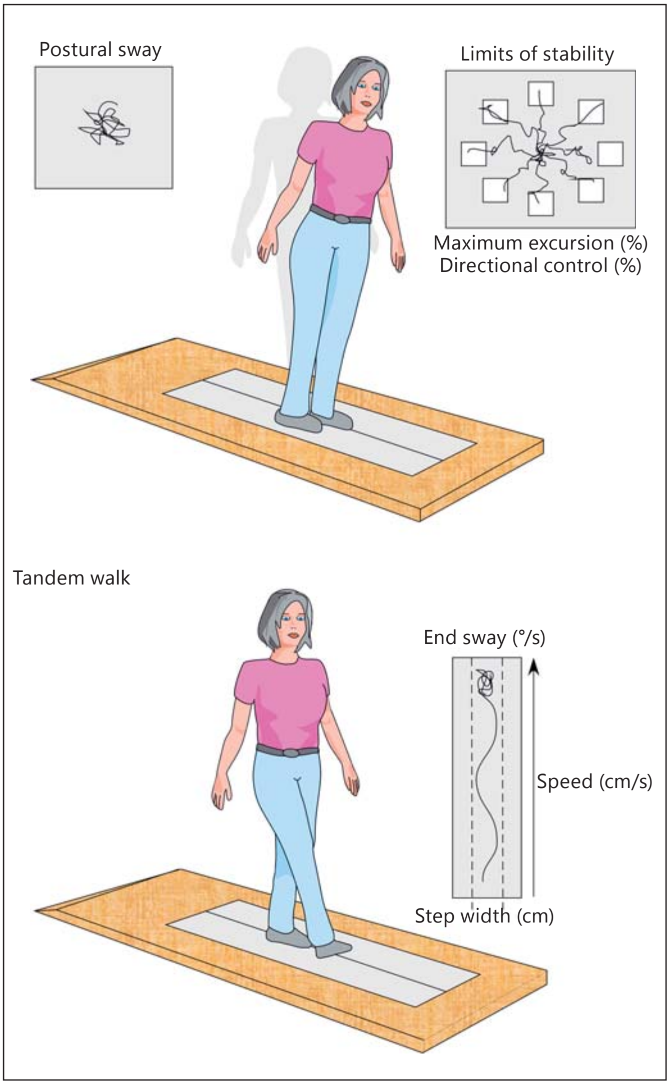

Fig. 1. Balance testing protocol using the NeuroCom® Balance Master. See the main text for explanation.

tional control (expressed as a percentage, with 100% representing a straight line from the centre of pressure to the target) were averaged across the eight directions. Third, the tandem walk test required participants to walk heel to toe from one end of the force plate to the other 3 times. Measured parameters during this test were speed (cm/s), step width (cm), and endpoint sway velocity (°/s) (fig. 1).

Gait Assessment

Spatiotemporal gait data (walking speed, cadence, and step length) were collected using a GAITRite® electronic walkway (CIR Systems, Inc., Franklin, N.J., USA). The walkway was 830 cm long and 89 cm wide, with an active sensor area 732 cm long and 61 cm wide and with a sampling frequency of 80 Hz. Participants were asked to walk at their normal comfortable speed, and 3 trials under each footwear condition were recorded. This system has high test-retest reliability for gait measures in older people [29].

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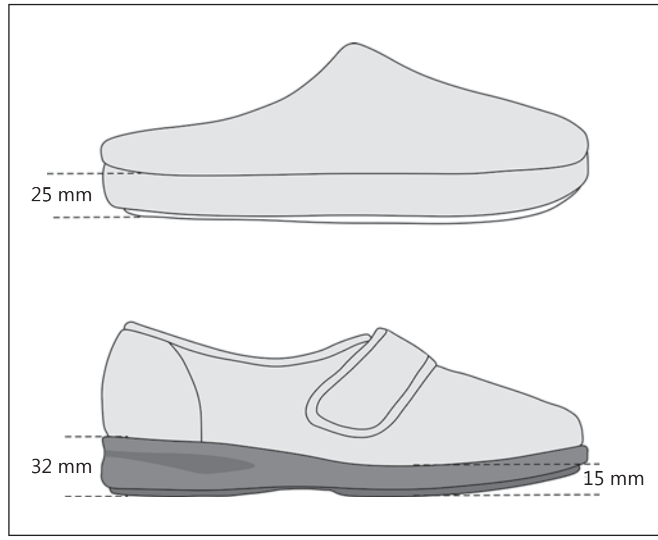

Fig. 2. Indoor footwear conditions. Top: backless slipper; bottom: enclosed slipper.

Footwear Conditions

The participants performed each of the balance and gait assessments while wearing standard socks, backless slippers, and enclosed slippers (fig. 2). The socks (All Day Socks™; Underworks, Broadmeadows, Vic., Australia) were manufactured from 84% cotton, 13% nylon, and 3% elastane. The backless slippers (Emerson Scuffy; Big W, Baulkham Hills, N.S.W., Australia) had a synthetic microfibre upper, a soft (Shore A hardness 15 [30]) foam sole of uniform 25-mm thickness, and no method of fixation to the foot. Across the size range, the weight of the slipper was 97–122 g. The enclosed slippers (DB House Shoes; DB Shoes Ltd, Rushden, UK) had a firm (Shore A hardness 50 [30]) rubber sole 32 mm thick under the heel and 15 mm thick under the forefoot, Velcro® fastening, and a firm heel counter. Across the size range, the weight of the slipper was 285–345 g. The order of testing was randomised across the footwear conditions to avoid order effects (i.e. learning, habituation, and fatigue).

Perceptions of Footwear

After the gait testing had been performed for each footwear condition, the participants were asked to report their perceptions of the footwear, using questions selected from the Monitor Orthopaedic Shoes questionnaire [31] and scored on a 100-mm visual analogue scale. The selected questions were: (1) 'Please mark on the following line how attractive you think the shoes are' (with the anchors 'extremely unattractive' and 'extremely attractive'), (2) 'Please mark on the following line how attractive you think other people would think the shoes are' (with the anchors 'extremely unattractive' and 'extremely attractive'), (3) 'Please mark on the following line how comfortable you think the shoes are' (with the anchors 'extremely uncomfortable' and 'extremely comfortable'), (4) 'Please mark on the following line how well you think the shoes fit you' (using the anchors 'poorest fit possible' and 'best fit possible'), (5) 'Please indicate how easy it is for you to don the shoes on and off' (using the anchors 'most difficult as

Table 1. Participant characteristics

Age, years	74.4±5.6
Height, cm	158.9±5.77
Weight, kg	75.5±12.8
Body mass index	29.9±4.8
Major medical conditions	
Heart disease	10 (33.3)
Diabetes	4 (13.3)
Stroke	3 (10.0)
Osteoarthritis	24 (80.0)
High blood pressure	18 (60.0)
Peripheral vascular disease	2 (6.7)
Short Form-12 Version 2 score	
Role – physical	44.4±9.5
Role – mental	54.2±8.6
Incidental and Planned Exercise Questionnaire total, h/week	19.8±14.8
QuickScreen© falls risk factors	
At least one falls risk factor	27 (90.0)
Fallen in previous 12 months	7 (23.3)
Use of 4 or more medications	16 (53.3)
Use of psychotropic medications	16 (53.3)
Impaired visual acuity	15 (50.0)
Impaired peripheral sensation	6 (20.0)
Failed near tandem stand test	9 (30.0)
Failed alternate step test	12 (40.0)
Failed sit-to-stand test	10 (33.3)
Total falls risk score[a]	3.3±3.0
Falls Efficacy Scale International score[b]	25.2±7.4
Foot problems	
Hallux valgus	14 (46.7)
Lesser toe deformity	20 (66.7)
Plantar keratotic lesions	20 (66.7)
Keratotic lesions on toes	12 (40.0)
Manchester Foot Pain and Disability Index	
Pain subscale[c]	2.8±2.6
Functional limitation subscale[d]	4.7±4.0

Values are expressed as n (%) or means ± SD. [a] Score ranging from 1 to 8.6; a higher score indicates greater risk. [b] Score ranging from 16 to 64; a higher score indicates greater fear (low: 16–19; moderate: 20–27; high: 28–64). [c] Rasch-transformed score ranging from 0 to 10; a higher score indicates greater impairment. [d] Rasch-transformed score ranging from 0 to 20; a higher score indicates greater impairment.

possible' and 'as easy as imaginable'), and (6) 'Please indicate how heavy the shoes are' (using the anchors 'extremely light' and 'extremely heavy'). We did not administer the remaining questions from the Monitor Orthopaedic Shoes questionnaire, as they relate to the perceived effectiveness of footwear in the treatment of foot pain, wounds, and sprains. The participants were also asked whether they would consider wearing the enclosed slipper if it were found to be beneficial for balance (with the options 'yes', 'no', or 'maybe').

Statistical Analysis

Statistical analysis was undertaken using SPSS version 22.0 (IBM, Armonk, N.Y., USA). Participants who had missing data because they were unable to complete the task were given the 'worst' score of the remaining sample. All data were explored for normality prior to inferential analysis. Differences between the three footwear conditions (socks, backless slippers, and enclosed slippers) were evaluated using repeated-measures analysis of variance (ANOVA) with Bonferroni-adjusted post hoc tests for pairwise comparisons. The effect sizes for all significant main effects were calculated using the η^2 statistic and were interpreted using the following cut-offs: 0–0.06 (small), >0.06–0.14 (medium), and >0.14 (large) [32]. Differences in perceptions of the two types of indoor footwear (backless vs. enclosed) were evaluated using t tests. The level of significance was set at 0.05.

Results

Participant Characteristics

The characteristics of the sample were typical of community-dwelling older women in this age group (table 1). With regard to falls, 7 (23%) reported having fallen in the previous 12 months, and 23 (90%) had at least one falls risk factor identified with the QuickScreen© tool; overall the sample had a moderate fear of falling. Four participants had missing data for the tandem walking test and were given the 'worst' score of the remaining sample.

Effects of Indoor Footwear on Balance

The results of the repeated-measures ANOVAs for the balance tests are shown in table 2. There was a significant overall effect of footwear on postural sway ($F = 4.5$, $p = 0.020$; $\eta^2 = 0.24$, medium effect size), with post hoc comparisons indicating that postural sway was significantly greater in the backless slippers compared to wearing socks or the enclosed slippers. For the limits of stability test, there was no overall effect of footwear on maximum excursion ($F = 1.5$, $p = 0.240$). However, there was a significant overall effect of footwear on directional control ($F = 4.6$, $p = 0.019$; $\eta^2 = 0.25$, large effect size), with post hoc comparisons indicating that directional control was significantly lower in the backless slippers compared to the enclosed slippers. For the tandem walk test, there was no overall effect of footwear on speed ($F = 2.7$, $p = 0.086$). However, there was a significant overall effect of footwear on step width ($F = 13.4$, $p < 0.001$; $\eta^2 = 0.49$, large effect size), with post hoc comparisons indicating that step width was significantly higher in the backless slippers compared to wearing socks or the enclosed slippers, and significantly higher

Table 2. Differences in balance and gait patterns between the footwear conditions

	Socks	Backless slippers	Enclosed slippers	p value[a]
Balance				
Postural sway velocity[b], °/s	0.14±0.12	0.22±0.14[c]	0.13±0.09[d]	0.020
Limits of stability test				
Maximum excursion[e], % LOS	72.0±17.1	71.3±15.5	74.5±14.1	0.240
Directional control[b], %	54.3±14.7	52.2±14.8	57.9±14.3[d]	0.019
Tandem walk test				
Speed[e], cm/s	16.0±9.2	13.2±7.5	17.7±9.6	0.086
Step width[b], cm	12.6±6.8	16.3±9.1[c]	11.4±7.5[c, d]	<0.001
End sway[b], °/s	8.0±7.6	9.0±8.1	5.9±4.0[c, d]	0.016
Gait patterns				
Walking speed[e], cm/s	99.2±18.9	99.2±18.0	105.2±18.2[c, d]	<0.001
Cadence[b], steps/min	112.8±10.9	108.8±9.9[c]	109.9±10.8[c]	0.006
Step length[e], cm	53.3±7.5	54.8±8.0[c]	57.9±7.4[c, d]	<0.001

Values are expressed as means ± SD. LOS = Limits of stability. [a] p value for the main effect of one-way ANOVA. [b] Lower scores represent better performance. [c] Significantly different to socks. [d] Significantly different to backless slippers. [e] Higher scores represent better performance.

in socks compared to enclosed slippers. There was also a significant overall effect of footwear on end sway ($F = 4.8$, $p = 0.016$; $\eta^2 = 0.27$, large effect size), with post hoc comparisons indicating that end sway was significantly greater in socks and backless slippers compared to wearing the enclosed slippers.

Effects of Indoor Footwear on Gait Patterns

The results of the repeated-measures ANOVAs for gait patterns are shown in table 2. There was a significant overall effect of footwear on walking speed ($F = 12.0$, $p < 0.001$; $\eta^2 = 0.46$, large effect size), with post hoc comparisons indicating that walking speed was significantly slower in socks and backless slippers compared to wearing the enclosed slippers. There was also a significant overall effect of footwear on cadence ($F = 6.2$, $p = 0.006$; $\eta^2 = 0.31$, large effect size), with post hoc comparisons indicating that cadence was significantly higher in socks compared to wearing backless slippers or enclosed slippers. Finally, there was a significant overall effect of footwear on step length ($F = 55.7$, $p < 0.001$; $\eta^2 = 0.80$, large effect size), with post hoc comparisons indicating that step length was significantly shorter in socks compared to backless slippers or enclosed slippers, and significantly shorter in backless slippers compared to enclosed slippers.

Perceptions of Indoor Footwear

The participants' perceptions of the indoor footwear are shown in table 3. The enclosed slippers were perceived to be significantly more attractive (to both self and others), comfortable, and well fitted, but heavier than the backless slippers. The ease of donning and doffing did not differ between the two kinds of slippers. When asked if they would consider wearing the enclosed slippers to reduce their risk of falling, 23 (77%) of the participants said 'yes', 2 (7%) said 'no', and 5 (17%) said 'maybe'.

Discussion

The objective of this study was to evaluate balance and gait patterns in older women when wearing three types of indoor footwear: socks, backless slippers, and enclosed slippers. The enclosed slippers were specifically selected as they incorporate several features considered beneficial to balance (i.e. a low, firm sole, a rigid heel counter, and Velcro® fastening) [5, 6]. Our findings indicate that balance ability – as evidenced by performances on tests of postural sway, limits of stability, and tandem walking – was optimised when wearing the enclosed slipper. Similarly, gait patterns – as evidenced by measures of walking speed, cadence, and step length – were optimal while wearing the enclosed slippers, intermediate with backless slippers, and worst with socks. Taken together, these find-

Table 3. Differences in perceptions of the footwear

	Backless slippers	Enclosed slippers
Attractiveness to self	33.6±25.6	59.3±28.1*
Attractiveness to others	33.9±24.0	58.0±27.8*
Comfort	44.3±31.0	71.6±26.1*
Fit	45.1±32.4	70.6±25.8*
Ease of donning and doffing	81.6±19.9	83.2±19.5
Heaviness	15.2±19.3	33.6±22.3*

Values are means ± SD in millimetres on 100-mm visual analogue scales. Higher scores represent greater perceived attractiveness, comfort, fit, ease of donning and doffing and heaviness.* Significant difference at $p < 0.01$.

ings suggest that enclosed slippers may be the most appropriate indoor footwear for older women with an increased risk of falling.

The detrimental effect of backless slippers observed in our study is consistent with results by Cho and Lee [33], who reported that postural sway in older stroke patients was increased when wearing backless slippers or flat shoes compared to being barefoot or wearing high-heel collar shoes, and Ng et al. [10], who found that older stroke patients walked more slowly when wearing slippers compared to walking shoes. These findings are also consistent with previous studies which have identified slippers as a risk factor for falls [12, 13] and fall-related injury [14–17] in older people. There are two possible explanations for this finding. Firstly, the backless slippers had a very thick and soft sole, which is thought to dampen tactile sensory input from the sole of the foot, thereby impairing foot position sense and postural corrections to maintain balance [34, 35]. Secondly, the lack of support in the upper section of the slipper may allow the foot to slide and require the wearer to consciously alter foot motion to hold the slipper in place, resulting in cognitive demands being allocated away from the postural task [36].

Wearing socks alone resulted in better balance performances than when wearing the backless slippers, which is most likely due to maximising tactile sensory input from the sole of the foot. However, wearing socks alone resulted in the most cautious gait pattern, as evidenced by the slowest speed and shortest step length across the three footwear conditions. This observation is consistent with previous studies which have shown that wearing socks or being barefoot results in more cautious gait patterns (both on level ground [37, 38] and when descending stairs [39]) compared to being shod, and may represent a strategy to decrease plantar loading in those with foot pain and/or reduce the risk of slipping on the relatively hard and smooth surfaces within the gait laboratory environment.

Overall, both balance and gait patterns were optimal when wearing the enclosed slippers. These slippers incorporate several design features which are considered to be beneficial to balance, such as a relatively thin, firm rubber sole, a firm heel counter, and sturdy fixation provided by the Velcro® straps [5, 6]. Our findings therefore confirm the observations of previous laboratory studies using outdoor footwear. However, in order for this slipper to be acceptable to older people for use indoors, it needs to be perceived as being similarly comfortable and easy to take on and off as the more commonly used backless slippers. Participants' responses to the Monitor Orthopaedic Shoes questionnaire indicate that despite being heavier, the enclosed slippers were considered to be more attractive (both to self and others), comfortable, and well fitted than the backless slippers, with similar ease of donning and doffing. Furthermore, most participants (n = 23; 77%) reported that they would consider wearing the enclosed slippers to reduce their risk of falling.

The findings of this study need to be interpreted in the context of several limitations. First, the participants were only provided with a brief period of time to acclimatise to the different footwear conditions before undertaking the balance tests. Although previous research has shown that 5 weeks of habituation to new shoes does not significantly affect standing balance or gait in older women [40], it may take longer for this to occur. Second, because women are more likely to wear slip-on indoor footwear [8] and fall indoors [7], we specifically recruited older women into the study, so we cannot be certain that the findings are generalisable to older men. Third, it could be argued that older women at a higher risk of falling may have been a more appropriate target sample. However, because hazardous footwear can be considered to be an *extrinsic* falls risk factor, it has the potential to increase the risk of falling in older people who otherwise have a low *intrinsic* risk of falling. Indeed, our results indicate that even among older women with few falls risk factors, the wearing of the backless slipper leads to quite marked impairment in their balance ability. Fourth, the questions we used to assess footwear perceptions were derived from a questionnaire focusing on custom-made orthopaedic footwear and have not been specifically validated in relation to commercially available footwear. Finally, we used standard cotton socks as the control condition; we acknowledge that non-slip socks may be preferable for older people who prefer not to wear shoes indoors [41].

In summary, this study has shown that indoor footwear with an enclosed heel, Velcro® fastening, and a firm sole optimises balance and gait compared to backless slippers and is therefore recommended to reduce the risk of falling in older women. Future studies should consider incorporating this style of indoor footwear as part of a multifaceted falls prevention programme using prospectively documented incident falls as the primary outcome measure.

Acknowledgements

H.B.M. is currently a National Health and Medical Research Council Senior Research Fellow (ID: 1020925). We would like to thank Comfort and Fit Footwear (Warriewood, N.S.W., Australia) for providing the enclosed slippers. This study was funded by a grant from the La Trobe University Research Focus Area in Sport, Exercise and Rehabilitation.

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