Effects of Nonslip Socks on the Gait Patterns of Older People When Walking on a Slippery Surface

Anna L. Hatton, PhD*
Daina L. Sturnieks, PhD†
Stephen R. Lord, PhD†
Joanne C.M. Lo, BS†
Hylton B. Menz, PhD‡
Jasmine C. Menant, PhD†

Background: Slips are a common cause of falls, and nonslip socks have been marketed to prevent slips in older people. However, few studies have investigated the biomechanical and clinical effects of walking in nonslip socks. This study aimed to examine gait parameters in older people walking on a slippery surface wearing nonslip socks compared with standard sock and barefoot conditions.

Methods: Fifteen older people completed five trials of the fast-paced Timed Up and Go test while barefoot and while wearing standard socks and nonslip socks. Kinematic data (step length, heel horizontal velocity at heel strike, and foot-floor angle at heel strike) and clinical data (total Timed Up and Go test time, total number of steps, number of steps in turn, and observed slips, trips, or falls) were collected.

Results: Performance on the Timed Up and Go test did not differ between the barefoot and nonslip sock conditions; however, participants walked more slowly and took shorter steps when wearing standard socks. Participants rated nonslip socks to feel less slippery than barefoot and standard socks.

Conclusions: Compared with wearing standard socks, wearing nonslip socks improves gait performance and may be beneficial in reducing the risk of slipping in older people. (J Am Podiatr Med Assoc 103(6): 471-479, 2013)

Slip-related falls are reported to contribute up to 25% of fall-related hip fractures in older people,[1,2] with 66% occurring on wet or slippery surfaces.[3] In 1 year, 59% of 91 self-reported falls were attributed to trips and slips in 50 independent, community-dwelling older people.[4] Because most falls in older people occur during locomotion,[5] the development of therapeutic interventions to enhance walking and reduce slip propensity is of great clinical importance.

The influence of shoe characteristics, including heel height, shoe fastenings, and outer sole treading,[6] on slip propensity in older people has been explored by several groups[7-10] with a view to identifying the optimal footwear for the prevention of falls. However, shoes are commonly not worn indoors, and walking barefoot or in stockings on a wet or polished indoor surface has been suggested to exacerbate the risk of slipping.[10]

A few laboratory studies have investigated slip events while walking on slippery surfaces and have quantified heel-contact dynamics in young people[11] and gait parameters[12] and postural responses[13] in older people. Findings from these studies indicate that older people reduce their step length, heel-

*School of Health and Rehabilitation Sciences, The University of Queensland, Brisbane, Queensland, Australia.

†Neuroscience Research Australia, University of New South Wales, Randwick, Sydney, New South Wales, Australia.

‡Lower Extremity and Gait Studies Program, Faculty of Health Sciences, La Trobe University, Bundoora, Victoria, Australia.

Corresponding author: Anna L. Hatton, PhD, School of Health and Rehabilitation Sciences, Therapies Building (84A), The University of Queensland, Queensland 4072, Australia. (E-mail: a.hatton1@uq.edu.au)

contact velocity, and friction utilization when walking on a slippery surface compared with nonslippery walking conditions. Such alterations in gait patterns may be due to conscious slip avoidance strategies adopted by older people to avoid loss of balance. Although this evidence helps us better understand gait mechanics related to slip events, there is an urgency to identify and assess interventions that may assist in reducing the risk of slipping in older people.

Commercially available nonslip socks may have the capacity to prevent slipping in older people when walking indoors. However, evidence for the effect of nonslip socks on slip propensity is limited and conflicting. A recent study by Tsai and Lin[14] reported that older people adopt a more cautious gait pattern when wearing socks, compared with when barefoot, by walking at a slower speed and taking shorter steps. Wearing socks may reduce the friction between the foot and a floor surface such as linoleum or floorboards, therefore presenting a greater threat of slipping to older people. Nonslip socks with rubber grip components may lessen this threat.

However, Chari et al[15] examined the traction benefits of nonslip socks relative to barefoot, compression stockings, and standard socks. Nonslip socks were reported to show less slip resistance compared with barefoot during a standing inclined ramp test in three older people. However, it remains unclear whether, in older people, nonslip socks would provide greater traction while walking on a slippery surface.

To date, only one study has explored the biomechanical effects of nonslip socks on slip resistance during walking compared with barefoot, standard socks, and backless slippers.[16] Hübscher et al[16] used a heel-mounted accelerometer to measure heel deceleration time as a marker of slip resistance during a level-ground 12-m walk in healthy young people. Relative to the barefoot condition, heel deceleration time significantly increased when wearing standard socks and backless slippers, indicating a detrimental effect. However, no significant differences were observed between the barefoot and nonslip sock conditions.[16] These findings suggest that nonslip socks may provide a greater degree of traction than standard socks and slippers and equivalent slip resistance to walking barefoot. This promising evidence in young people points to the need for further investigation into the potential for nonslip socks to provide a simple and effective intervention to reduce the risk of slipping during indoor walking and turning in older people.

Therefore, the aim of this study was to investigate the effects of wearing nonslip socks on gait parameters in older people when walking on a slippery surface. These effects were quantified by measuring the number of steps and time taken to complete a common clinical test of mobility involving walking and turning on a slippery polished surface, in addition to biomechanical measures of step length, horizontal heel velocity, and foot-floor angle at heel strike.[17] We hypothesized that wearing nonslip socks would result in 1) faster walking times, 2) fewer steps taken during the walking task, 3) increased step length, 4) reduced horizontal heel strike velocity, and 5) increased foot-floor angle at heel strike relative to the barefoot and standard cotton sock conditions.

Methods

Participants

Community-dwelling men and women older than 70 years were recruited from a volunteer database and through advertising at community group meetings. The exclusion criteria included self-reported neuromuscular disease and orthopedic conditions that impaired walking, recent injury to the back or legs, inability to walk 12 m unassisted, acute psychiatric conditions with psychosis, unstable medical conditions, and cognitive impairment (Mini-Mental State Examination score $<$24).[18] All of the participants gave written informed consent, and the study was approved by the University of New South Wales Human Research Ethics Committee (Sydney, Australia).

Equipment

Kinematic data were collected using two CODA scanner units (Codamotion, Charnwood Dynamics Ltd, Rothley, England) at a sampling rate of 200 Hz. During all of the trials, participants wore a safety harness secured to a frictionless trolley that followed along an overhead rail mounted to the ceiling.[6]

Procedures

Participants completed a short questionnaire detailing their current health status and basic demographics. All of the participants completed the Timed Up and Go (TUG) test[19] at a fast walking speed[20-22] under three randomly presented conditions: barefoot (control), wearing nonslip socks, and wearing standard cotton socks. The order of the barefoot and sock conditions was block randomized within each session. A 4-m-long wooden walkway was constructed to simulate interior polished wooden floorboards. The wooden surface was sanded and treated with water-based Estapol clear gloss polyurethane (Wattyl, Blacktown, NSW, Australia). Immediately before testing, beeswax was applied to the surface using a cloth, followed by a period of buffing to achieve a slippery surface.

The slipperiness of the wooden surface was calculated using the inclined ramp test,[15] a modification of the procedures from the Australian standard *Slip Resistance Classification of New Pedestrian Surface Materials*.[23] This test was performed to confirm that a slippery surface had been created and for comparison with previous literature.[15] The wooden surface was raised to create a ramp. The angle of inclination was adjusted by adding or removing supporting blocks, and an inclinometer was used to accurately measure the angle. Two healthy young people were asked to stand on the ramp and maintain an unsupported upright position for at least 3 sec in three conditions: barefoot, wearing nonslip socks, and wearing standard cotton socks. If this test was performed successfully, without a slip occurring, the angle of inclination of the ramp was increased by 1°. This process was repeated until a slip was observed, at which point the angle was recorded as the slip threshold.

Older participants were asked to remove all hosiery and footwear. Active CODA markers were attached bilaterally directly to the skin on the first metatarsal head, fifth metatarsal head, heel (one medial and one lateral to the Achilles tendon), lateral malleolus, medial malleolus, and head of the fibula using double-sided tape and through precut holes in the socks, as necessary.

Participants wore two different types of socks. The nonslip anklet socks (GripSox, Brighton East, VIC, Australia) were 95% cotton and 5% elastane, with a noncushioned rubberized sole designed to provide extra grip and foot sensation for improved performance and gripping of floor surfaces (Fig. 1A). The rubber grip components (diameter, 3 mm; minimum center-to-center distance, 6 mm) were regularly spaced over the sole of the sock. The standard anklet socks were 100% cotton, with no rubber grip components (Fig. 1B). Participants were not told which socks were nonslip and which were standard. However, it is possible that participants were aware of the sock condition because of the appearance of the grip components on the nonslip socks, which were possible to feel on the soles of the feet of participants while standing and walking.

Participants were asked to sit on a 46-cm chair at one end of the walkway. A 10-cm-high by 5-cm-wide marker was placed 3 m from the chair to identify the turnaround point (Fig. 2). Once seated, participants were connected to the overhead safety harness. In line with the fast-paced TUG test,[20-22] the researcher provided the standardized instruction to "get up (with arms crossed), walk around the marker, come back, and sit down as quickly as you can, but do not run." Participants completed five trials for each condition (barefoot, wearing nonslip socks, and wearing standard socks) for a total of 15 walking trials.

During each trial, clinical data were collected for TUG test performance. A digital stopwatch was used to measure the total TUG test time. Two researchers (A.L.H. and J.C.M.L.) counted and recorded the total number of steps taken during each TUG test trial, including the number of steps in the turn, and any observed slips, trips, or falls.

To capture participants' initial responses to walking in each condition, kinematic and clinical data from the first TUG test trial were analyzed. It was assumed that this trial would best identify any potential slips before participants became familiar with the sock/foot-surface traction and adjusted their walking patterns accordingly.[24]

Kinematic data were extracted and averaged from the three steps before and the three steps after the turnaround point. To ensure consistency in identifying the number of steps in the turn, a line was taped at the 3-m marker perpendicular to the line of travel. On approach to the turn, when any part of the participant's foot stepped on or passed over this line, that step was considered to be the first step of the turn. When completing the turn, when any part of the participant's foot stepped on or over the line, that step was not considered to be part of the turn.

Kinematic outcome measures of interest were step length,[25] heel horizontal velocity at heel strike,[11] and foot-floor angle at heel strike.[25] These variables are reported to be associated with the probability of experiencing a hazardous slip. Heel strike was identified as being the point at which the heel marker was at its lowest position in the vertical plane combined with visual inspection of three-dimensional stick figures, particularly where partic-

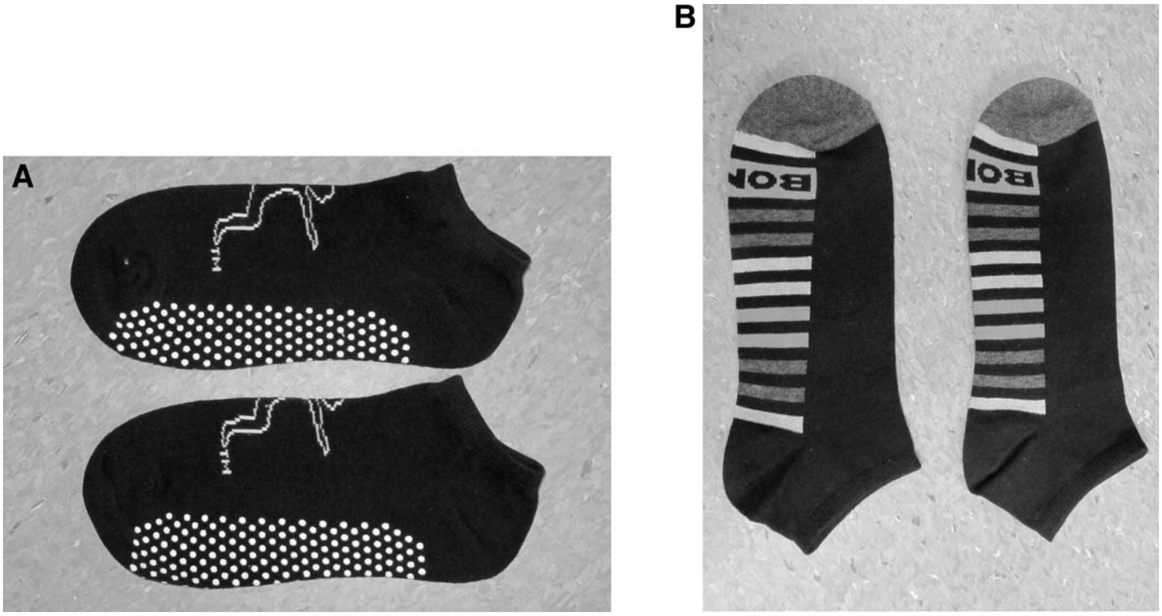

Figure 1. A, Nonslip socks. B, Standard cotton socks.

ipants walked using a toe strike or flatfoot strike gait pattern.

At the end of each condition block of trials, the degree of perceived slipperiness of the floor surface was assessed. Participants were asked to score how it felt when they were walking using a 5-point Likert scale (1 = very grippy; 2 = grippy; 3 = neither grippy nor slippery; 4 = slippery; and 5 = very slippery).

Statistical Analysis

Data were analyzed with a statistical software program (SPSS, version 18.0.0; IBM Corp, Chicago, Illinois). For each variable, a repeated measures analysis of variance was conducted to determine the within-participant condition (wearing standard socks, wearing nonslip socks, or barefoot) effects on clinical and kinematic data during walking on a slippery surface. The α was set at 0.05, with Bonferroni adjustments for multiple comparisons ($P < .017$). It is possible that older people who walk slower (demonstrating longer TUG test times) when wearing standard socks may show greater benefit from wearing nonslip socks relative to those who walk faster (demonstrating lower TUG test times) in standard socks. Therefore, Pearson correlation

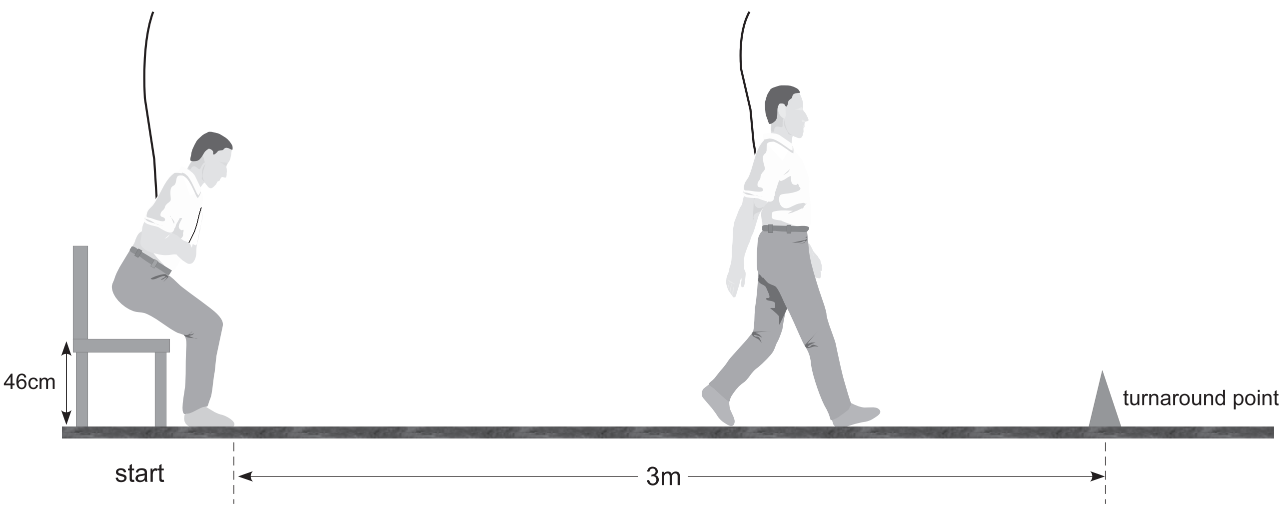

Figure 2. Timed Up and Go test experimental setup.

coefficients and paired-samples Student t tests were conducted to explore the relationships between participants with slower and faster TUG test times when walking in standard socks and nonslip socks.

Results

Inclined Ramp Test

Two healthy young people, one woman (age, 24 years; height, 1.63 m; weight, 44 kg) and one man (age, 24 years; height, 1.80 m; weight, 93 kg), completed the ramp test to assess the degree of slipperiness achieved on the polished wooden surface. Table 1 presents the threshold angles of inclination at which a slip was observed for each condition. The results suggest that standard socks were the most slippery condition, followed by nonslip socks, then barefoot.

Fifteen community-dwelling older people (five women and ten men; mean [SD]: age, 76.1 [5.0] years; height, 1.67 [0.1] m; and weight, 75.6 [10.1] kg) were recruited and completed the study.

TUG Test Clinical Measures

Tables 2 and 3 present the clinical measures for each condition for the first trial and for the average of five trials respectively. There were significant main effects of condition on total TUG test time for the first trial ($P = .004$) and for the five averaged trials ($P = .002$). Older people took significantly longer to complete the TUG test when walking in standard socks compared with barefoot and in nonslip socks. However, no significant within-participant differences were observed for TUG test time between the barefoot and nonslip sock conditions. Subgroups were created using the median TUG test time for the standard sock condition (8.26 sec) to categorize older people as slower walkers (TUG test time >8.26 sec) or faster walkers (TUG test time ≤8.26 sec). A significant positive correlation was observed for TUG test times when wearing standard socks and nonslip socks in slower walkers ($n = 8$, $r = 0.957$, $P < .001$) but not in faster walkers ($n = 7$, $r = 0.550$, $P = .201$). A paired-samples Student t test indicated a significant difference between TUG times when slower walkers completed the TUG test in standard socks compared with nonslip socks (mean difference, 0.72; 95% confidence interval, 0.3–1.1; $P = .005$). Mean TUG test times for faster walkers when wearing standard socks and nonslip socks were not significantly different ($P = .211$).

There were significant main effects of condition on the total number of steps taken to complete the TUG test for the first trial and for the five averaged trials ($P < .001$). A similar number of steps were taken in the barefoot and nonslip sock conditions. Participants walked with significantly fewer steps when barefoot compared with when wearing standard socks during the first trial and the five averaged trials ($P < .001$). Participants walked with significantly fewer steps in nonslip socks compared with standard socks across the five averaged trials

Table 1. Results of the Inclined Ramp Test to Measure the Slipperiness of the Surface

Participant No.	Threshold Angle at Which a Slip Occurred (°)		
	Barefoot	Nonslip Socks	Standard Cotton Socks
1	46	31	14
2	42	31	16

Table 2. Clinical Measures for the First Trial of the Timed Up and Go Test (n = 15)

	Mean (SD)			Mean Difference (95% CI) P Value			
Clinical Measure	Barefoot	Nonslip Socks	Standard Socks	Nonslip Socks – Barefoot	Standard Socks – Barefoot	Standard Socks – Nonslip Socks	ANOVA P Value
Total time (sec)	8.79 (1.77)	8.95 (1.56)	9.86 (2.03)	0.16 (−0.6 to 0.9) >.99	1.06 (0.2 to 2.0) .021	0.91 (0.1 to 1.8) .035	.004[a]
Total steps (No.)	14.73 (2.19)	15.53 (2.53)	17.13 (2.75)	0.80 (−0.4 to 2.0) .290	2.40 (1.3 to 3.5) <.001[a]	1.60 (0.2 to 3.0) .023	<.001[a]
Steps in turn (No.)	3.33 (0.72)	3.87 (0.64)	4.27 (0.88)	0.53 (−0.3 to 1.3) .263	0.93 (0.3 to 1.6) .003[a]	0.40 (−0.3 to 1.1) .415	.005[a]

Abbreviations: ANOVA, analysis of variance; CI, confidence interval.
[a]$P < .017$.

Table 3. Clinical Measures for the Timed Up and Go Test, Average of Five Walking Trials (n = 15)

Clinical Measure	Mean (SD) Barefoot	Mean (SD) Nonslip Socks	Mean (SD) Standard Socks	Mean Difference (95% CI) *P* Value: Nonslip Socks – Barefoot	Mean Difference (95% CI) *P* Value: Standard Socks – Barefoot	Mean Difference (95% CI) *P* Value: Standard Socks – Nonslip	ANOVA *P* Value
Total time (sec)	8.38 (1.64)	8.50 (1.67)	9.04 (1.69)	0.12 (−0.3 to 0.6) .171	0.66 (0.1 to 1.2) .016[a]	0.54 (0.1 to 1.0) .009[a]	.002[a]
Total steps (No.)	14.19 (2.06)	14.83 (2.09)	16.15 (2.35)	0.64 (0.1 to 1.2) .021	1.96 (1.0 to 2.9) <.001[a]	1.32 (0.5 to 2.1) .002[a]	<.001[a]
Steps in turn (No.)	3.36 (0.45)	3.67 (0.37)	4.03 (0.53)	0.31 (−0.1 to 0.7) .174	0.67 (0.2 to 1.1) .005[a]	0.36 (0.1 to 0.6) .011[a]	<.001[a]
Perceived degree of slipperiness (scale, 1–5)	2.60 (0.83)	2.13 (0.83)	3.73 (0.70)	−0.47 (−0.9 to −0.02) .041	1.13 (0.5 to 1.7) <.001[a]	1.60 (1.1 to 2.1) <.001[a]	<.001[a]

Abbreviations: ANOVA, analysis of variance; CI, confidence interval.
[a] $P < .017$.

($P = .002$), whereas the first trial did not reach significance ($P = .023$).

There were significant main effects of condition on the number of steps during the turn phase for the first trial and the five averaged trials of the TUG test. The pairwise comparison for the number of steps taken in the turn showed that older people took significantly more steps when wearing standard socks compared with nonslip socks for the five averaged trials only ($P = .011$). Similarly, older people took significantly more steps in the turn when wearing standard socks compared with the barefoot condition for the first trial ($P = .003$) and for the five averaged trials ($P = .005$)

There were significant main effects of condition on participants' perceived degree of slipperiness ($P < .001$). The standard sock condition was considered to be the most slippery, followed by barefoot, with the nonslip sock condition perceived to be the least slippery. The pairwise comparisons between standard socks and the nonslip sock and barefoot conditions reached significance ($P \leq .001$ for both).

TUG Test Kinematic Data

Table 4 shows the results of the kinematic analyses for the sock and barefoot conditions during the first

Table 4. Kinematic Measures for the First Timed Up and Go Trial, Averaged Over the Three Steps Before the Turn and the Three Steps After the Turn (N = 15)

Kinematic Measure	Mean (SD) Barefoot	Mean (SD) Nonslip Socks	Mean (SD) Standard Socks	Mean Difference (95% CI) *P* Value: Nonslip Sock – Barefoot	Mean Difference (95% CI) *P* Value: Standard Sock – Barefoot	Mean Difference (95% CI) *P* Value: Standard Sock – Nonslip	ANOVA *P* Value
Step length (mm)[a]	537 (83)	565 (142)	458 (53)	28 (−69 to 123) >.99	−79 (−123 to −35) .001[b]	−107 (−209 to −4) .040	.001[b]
Heel horizontal velocity at heel strike ($m.s^{-1}$)	0.784 (0.403)	0.880 (0.509)	0.974 (0.429)	0.10 (−0.07 to 0.26) .389	0.19 (−0.1 to 0.5) .370	0.09 (−0.3 to 0.5) >.99	.233
Foot-floor angle at heel strike (°)[c]	3.64 (3.57)	3.77 (7.75)	2.15 (7.30)	0.13 (−4.9 to 5.2) >.99	−1.49 (−5.1 to −2.1) .834	−1.62 (−6.7 to 3.4) >.99	.569

Abbreviations: ANOVA, analysis of variance; CI, confidence interval.
[a] Missing data for one participant (n = 14).
[b] $P < .017$.
[c] One outlier participant was excluded (n = 14).

TUG test trial. There was a significant main effect of condition on step length ($P < .001$). Older people took shorter steps when walking in standard socks compared with the barefoot condition ($P = .001$). There was a trend toward shorter step length in the standard sock versus nonslip sock conditions ($P = .040$). No significant differences were reported for step length between the barefoot and nonslip sock conditions. No significant differences were observed for horizontal heel velocity or foot-floor angle at heel strike among the three conditions.

Discussion

This study examined the effect of wearing nonslip socks on clinical and biomechanical measures during walking on a slippery surface in healthy older people. The findings suggest that when walking in nonslip socks, older people adopt similar walking patterns to walking barefoot. Conversely, while walking in standard socks, older people walk slower and with shorter steps.

When wearing standard cotton socks, older people took a significantly longer time and a greater number of steps to complete the TUG test compared with the barefoot and nonslip sock conditions. These gait adaptations were suggested during the first walking trial and were confirmed across the five averaged trials. It is possible that such adaptations may have occurred within the first few steps of each trial or even before walking, as participants may have been aware that they were wearing the standard socks.

The present findings seem to suggest that older people who walk slower when wearing standard socks may benefit more from wearing nonslip socks. The TUG test times for slower walkers significantly reduced by 0.7 sec when wearing nonslip socks relative to standard socks, indicating that these older people walked more quickly, completing the TUG test in less time. It is possible that wearing nonslip socks enables slower older people to walk with greater confidence. For the faster walkers, TUG test times reduced by 0.3 sec when wearing nonslip socks compared with standard socks; however, this difference was not significant ($P = .211$).

The present kinematic data support the clinical measures, showing that older people walked with significantly shorter steps when wearing standard socks relative to being barefoot. In the present study, we used the fast-paced version of the TUG test, requiring older people to walk as fast as possible.[20-22] While wearing standard socks, older people may not have walked at their maximum speed owing to their awareness of the limited degree of slip resistance offered by this sock condition. Therefore, similar to the findings of Tsai and Lin,[14] it is likely that gait adaptations observed when wearing standard socks represent a more cautious walking pattern owing to the minimal friction available between the slippery surface and the standard socks. Previous research indicates that reduced walking speeds and taking shorter steps are characteristic changes in gait observed in older people who adopt a conservative walking pattern to maintain balance.[14,26]

We also observed a trend toward greater horizontal heel velocity at heel strike when wearing standard socks compared with the barefoot and nonslip sock conditions, although this did not reach statistical significance. Previous research has shown that a greater heel velocity at heel strike is an indicator of increasing slipping motion of the foot.[11] The present data provide some indication of greater slip propensity at heel strike when wearing standard socks, but this finding needs to be verified in a larger study.

Foot-floor angle at heel strike was not significantly different between sock conditions; however, this angle trended toward being smaller when wearing standard socks relative to the barefoot and nonslip sock conditions. Greater foot-floor angles may, in part, be attributed to a greater degree of ankle dorsiflexion and, as such, leads to a reduced area of the heel contacting the ground at heel strike during walking. Therefore, it is possible that when wearing standard socks, participants may have stepped using a more flatfoot or toe strike strategy to increase the contact area and the amount of traction available between the plantar surface of the foot and floor during what was perceived to be the most slippery condition. A flatfoot contact may also be associated with a more stable position of the center of mass over the foot.

In the present study, there were few significant differences in any of the clinical and kinematic measures between the nonslip sock and barefoot conditions, likely owing to equivalent levels of slip resistance enabling similar gait patterns. These findings confirm those of Hübscher et al,[16] who reported that nonslip socks provide comparable levels of slip resistance as barefoot and greater resistance than standard socks or backless slippers, as evidenced by reduced heel deceleration. In the present study, we calculated horizontal heel velocity rather than heel deceleration, which has been shown to be associated with slip events in older people.[11,25]

The inclined ramp test results suggested that standing barefoot provided substantially greater slip resistance relative to nonslip and standard socks. However, these findings indicate that performance on the TUG test did not differ between the barefoot and nonslip sock conditions. It is possible that during static standing on a slope the slip resistance required to stay upright above a threshold angle of 30° (the lower incline of the two conditions at which upright stance could be maintained) might have been sufficient to undertake the TUG test without needing to modify gait parameters.

It is important to consider the frictional properties of different floor surfaces on which nonslip socks are tested. The present study investigated walking on a polished wooden surface, whereas Hübscher et al[16] used a linoleum walkway. However, both studies report promising evidence for the slip-resistant properties of nonslip socks during gait. In contrast, Chari et al[15] reported that the slip resistance of nonslip socks on a vinyl surface was poorer than the barefoot condition. However, in that study, slip resistance was assessed during static standing on an inclined ramp. The degree of traction between a floor surface and a sock may differ considerably during a dynamic task, such as walking, and on a level surface.

It has been suggested that wearing socks may dampen sensory information from the foot[16,27] relative to barefoot, thereby worsening walking performance. It is possible that nonslip socks have the capacity to bring gait patterns back to optimal barefoot levels in older people. It is also possible that the rubber grip components of the nonslip socks may have provided enhanced tactile stimulation to cutaneous mechanoreceptors on the soles of the feet, leading to alterations in gait. Other footwear interventions, such as textured insoles[28] with indentations that are proposed to stimulate plantar mechanoreceptors, have been shown to positively influence gait in older people.

As expected, the perceived degree of slipperiness was highest for standard socks. However, note that participants considered the nonslip sock to be less slippery than walking barefoot despite the slip threshold test indicating otherwise. It is possible that purely kinesthetic input from the nonslip rubber grip components on the soles of the feet, may have drawn participants' attention to their walking, leading them to feel more stable and to walk as confidently as when barefoot.

These findings need to be interpreted in the context of several limitations. First, heel strike during walking was identified based on the observation of heel marker positions and three-dimensional stick figures. Because we did not have a more objective indicator of heel strike, such as ground reaction forces or footswitch data, it is possible that these measures of horizontal heel velocity may have been underestimated. However, these findings suggest a trend toward greater horizontal heel velocity at heel strike with decreasing slip resistance, which concurs with previous research.[11] Second, the small sample size may have underpowered some of the tests. Missing data for one participant and the exclusion of one outlier in the kinematic data set may have further reduced the statistical power of these tests. Finally, although participants were instructed to walk as quickly as they could across the slippery surface, fear of slipping and falling, lack of motivation, and restricted movement while wearing the safety harness may have been limiting factors. Because we did not observe any slips or falls during the test procedures, this may further suggest that participants walked more cautiously during the study than would be expected in real-life conditions. Findings from this study may not extrapolate to other commercially available nonslip socks. It is possible that differences in the geometric pattern, distribution, or rubber material of grip components on nonslip socks may provide varying levels of slip resistance.

Conclusions

The findings from this study provide preliminary evidence that nonslip socks enhance gait and may have the capacity to reduce slip propensity in older people, particularly in those who walk slower in standard socks. Nonslip socks seem to provide comparable slip resistance as the barefoot condition and greater resistance than standard cotton socks. Based on these findings, barefoot or nonslip socks may be a safer footwear option than standard cotton socks for older people walking indoors on potentially slippery surfaces.

Acknowledgment: Mina Sarofim and Mikhail Sarofim for their assistance with data collection.

Financial Disclosure: This work was supported by an Endeavour Research Fellowship (Australia Awards) and Baroness Robson Travel Scholarship (Chartered Society of Physiotherapy) awarded to A.L.H. The study sponsors had no involvement in

the study design; the collection, analysis, and interpretation of data; the writing; or the submission of this manuscript.

Conflict of Interest: None reported.

References

1. Cumming RG, Klineberg RJ: Fall frequency and characteristics and the risk of hip fractures. J Am Geriatr Soc **42**, 774, 1994.
2. Nyberg L, Gustafson Y, Berggren D, et al: Falls leading to femoral neck fractures in lucid older people. J Am Geriatr Soc **44**, 156, 1996.
3. Norton R, Campbell J, Lee-Joe T, et al: Circumstances of falls resulting in hip fractures among older people. J Am Geriatr Soc **45**, 1108, 1997.
4. Berg WR, Alessio HM, Mills EM, et al: Circumstances and consequences of falls in independent community dwelling older adults. Age Ageing **26:** 261, 1997.
5. Niino N, Tsuzuku S, Ando F, et al: Frequencies and circumstances of falls in the National Institute for Longevity Sciences, Longitudinal Study of Aging. J Epidemiol **10:** S90, 2000.
6. Menant JC, Steele JR, Menz HB, et al: Effects of walking surfaces and footwear on temporo-spatial gait parameters in young and older people. Gait Posture **29:** 392, 2009.
7. Menant JC, Steele JR, Menz HB, et al: Optimizing footwear for older people at risk of falls. J Rehabil Res Dev **45:** 1167, 2008.
8. Menz HB, Lord SR, McIntosh AS: Slip resistance of casual footwear: implications for falls in older adults. Gerontology **47:** 145, 2001.
9. Menz HB, Morris ME: Footwear characteristics and foot problems in older people. Gerontology **51:** 346, 2005.
10. Menz HB, Morris ME, Lord SR: Footwear characteristics and risk of indoor and outdoor falls in older people. Gerontology **52:** 174, 2006.
11. Cham R, Redfern MS: Heel contact dynamics during slip events on level and inclined surfaces. Safety Sci **40:** 559, 2002.
12. Lockhart TE, Spaulding JM, Park SH: Age-related slip avoidance strategy while walking over a known slippery floor surface. Gait Posture **26:** 142, 2007.
13. Tang PF, Woollacott MH: Inefficient postural responses to unexpected slips during walking in older adults. J Gerontol A Biol Sci Med Sci **53:** M471, 1998.
14. Tsai YJ, Lin SI: Older adults adopted more cautious gait patterns when walking in socks than barefoot. Gait Posture **37:** 88, 2013.
15. Chari S, Haines T, Varghese P, et al: Are non-slip socks really “non-slip”? an analysis of slip resistance. BMC Geriatr **9:** 39, 2009.
16. Hübscher M, Thiel C, Schmidt J, et al: Slip resistance of non-slip socks: an accelerometer-based approach. Gait Posture **33:** 740, 2011.
17. Lockhart TE, Smith JL, Woldstad JC: Effects of aging on the biomechanics of slips and falls. Hum Factors **47:** 708, 2005.
18. Folstein M, Folstein S, McHugh P: “Mini-mental state”: a practical method for grading the cognitive state of participants for the clinician. J Psychiatr Res **12:** 189, 1975.
19. Podsiadlo D, Richardson S: The timed “Up & Go”: a test of basic functional mobility for frail elderly persons. J Am Geriatr Soc **39:** 142, 1991.
20. Arnold CM, Faulkner RA: The history of falls and the association of the timed up and go test to falls and near-falls in older adults with hip osteoarthritis. BMC Geriatr **7:** 17, 2007.
21. Aslan UB, Cavlak U, Yagci N, et al: Balance performance, aging and falling: a comparative study based on a Turkish sample. Arch Gerontol Geriatr **46:** 283, 2008.
22. Sai AJ, Gallagher JC, Smith LM, et al: Fall predictors in the community dwelling elderly: a cross sectional and prospective cohort study. J Musculoskelet Neuronal Interact **10:** 142, 2010.
23. Standards Australia: *Slip Resistance Classifications of New Pedestrian Surface Materials AS/NZS 4586:2004*, Standards Australia, Sydney, 2004.
24. Cham R, Redfern MS: Changes in gait when anticipating slippery floors. Gait Posture **15**, 2002.
25. Moyer BE, Chambers AJ, Redfern MS, et al: Gait parameters as predictors of slip severity in younger and older adults. Ergonomics **49:** 329, 2006.
26. Menz HB, Lord SR, Fitzpatrick R: Age-related differences in walking stability. Age Ageing **32:** 137, 2003.
27. Davids K, Shuttleworth R, Button C, et al: “Essential noise”: enhancing variability of informational constraints benefits movement control: a comment on Waddington and Adams (2003). Br J Sports Med **38:** 601, 2004.
28. Hatton AL, Dixon J, Rome K, et al: Altering gait by way of stimulation of the plantar surface of the foot: the immediate effects of wearing textured insoles in older fallers. J Foot Ankle Res **5:** 11, 2012.