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Effects of Slipper Features and Properties on Walking and Sit-to-Stand Tasks of Older Women

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Indoor slippers with a strap across the dorsal forefoot are popular with older women. However, their influence on the foot motion has not been reported. This study evaluated the range of movement in the knee and ankle joints during walking and changes in trunk displacement during sit-to-stand when 10 healthy older women wore two types of slippers and were barefoot. Compared to barefeet, walking in slippers results in significant increases in the knee flexion angle in the swing phase. However, there is nonsignificant differences in the ankle angle in any phase across all conditions. During the sit-stand transition when slippers are worn, there is a significant reduction in the peak trunk tilt angle and range, as well as the duration of the weight shift when motion is initiated. The findings therefore provide a better understanding of slipper features and designs associated with changes in foot kinematics in older women.

Keywords: foot kinematics, trunk orientation, sit-stand transition, dynamic motion, footwear design

Slip-on slippers that have a strap across the dorsal forefoot are popular as indoor footwear, especially for older women because they are flexible, convenient, and non- restricting. Nonetheless, the mule design of slippers, which does not have any form of fixation or stabilization around the heel or sole area, also fail to control heel motions and maintain gait stability (Yick, Tse, Lo, Ng, & Yip, 2016). The absence of these key structural features of slippers may lead to slipping of the foot and therefore high risks of falls (Menz & Morris, 2005). Footwear characteristics, such as hardness, weight, sole thickness, and heel height change the foot motion and gait during walking (Morio, 2009; Schulze et al., 2014; Shakoor, 2010), and also contribute to changes in the plantar pressure and dynamic balance, which lead to increased muscle activity during locomotion, and potentially increase the risks of fatigue and falling (Lord, 1999; Menz, Lord, & McIntosh, 2001; Robbins, Gouw, & McClaran, 1992). However, there has been a scarcity of scientific work that offers a comfortable and safe footwear solution for older people that can be worn at home.

As gait performance declines with age, older individuals often have a slower walking speed, shorter and wider stride length, as well as lower joint power in the lower limb (Devita & Hortobagyi, 2000; Hageman & Blanke, 1986; Ostrosky, VanSwearingen, Burdett, & Gee, 1994; Stief et al., 2016). They also move more slowly or experience difficulties when carrying out various activities, such as walking a straight line, presumably because of musculoskeletal and postural control challenges (Buckley, Pitsikoulis, Barthelemy, & Hass, 2008; Cromwell & Newton, 2004; Kim & Yoo, 2014). Previous studies have reported that there is a reduced range of motion in the ankle and first metatarsophalangeal joints with increased age (James, 1989; Scott, Menz, & Newcombe, 2006), whilst reduced strength of the ankle and hallux plantar flexor muscles may affect balance and locomotion performances (da Silva Homem et al., 2016; Mecagni, Smith, Roberts, O'Sullivan, 2000; Spink et al., 2011). Even though previous research has recommended that improvements in the motion control properties of footwear are crucial in the design and development of geriatric indoor footwear (Byrne & Curran, 1998; Hall & Nester, 2004), to the best of our knowledge, kinematical studies on slippers with different design features compared to a barefoot condition in older people are very scarce. Amongst the different types of human physical configurations, the ability to stand up after sitting (i.e., sit-to-stand [STS]), which is an essential prerequisite for walking, is one of the most fundamental and frequent motions in maintaining the independence of elderly persons. There are important elements in natural rising from a seated position. The base of support is narrowed in the seated position, and there is the forward shifting of the trunk. The center of gravity also shifts forward to a base of support that comprised the feet. Finally, there is an upward shifting of the center of gravity due to the extension of the knee and hip joints (Tully, Fotoohabadi, & Galea, 2005; Vander Linden, Brunt, & Mcculloch, 1994). The shifting in the trunk and center of gravity can greatly alter balance during different postural transition phases and the reason why STS requires good coordination of muscle activity to achieve postural stability. With age-related reductions in the physical mobility of older adults, decreased motor control ability exerts greater impacts on STS postures (Arnold, Lanovaz, Oates, Craven, & Butcher, 2015; Mazza, Benvenuti, Bimbi, & Stanhope, 2004; Millington, Myklebust, & Shambes, 1992). A previous study (Ganea, Paraschiv-Ionescu, Büla, Rochat, & Aminian, 2011) showed that older frail persons have significantly reduced smoothness and stability to rise from a chair, which may contribute to a greater degree of trunk tilt and higher risks of falling. The trunk displacement in the mediolateral plane and weight-bearing asymmetry were also observed during the STS transition (Lecours, Nadeau, Gravel, & Teixera-Salmela, 2008; Roy et al., 2006). Besides, the anterior- posterior and mediolateral postural sway were significantly affect- ed by the hardness of the insole during standing after the entire transition took place (Qiu et al., 2012). However, the effects of slippers on the trunk kinematics during STS posture remain unclear. Understanding the impacts of slippers on the range of joint motion will help to identify at which point during a task when the concerned individual has less stability, and may provide warning signs of the potential of falling during the task. A better understanding will also have great importance when it comes to material consideration and design of indoor slippers for older people.

Therefore, one of the goals of this study is to evaluate the effects of two typical kinds of open-toe slippers without a heel counter on range of motion of the knee and ankle joints at critical gait events in older adults, as compared to barefoot walking. Another goal is to determine whether different footwear conditions have any impact on the orientation of the mediolateral trunk and trunk tilt during the STS transition. We hypothesize that (1) walking in open-heel slippers would alter the range of motion of the knees and ankles due to lack of fixation, especially during the swing phase; (2) slippers with a more rigid footbed would induce smaller mediolateral displacements of the trunk; and (3) slippers would alter the duration of any of the phases during the STS transition.

Methods

Participants

Ten healthy females between the ages of 60 and 67 years (mean: 62.85; SD: 2.81) were recruited for this study. Their body mass index (BMI) ranged from 20.41 to 28.62 kg/m^2 (mean: 23.40; SD: 2.67). Their foot size ranges from a European size 35 to 38. Prior to participation in the study, each subject received a foot and gait assessment provided by the same physiotherapist to determine that they have healthy feet with good feet sensitivity, the ability to walk unaided for 10 m, and a normal balance and gait performance. Those with any current or history of major foot pain, deformities, or orthopedic or neurological problems in the lower limbs were excluded. This study was approved by the Human Subjects Ethics Sub-committee of the Research Committee, and all of the participants gave their informed written consent to participate in the study.

Footwear

Three conditions were evaluated: barefoot and with the use of two types of slippers – hard and soft. The style of the slippers selected is a popular type of indoor footwear worn by local older adults (Figure 1), which is typically open-toe, and secured to the foot with a strap across the dorsal forefoot. Their physical properties are shown in Table 1

Figure 1 — Slippers used during wear trials (left: soft slipper; right: hard slipper).

Table 1 Physical Property of Soft and Hard Slippers

	Soft Slipper	Hard Slipper
Shoe size range (mm)	220–245	220–245
Weight range (g)	58.01–60.64	186.99–215.34
Strap girth (mm)	212–218	217–233
Thickness under heel (mm)	21.1	18.8
Hardness (Shore A) ASTM D 2240	20	32
Coefficient of friction	0.69	0.78
Compression (kPa) ISO 3386-1	1607	13713
Force reduction (%) ASTM D 2632	70.1	54.2
Bending stiffness (N mm)	55.02	22.23

Experimental Protocol

The experiment involved two components as shown in Figure 2; one in which the participants had to walk, and another in which they had to perform an STS task. In each component, the participants were asked to walk in their bare feet and then walk after donning two types of common indoor slippers (soft and hard). The sequence of the three conditions (barefoot, soft slippers, and hard slippers) was counter- balanced to minimize potential order effects. A 12-camera motion capture system (Motion Analysis Eagle System, CA, USA) was used to record and analyze the motion of the lower limbs during walking and the STS movement. The sampling rate was 60 Hz. The data were processed by using a second-order Butterworth filter with a cut-off frequency of 6 Hz, and time normalized to 100% of the stance phase. The participants were required to change into tight-fitting clothes. Twenty-nine retroflective markers were placed bilaterally over the bony landmarks of the body (Figure 3) and one marker was placed at the back of each slipper heel.

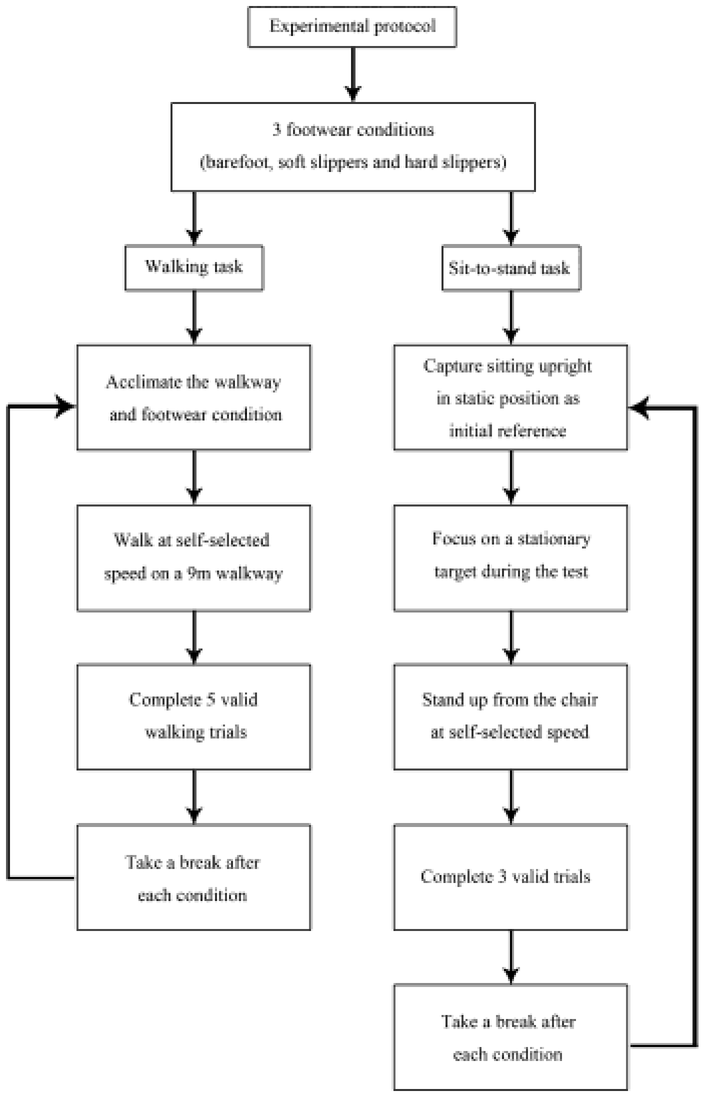


Figure 2 — Wear trial flow chart.

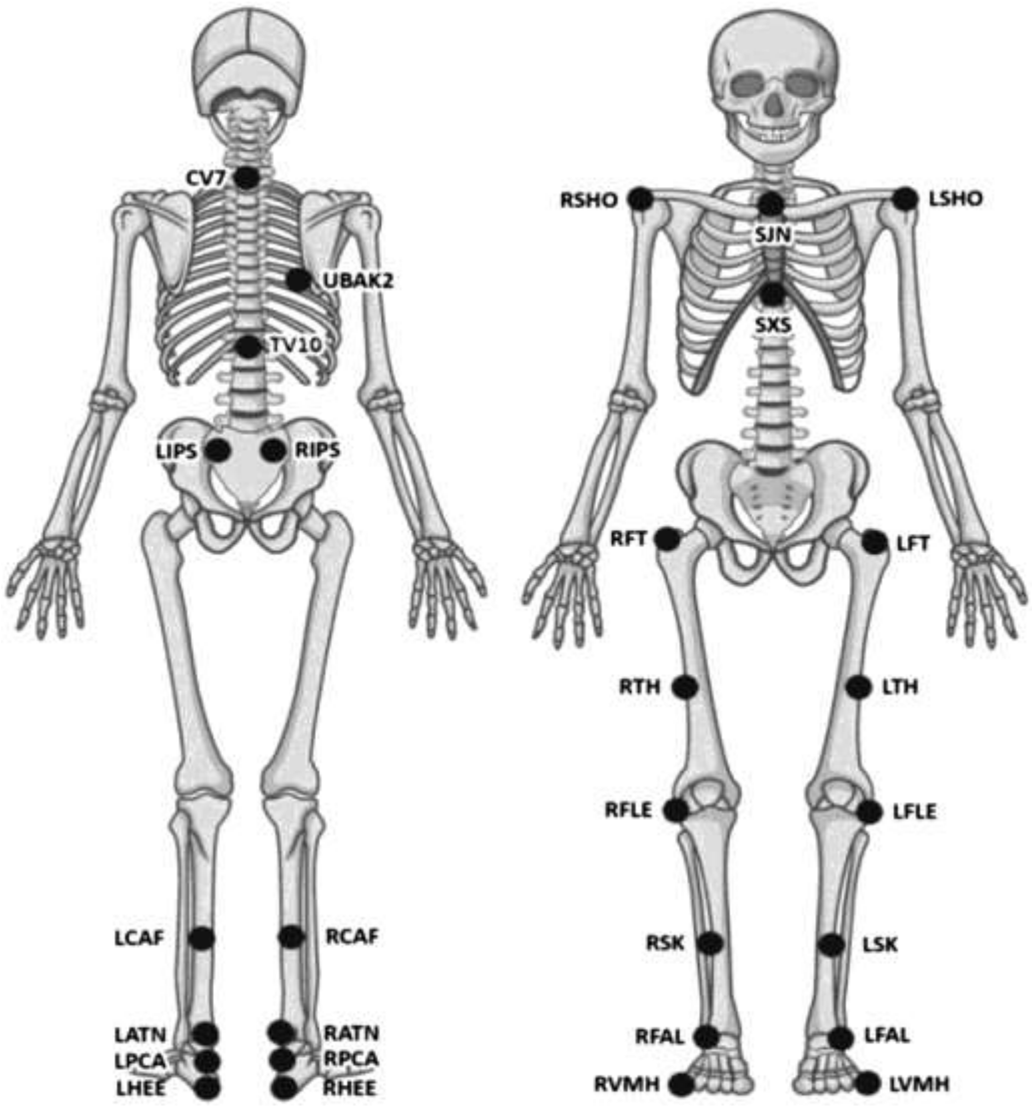
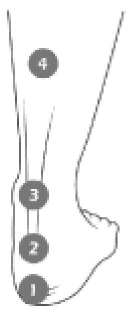


Figure 3 — Marker placement on human body.

In the walking component of the experiment, the participants were asked to first walk at a comfortable self- selected speed on a 9- m walkway. The average self- selected speed was then recorded for each subject, which is 3.17 km/h (SD: 0.48), and ranges from 3.03 to 3.29 km/h. The trials were acceptable if the measured speed was within 5% of the target speed to minimize the effects of different walking speeds. In each test condition, the participants were given a 5-min acclimatization period to walk along the pathway and familiarize themselves with the surroundings and footwear conditions. They were then instructed to complete five valid walking trials. The range of motion of the ankle and knee of the dominant leg was reported at critical gait events. To estimate the amount of foot pronation-supination, the rearfoot angle was calculated because this angle is relatively independent from motions in other joints, and thus less prone to error (Cheung & Ng, 2007). Markers 1 and 2 formed a vector from the foot segment and markers 3 and 4 formed another vector representing the lower leg segment (Figure 4). The rearfoot angle is defined as the acute intercepting angle between these two vectors with Equation (1).



Marker 1: Center of heel cap

Marker 2: Center of heel cap at the insertion of the Achilles tendon

Marker 3: Center of the Achilles tendon at the height of medial malleolus

Marker 4: 15 cm above Marker 3 at the center of the leg

Figure 4 — Location of markers.

$$Rear\ foot\ angle = \cos^{-1}\left(\frac{\overrightarrow{M_2M_1}\cdot\overrightarrow{M_3M_4}}{|\overrightarrow{M_2M_1}|\times|\overrightarrow{M_3M_4}|}\right) \qquad (1)$$

In the STS task, the participants were instructed to stand up from an armless, backless, and height-adjustable chair at their own self-selected speed and with their arms hanging by their sides without touching the chair. The starting position before each trial was standardized by adjusting the chair so that a 90° angle was symmetrically formed between the thigh, shank, and the foot. They were instructed not to move their feet during testing and keep their eyes focused on a stationary target. They were also instructed to begin the task after the command “ready, start, stand”. They practiced the task several times prior to the actual data collection until, visually, their performance appeared to be smoothly executed. Three successful trials were recorded. A trial was considered unsuccessful if the participants moved their feet or touched the chair with their arms. The trunk segment, with representation of the sagittal plane, was initially defined by five markers: CV7, T10, RIPS, LIPS and SIN. The initial reference was captured with the subject sitting upright at static position for 5 s. The local coordination system (as reference as trunk segment) was then calculated and defined by averaging the segment data of the 5 s. During STS transition, the trunk segment is flexed and extended with respect to the trunk tilt; while the trunk segment is medial and lateral bended with respect to mediolateral displacement (Figure 5). The examination of mediolateral displacement of the trunk is shown in Figure 6 in red color.

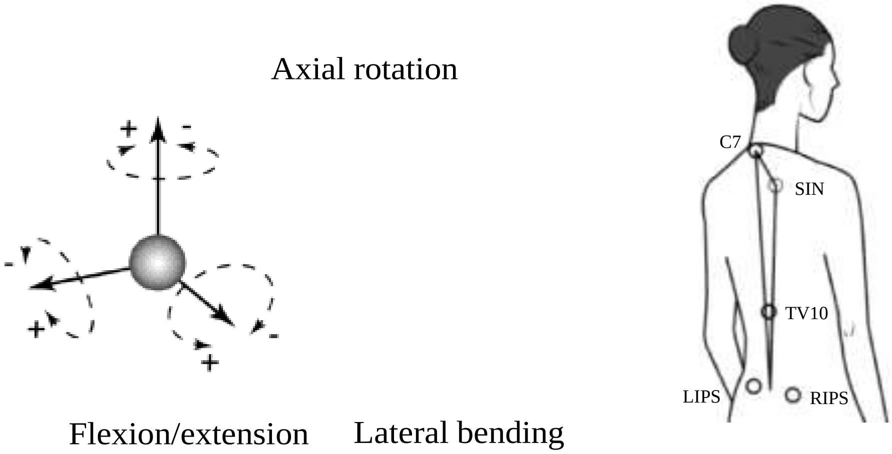


Figure 5 — Illustration of rotation on trunk segment.

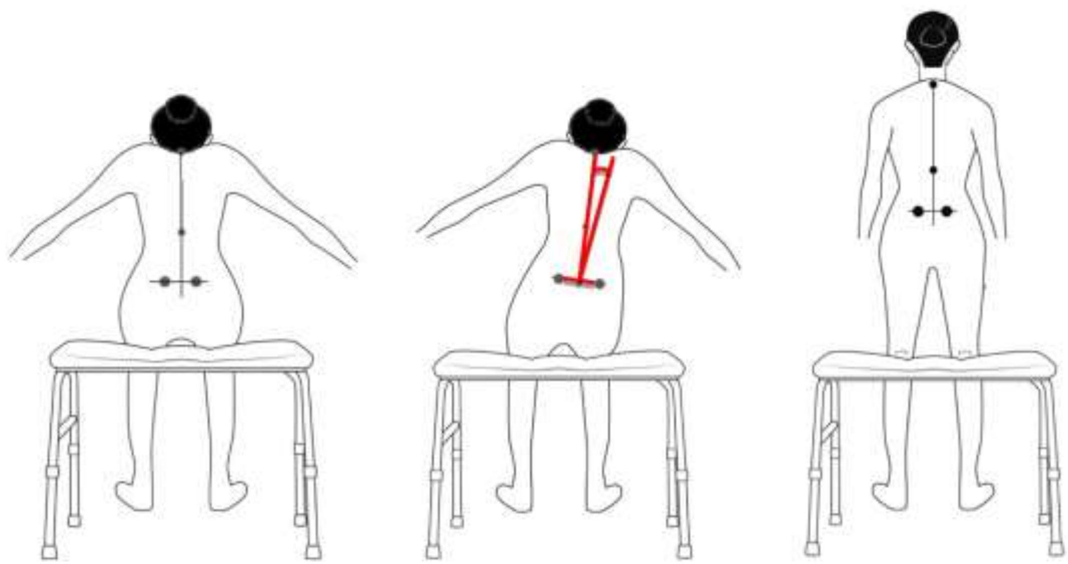


Figure 6 — Schematic diagram of subject performing sit-to-stand (STS) task. Dashed line connects markers on spine (CV7, TV10, left and right of the posterior iliac spine) to illustrate orientation of trunk.

The STS task was then further divided into three phases from the kinematic data as shown in Figure 7 (Millington et al., 1992): phases I, II and III. In Phase I, there is a weight shift, which begins at the first discernible trunk flexion (more than 0.05° in one frame of motion) and pelvis rotation, and continues until knee extension is initiated. Phase II is the transition, which begins with the initiation of knee extension (more than 0.05° in one frame of motion) and ends with reverse trunk flexion to trunk extension. The transition from shifting the weight of the body forward to lifting the body upwards takes place. Phase III is lifting, which begins with reverse trunk motion to trunk extension. Full extension to the standing position is achieved. The start and finish times of the STS task were determined based on the joint angle deviation (3 degrees) with respect to the stationary initial and final joint angles, respectively. In addition, the percentage of motion and trunk tilt (Figure 8 and Equations 2–

4) during the STS task was also analyzed. A 3-min rest period with the slippers taken off was provided in each phase of the task to reduce potential muscle fatigue effects (Cram, 1998).

$$Peak\ angle = \mathrm{MAX}[(\mathrm{SGP}_{\mathrm{tilt}})_i]\ with\ i \in [0 \ldots N-1] \quad (2)$$

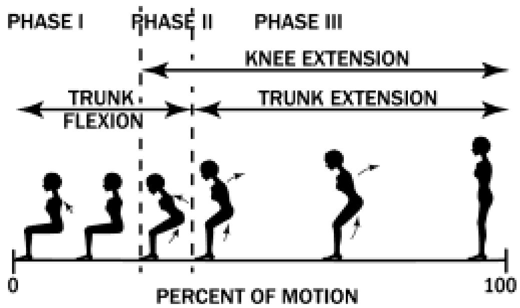


Figure 7 — Three phases of sit-to-stand (STS) transition.

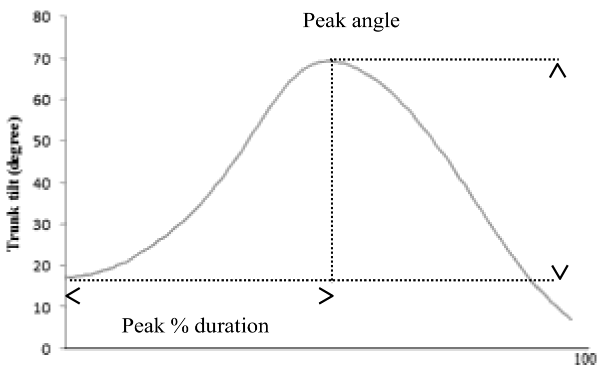


Figure 8 — Kinematic features of a sit-to-stand (STS) transition.

where N is the number of frames of an STS transition and SGP is the trunk segment.

$$Peak\ \%\ duration = \frac{d}{N} \cdot 100\% \quad (3)$$

where d is the frame instance with data points at peak angle.

$$Range = \mathrm{MAX}[(\mathrm{SGP}_{\mathrm{tilt}})_i] - (\mathrm{SGP}_{\mathrm{tilt}})_0\ with\ i \in [0 \ldots N-1] \quad (4)$$

where N is the number of frames of an STS transition and SGP is the trunk segment.

Statistical Analysis

The Statistical Package for the Social Sciences (SPSS) Version 17.0 (SPSS Inc., Chicago, IL) was used for the statistical analysis. A one-way repeated measure analysis of variance (ANOVA) was performed to assess the effects of the different footwear conditions on the range of motion of the joints and rearfoot angle during walking, as well as the orientation of the trunk and trunk tilt during STS motion. Bonferroni-adjusted post hoc tests were subsequently used to compare the measurements between each of the conditions. The alpha level was set at the conventional level of .05.

Results

Walking Task

Table 2 lists the parameters of the joint motion of the knee and ankle of the dominant leg during walking in different footwear conditions. It can be observed that there is a significant difference ($p < .05$) in knee flexion and rearfoot angle in the swing phase amongst the three footwear conditions. The results of the Bonferroni pair-wise comparison show that wearing hard slippers leads to increased knee flexion ($p < .05$) as compared to the barefoot condition during swing. When wearing a soft slipper, the rearfoot angle is significantly larger ($p < .05$) than that in a barefoot condition during foot swing. There is no significant difference between the stride length and ankle joint angle in any of the phases amongst the different footwear conditions.

Table 2 Joint Motion Parameters of Dominant Leg During Walking in Different Footwear Conditions, Mean (SD) (N = 10)

	Barefoot	Soft Slippers	Hard Slippers
Stride length (normalized to body height)	0.68 (0.1)	0.70 (0.1)	0.70 (0.1)
Joint motion (in degree)			
Knee flexion at early stance	11.1 (4.7)	8.9 (3.7)	10.4 (5.2)
Knee flexion at preswing	47.1 (3.9)	51.7 (4.5)	51.1 (5.2)
Knee flexion in swing*	57.5 (3.9)	60.4 (4.2)	61.3 (4.7)**
Ankle dorsiflexion at early stance	12.3 (3.1)	12.0 (3.0)	12.1 (3.6)
Ankle plantar flexion at preswing	−21.9 (3.7)	−17.4 (3.9)	−18.2 (7.4)
Ankle dorsiflexion in swing	1.2 (4.8)	0.2 (4.9)	0.1 (5.7)
Rearfoot angle in midstance phase	28.7 (7.4)	30.0 (6.2)	30.5 (7.3)
Rearfoot angle in swing phase*	32.2 (5.2)	29.6 (6.6)#	32.1 (7.2)+

*Significant differences among footwear conditions; #significant differences between barefoot and soft slippers; ** significant differences between barefoot and hard slippers; + = significant differences between soft slipper and hard slipper.

Sit-to-Stand Task

Two participants with missing data showed different outcomes from those who were able to provide all of the required data. To reduce the risk of bias in the results of the individual trials, the data of these two participants were excluded in the STS analysis. With reference to Table 3 and Figure 9, a significant difference is found in the peak trunk tilt angle and range across the three conditions. In the pair-wise comparison, the use of hard slippers leads to a significantly reduced peak trunk tilt angle and range. Regarding the percentage of motion (Table 3), there is a significant difference in phase I amongst the barefoot and slipper conditions, of which wearing slippers results in less time in which the weight shifting occurs (phase I percentage of motion) as opposed to the barefoot condition. Besides, as shown in Figure 10, the average time used to complete the motion in both phase I and phase III is somewhat similar in all conditions. The transition phase (phase II) is notice- ably short as well in each condition. The mean duration of barefoot condition is shorter and has the standard deviation of lower value as compared to other conditions, though not statistically significant. The time used to complete the entire motion and the mediolateral displacement of the trunk between the three experimental conditions does not reach statistical significance.

Table 3 Data on Trunk for STS (Mean [SD]) (N = 8)

	Barefoot	Soft Slippers	Hard Slippers
Time duration (s)	109 (11.4)	110 (14.3)	111 (13.7)
Trunk displacement			
Mediolateral angle (°)	2.4 (4.0)	2.4 (6.0)	1.6 (5.1)
Trunk tilt			
Peak angle (°)*	53.2 (5.6)	48.5 (4.3)	47.9 (4.6)+
Peak % duration	47.7 (5.3)	43.2 (4.4)	43.5 (5.0)
Range (°)*	44.2 (3.9)	39.0 (4.0)	39.3 (4.5)+
Percentage of motion			
Phase I*	47.0 (7.9)	42.6 (7.5)#	42.3 (5.2)+
Phase II	5.1 (2.7)	6.6 (4.6)	6.4 (4.5)
Phase III	52.3 (5.3)	56.8 (4.4)	56.5 (5.0)

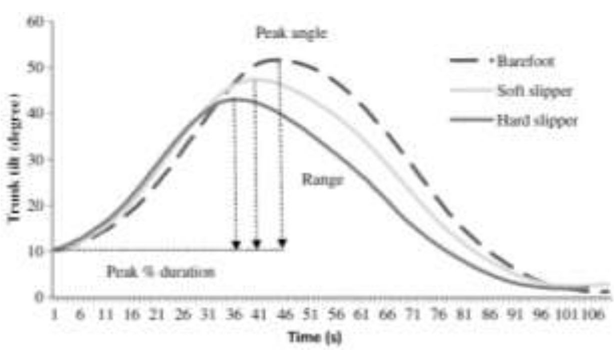


Figure 9 — Trunk tilt for sit-to-stand (STS) task. Trunk data extracted from a single trial as an example of one test subject in three footwear conditions.

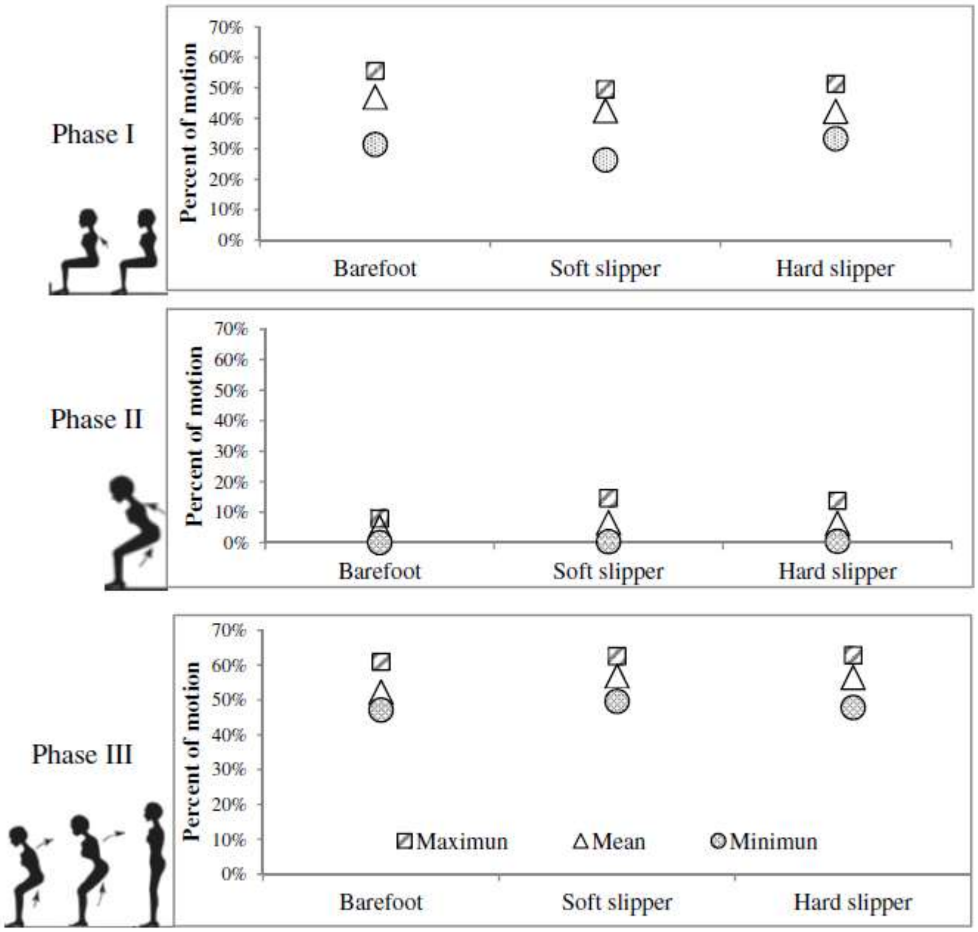


Figure 10 — The maximum, mean, and minimum value of each phase during the sit-to-stand (STS) task.

Discussion

Evaluation of the kinematic effects of indoor slippers is crucial for older adults as many older people spend most of their time at home. Therefore, in this study, the effects of two kinds of typical open-toe slippers without a heel counter during two basic daily activities are examined in a group of healthy older subjects: walking and STS transition. The results support the hypothesis that wearing slippers will alter the joint motions of the knees during walking and the duration of the STS movement when compared to the barefoot condition. However, no significant difference is found in the ankle joint angle at any phase of the walking or in the mediolateral displacement of the trunk during the STS transition when slippers are worn.

Walking in slippers probably alters gait because they are an additional mass to the body. The knee flexion angle tends to be greater with the use of slippers in the swing phase. The weight of the footwear may cause an increase in distal mass, thus producing a pendulum-lengthening effect on the leg, and resulting in increased inertia during the swing phase (Majumdar et al., 2006; Oeffinger et al., 1999). Hence, wearing slippers tends to result in a larger knee flexion angle in swing. In addition to the weight, walking in slippers with a harder footbed, i.e., hard slippers, induced a significantly larger knee flexion angle in the swing phase versus a barefoot condition. One possible reason is for foot clearance so as to prevent tripping (Greene & Granat, 2000; Judge, Davis, & Ounpuu, 1996; Yick et al., 2016). In fact, knee flexion alone is not sufficient enough for ground clearance, and reaching maximum dorsiflexion during swing is essential for providing sufficient ground clearance to reduce trips and falls during walking (Begg, Best, Dell'Oro, & Taylor, 2007; Greene & Granat, 2000; Nagano, Begg, Sparrow, & Taylor, 2011). This is especially important in older people to prevent their slippers from falling off from their feet, or coming unsecured during walking due to the absence of a heel counter. It is interesting that a shuffling gait was observed when the subjects were walking in their slippers. At the moment just before the heel strike, the participants swung their feet past the floor and then drew the heels to the floor. This might be due to insufficient fixation as the heel counter is absent, and therefore there is the tendency for the participants to drag their feet to reduce ground clearance and keep the slippers on (Yick et al., 2016). This dragging impairs normal gait which leads to unusual stresses and predispositions to trips and falls (Menant, Steele, Menz, & Munro, 2008; Shroyer & Weimar, 2010). However, no significant difference is found in the ankle dorsiflexion angle during swing amongst the different footwear conditions. It is possible that this could have been a statistical type II error in that the current subject pool size is unable to attain sufficient statistical power. Besides, the results revealed that these older adults had a smaller rearfoot angle (less pronated) when wearing soft slippers than hard slippers or when barefoot. With the soft slippers, rearfoot angle was reduced by around 3°. One possible explanation for this may be the softer footbed material of the soft slippers which offer higher compressibility than other footwear conditions. The older adults may have altered their muscular activity to the footwear with different footbed hardness.

The STS movement was divided into three phases to better characterize the knee and truck motions during the transition from sitting in a standard chair to a standing position. Phase I involved the weight shifting of the subject, which is characterized by the flexion of the trunk, thus resulting in a forward lean and change in the center of mass. The time taken to shift the weight is noticeably shorter when slippers are worn in comparison to bare feet. During phase I, the projection of the center of mass of the body is shifted from the initial base of support (the chair) to the new base of support (feet on the floor). The center of mass is moved anteriorly and upwardly, and the area of support may be moderately reduced while the load imposed on the feet may become greater. The presence of slippers probably increases the foot contact surface area for weight bearing and broadening the base of support. The ground reaction force is spread over a larger plantar region, thereby altering somatosensory feedback from the sole of the foot (Menz & Lord, 1999), and thus enhancing postural stability to prepare for the weight shift for standing. Phase II is the transition phase, in which the center of mass changes in the forward motion to an upward motion, with shifting the weight forward over the feet. In phase III, there is lifting, in which trunk extension starts and knee extension continues until a full standing position is reached. Although wearing slippers results in faster motions in both phases II and III versus in the barefoot condition, the influence of the footwear is not significant.

Besides, wearing slippers tends to reduce the peak trunk tilt angle, peak percent duration, and range of trunk tilt when the trunk is moving upward and forward during the STS transition. It is postulated that the reduced peak trunk tilt angle and range are more obvious after wearing hard slippers. When wearing slippers with a harder footbed, the dynamic postural stability tends to be improved (Qu, 2015), which is essential for preventing lateral falls during movement, especially when the buttocks begin to lift off from the seat of the chair (Maki & McIlroy, 1996; Schenkman, Berger, Riley, Mann, & Hodge, 1990). There is a relatively high tendency to fall at gait initiation as it requires a complex synergy of muscular movement (Henriksson & Hirschfeld, 2005), such as after rising from a chair and changing posture. As elderly people have age- related reduction of muscle activity, they are likely to have weak balance control when changing positions in an STS movement. The present findings therefore provide insights on slipper design that would improve postural stability with changes in position. Al- though no significant difference in the mediolateral displacement of the trunk amongst the footwear conditions was found, yet all of the participants tend to tilt towards their right side (dominant foot side) when rising from an STS posture, which implies that the body weight is shifting to the dominant side during the posture transition.

The study has certain limitations. The sample size of the subjects in our study is relatively small, which may limit the generalizability of the results. Nonetheless, the study provides preliminary evidence that wearing slippers can alter kinematic patterns during walking and sit-to-stand tasks, thereby providing the basis for future studies to optimize the design of indoor footwear for older adults. Besides, the participants in the current study are 60–67 years old and of Asian origin; as such, the results may only be valid for this population of older Asian women. Hence, future work could take into consideration for another population of older individuals and use lower limb electromyography to provide critical insights on the coordination of the muscles and activity of the lower leg musculatures in different conditions associated with different ranges of joint motion.

Conclusion

This research explores the kinematic differences in older adults amongst three conditions: wearing of hard and soft slippers and in their bare feet, when walking and during the STS transition. The results show that walking in slippers with a heavy and a hard footbed is an additional burden which may increase knee flexion during swing. Yet hard slippers tend to enhance postural stability during the STS transition. Besides, wearing slippers when rising from a chair enhances stability which results in shortening the duration of weight shifting. Walking and getting up from a chair are important daily activities of older people, and therefore these findings enhance our understanding of slipper features that are associated with changes in foot kinematics in older women, and provide the basis for indoor slipper designs that would enhance postural stability in older people.

References

Arnold, C., Lanovaz, J., Oates, A., Craven, B., & Butcher, S. (2015). The effect of adding core stability training to a standard balance exercise program on sit to stand performance in older adults: a pilot study. *Journal of Aging and Physical Activity*, *23*, 95–102. PubMed doi:10. 1123/JAPA.2013-0115

Begg, R., Best, R., Dell'Oro, L., & Taylor, S. (2007). Minimum foot clearance during walking: strategies for the minimisation of trip- related falls. *Gait and Posture, 25*, 191–198. PubMed doi:10.1016/ j.gaitpost.2006.03.008

Buckley, T., Pitsikoulis, C., Barthelemy, E., & Hass, C.J. (2008). Age impairs sit-to-walk motor performance. *Journal of Biomechanics, 42,* 2318–2322. PubMed doi:10.1016/j.jbiomech.2009.06.023

Byrne, M., & Curran, M.J. (1998). The development and use of a footwear assessment score in comparing the fit of children's shoes. *The Foot, 8*, 215–218. doi:10.1016/S0958-2592(98)90032-3

Cheung, R.T., & Ng, G.Y. (2007). Efficacy of motion control shoes for reducing excessive rearfoot motion in fatigued runners. *Physical Therapy in Sport, 8,* 75–81. doi:10.1016/j.ptsp.2006.12.002

Cram, J. (1998). *Introduction to surface electromyography*. Maryland, MD: Aspen Publishers.

Cromwell, R.L., & Newton, R.A. (2004). Relationship between balance and gait stability in healthy older adults. *Journal of Aging and Physical Activity, 12,* 90–100. PubMed doi:10.1123/japa.12.1.90

da Silva Homem, T., Guimarães, F.S., Dos Santos Soares, M., de Pinho, L.K., Gadelha, M.R., & Lopes, A.J. (2016). Balance control and peripheral muscle function in aging: a comparison between individuals with acromegaly and healthy subjects. *Journal of Aging and Physical Activity, 25*(2), 218–227. PubMed doi:10.1123/japa.2016-0100

Devita, P., & Hortobagyi, T. (2000). Age causes a redistribution of joint torques and powers during gait. *Journal of Applied Physiology, 88,* 1804–1811. PubMed

Ganea, R., Paraschiv-Ionescu, A., Büla, C., Rochat, S., & Aminian, K. (2011). Multi-parametric evaluation of sit-to-stand and stand-to-sit transitions in elderly people. *Medical Engineering and Physics, 33,* 1086–1093. PubMed doi:10.1016/j.medengphy.2011.04.015

Greene, P.J., & Granat, M.H. (2000). The effects of knee and ankle flexion on ground clearance in paraplegic gait. *Clinical Biomechanics, 15*, 536–540. PubMed doi:10.1016/S0268-0033(00)00008-5

Hageman, P.A., & Blanke, D.J. (1986). Comparison of gait of young women and elderly women. *Physical Therapy, 66,* 1382–1387. PubMed doi:10.1093/ptj/66.9.1382

Hall, C., & Nester, C.J. (2004). Sagittal plane compensations for artificially induced limitation of the first metatarsophalangeal joint: a preliminary study. *Journal of the American Podiatric Medical Association, 94,* 269–274. PubMed doi:10.7547/0940269

Henriksson, M., & Hirschfeld, H. (2005). Physically active older adults display alterations in gait initiation. *Gait and Posture, 21*, 289–296. PubMed doi:10.1016/j.gaitpost.2004.03.001

James, B. (1989). Active and passive mobility of lower limb joints in elderly men and women. *American Journal of Physical Medicine and Rehabilitation, 68*, 162–167. PubMed doi:10.1097/00002060- 198908000-00002

Judge, J.O., Davis, R.B., & Ounpuu, S. (1996). Step length reductions in advanced age: the role of ankle and hip kinetics. *The Journals of Gerontology. Series A, Biological Sciences and Medical Sciences, 51*, M303–M312. PubMed doi:10.1093/gerona/51A.6.M303

Kim, M.H., & Yoo, W.G. (2014). Comparison of center of force trajectory during sit-to-stand movements performed by elderly and old-old elderly subjects. *Journal of Physical Therapy Science, 26*, 1403– 1404. PubMed doi:10.1589/jpts.26.1403

Lecours, J., Nadeau, S., Gravel, D., & Teixera-Salmela, L. (2008). Interactions between foot placement, trunk frontal position, weight-bearing and knee moment asymmetry at seat off during rising from a chair in healthy and hemiparetic persons. *Journal of Rehabili- tation Medicine, 40*, 200–207. PubMed doi:10.2340/16501977-0155

Lord, S. (1999). Effects of shoe collar height and sole hardness on balance in older women. *The Journal of the American Medical Association, 47*(6), 681–684. doi:10.1111/j.1532-5415.1999.tb01589.x

Majumdar, D., Banerjee, P.K., Majumdar, D., Pal, M., Kumar, R., & Selvamurthy, W. (2006). Temporal spatial parameters of gait with barefoot, bathroom slippers and military boot. *Indian Journal of Physiology and Pharmacology, 50*, 33–40. PubMed

Maki, B.E., & McIlroy, W.E. (1996). Postural control in the older adult. *Clinics in Geriatric Medicine, 12*, 635–658. PubMed

Mazza, C., Benvenuti, F., Bimbi, C., & Stanhope, S.J. (2004). Association between subject functional status, seat height, and movement strategy in sit-to-stand performance. *Journal of the American Geriatrics Society, 52*, 1750–1754. PubMed doi:10.1111/j.1532-5415.2004. 52472.x

Mecagni, C, Smith, J.P., Roberts, K.E., & O'Sullivan, S.B. (2000). Balance and ankle range of motion in community-dwelling women aged 64 to 87 years: a correlational study. *Physical Therapy, 80*, 1004–1011. PubMed doi:10.1093/ptj/80.10.1004

Menant, J.C., Steele, J.R., Menz, H.B., & Munro, B.J. (2008). Optimizing footwear for older people at risk of falls. *Journal of Rehabilitation Research and Development, 45*, 1167. PubMed doi:10.1682/JRRD. 2007.10.0168

Menz, H.B., & Lord, S.R. (1999). Footwear and postural stability in older people. *Journal* *of the American Podiatric Medical Association, 89*, 346–357. PubMed doi:10.7547/87507315-89-7-346

Menz, H.B., Lord, S.R., & McIntosh, A.S. (2001). Slip resistance of casual footwear: implications for falls in older adults. *Gerontology, 47*, 145– 149. PubMed doi:10.1159/000052788

Menz, H.B., & Morris, M.E. (2005). Footwear characteristics and foot problems in older people. *Gerontology, 51*, 346–351. PubMed doi:10.1159/000086373

Millington, P.J., Myklebust, B.M., & Shambes, G.M. (1992). Biomechan- ical analysis of the sit-to-stand motion in elderly persons. *Archive Physical Medical Rehabilitation, 73*, 609–617. PubMed

Morio, C. (2009). The influence of footwear on foot motion during walking and running. *Journal of Biomechanics, 42*, 2081–2088. PubMed doi:10.1016/j.jbiomech.2009.06.015

Nagano, H., Begg, R.K., Sparrow, W.A., & Taylor, S. (2011). Ageing and limb dominance effects on foot-ground clearance during treadmill and overground walking. *Clinical Biomechanics, 26*, 962–968. PubMed doi:10.1016/j.clinbiomech.2011.05.013

Oeffinger, D., Brauch, B., Cranfill, S., Hisle, C., Wynn, C., Hicks, R., & Augsburger, S. (1999). Comparison of gait with and without shoes in children. *Gait and Posture, 9*, 95–100. PubMed doi:10.1016/S0966- 6362(99)00005-3

Ostrosky, K.M., VanSwearingen, J.M., Burdett, R.G., & Gee, Z. (1994). A comparison of gait characteristics in young and old subjects. *Physical Therapy, 74*, 637–644. PubMed doi:10.1093/ptj/74.7.637

Qiu, F., Cole, M.H., Davids, K.W., Hennig, E.M., Silburn, P.A., Netscher, H., & Kerr, G.K. (2012). Enhanced somatosensory information decreases postural sway in older people. *Gait and Posture, 35*, 630–635. PubMed doi:10.1016/j.gaitpost.2011.12.013

Qu, X. (2015). Impacts of different types of insoles on postural stability in older adults. *Applied Ergonomics, 46*, 38–43. PubMed doi:10.1016/ j.apergo.2014.06.005

Robbins, S., Gouw, G.J., & McClaran, J. (1992). Shoe sole thickness and hardness influence balance in older men. *Journal of the American Geriatrics Society, 40*, 1089–1094. PubMed doi:10.1111/j.1532- 5415.1992.tb01795.x

Roy, G., Nadeau, S., Gravel, D., Malouin, F., Mcfadyen, B.J., & Piotte, F. (2006). The effect of foot position and chair height on the asymmetry of vertical forces during sit-tostand and stand-to-sit tasks in indivi- duals with hemiparesis. *Clinical Biomechanics, 21*, 585–593. PubMed doi:10.1016/j.clinbiomech.2006.01.007

Schenkman, M., Berger, R.A., Riley, P.O., Mann, R.W., & Hodge, W.A. (1990). Wholebody movements during rising to standing from sitting. *Physical Therapy, 70,* 638–648. PubMed doi:10.1093/ptj/ 70.10.638

Schulze, C., Lindner, T., Woitge, S., Schulz, K., Finze, S., Mittelmeier, W., & Bader, R. (2014). Influence of footwear and equipment on stride length and range of motion of ankle, knee and hip joint. *Acta of Bioengineering and Biomechanics, 16*, 45–51. PubMed doi:10.5277/ ABB-00043-2014-02

Scott, G., Menz, H.B., & Newcombe, L. (2006). Age-related differences in foot structure and function. *Gait and Posture, 26,* 68–75. PubMed doi:10.1016/j.gaitpost.2006.07.009

Shakoor, N. (2010). Effects of common footwear on joint loading in osteoarthritis of the knee. *Arthritis Care and Research, 62,* 917–923. PubMed doi:10.1002/acr.20165

Shroyer, J.F., & Weimar, W.H. (2010). Comparative analysis of human gait while wearing thong-style flip-flops versus sneakers. *Journal of the American Podiatric Medical Association, 100,* 251–257. PubMed doi:10.7547/1000251

Spink, M.J., Fotoohabadi, M.R., Wee, E., Hill, K.D., Lord, S.R., & Menz, H.B. (2011). Foot and ankle strength, range of motion, posture, and deformity are associated with balance and functional ability in older adults. *Archives of Physical Medicine and Rehabilitation, 92*(1), 68– 75. PubMed doi:10.1016/j.apmr.2010.09.024

Stief, F., Schäfer, A., Vogt, L., Kirchner, M., Hübscher, M., Thiel, C., …Meurer, A. (2016). Differences in gait performance, quadriceps strength, and physical activity between fallers and nonfallers in women with osteoporosis. *Journal of Aging and Physical Activity, 24,* 430–434. PubMed doi:10.1123/japa.2015-0170

Tully, E.A., Fotoohabadi, M.R., & Galea, M.P. (2005). Sagittal spine and lower limb movement during sit-to-stand in healthy young subjects. *Gait Posture, 22,* 338–345. PubMed doi:10.1016/j.gaitpost.2004.11.007

Vander Linden, D.W., Brunt, D., & Mcculloch, M.U. (1994). Variant and invariant characteristics of the sit-to-stand task in healthy elderly adults. *Archives of Physical Medicine and Rehabilitation, 75*, 653– 660. PubMed doi:10.1016/0003-9993(94)90188-0

Yick, K.L., Tse, L.T., Lo, W.T., Ng, S.P., & Yip, J. (2016). Effects of indoor slippers on plantar pressure and lower limb EMG activity in older women. *Applied Ergonomics, 56*, 153–159. PubMed doi:10. 1016/j.apergo.2016.03.018