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Immediate effects of wearing knee length socks differing in compression level on postural regulation in community-dwelling, healthy, elderly men and women

Running Head: Knee length socks and postural regulation

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Highlights of Paper

- Wearing compression socks enhanced postural regulation in elderly population.
- Wearing compression socks reduced postural sway while standing on a foam surface.
- Gender differences were seen in response to the effects of wearing compression socks.
- Wearing compression socks decreased anterior-posterior sway in elderly men.
- Wearing compression socks decreased sway area and sway velocity in elderly women.

Postural regulation and stability of balance are affected by types of standing surfaces and somatosensory system function of an individual [1]. Standing on unstable surfaces, like foam surfaces, have revealed the important role of somatosensory information in postural regulation and balance [1,2]. Studies have suggested that postural sway increases for balance regulation, especially when individuals are standing on a foam surface [1,3]. Somatosensory function is important to study since neurodegeneration can result in age-related declines in postural regulation due to reduction in cognitive and sensory system capacities [4]. For example, ageing can result in decreased sensitivity to sensory information and motor output, slowing of cognitive capacities, increased reaction time, and decreased spinal-stretch reflex system function [4-6]. These deteriorations could possibly put elderly individuals at greater risk of falls [4]. To address the issue of decreased functionality of postural regulation, lower-limb stimulation strategies (LLS) such as wearable garments (braces & socks) [7,8], textured insoles [2,8], and application of Stochastic Resonance (SR) [8] have demonstrated some positive effects on postural regulation during balancing tasks in middle-aged and older adults (65 years and above). On the other hand, postural regulation and stability are affected by the types of standing surfaces and the visual conditions available to a person [1]. Specifically, foam surfaces are commonly used to disrupt somatosensory information [1,2]. With the absence of vision, studies have suggested that postural sway increases, especially when individuals are standing on a foam surface [1,3]. However, further investigation of elderly samples are needed to ascertain whether postural regulation can be enhanced during static balance, when standing on different surfaces and under varied visual conditions (e.g., with and without), when wearing compression socks. Therefore, this study aimed to investigate the effects of compression wearable garments on somatosensory feedback in static balance task, under different standing surfaces and vision conditions (e.g., with and without), in elderly people.

An ecological dynamics framework has been proposed to account for how compression and textured materials can support the exploitation of sensorimotor system noise to enhance functional performance. Davids et al. (2003) [9] argued that the functional role of variability induced in the sensorimotor system by textured insoles, acts as a form of “essential noise" which helps individuals regulate actions. They suggested that the addition of intermittent, intermediate levels of noise, via textured insoles, may help performers to pick up information from the background signals to enhance perception of somatosensory feedback [9]. Effects of wearable garments could be related to neuromotor function, specifically invoking the Hoffmann Reflex (H-reflex), an indirect measure of motorneuron excitability [10]. It has been reported that wearing an ankle brace increases motorneuron excitation in the afferent system at the Peroneus Longus muscle [10], providing additional active impact for proprioceptive control of movement in the ankle dorsiflexor muscles [11]. Evidence from research on performance of a younger, athletic population performing a sport action implies that stimulation of the sensory system in the lower limbs by wearable garments (e.g., compression socks and textured insoles) could potentially increase the efficiency of somatosensory system function and aid postural regulation of elderly individuals [12].

It has also been suggested that application of stimulation, provided by adding pressure, texture nodules, and velcro strapping on the cutaneous, joints, and muscle receptors of the lower limbs could enhance the level of sensorimotor system noise to improve perceptual-motor system functionality [2,8,9,13,14]. A postulation is that stimulation of the muscle spindles and mechanoreceptors along the shank, when wearing compression socks, enhances postural regulation by contortion and disturbances of haptic system receptors in the skin and soft tissue of the lower limbs [8]. Recent investigations have suggested some beneficial effects of wearing a knee compressive sleeve in reducing postural sway in the anteroposterior (AP) direction [15] and donning a compression stocking reduced the CoP trajectory amplitude [16]. In an elderly sample, Losa Iglesia (2012) [17] reported that wearing socks reduced sway areas compared to when the same participants regulated posture in a barefoot condition. These initial findings suggest that more research is needed to address the role of wearing compression socks in stimulating somatosensory system feedback that emerges from pressure on cutaneous and joint receptors in the lower legs in the elderly population.

Furthermore, no studies have addressed the question of effects of LLS related to gender differences associated with age-related degeneration of the perceptual-motor system. It is possible that elderly men and women respond differently, based on fundamental differences in morphology, exemplified by variations in brain structure and function, musculature, and the sensory systems [18]. For example, some studies have identified a possible gender effect with elderly women displaying greater CoP sway values [19], lower balance scores [20], and shorter nerve conduction pathways [18] than elderly men. Wearing compression garments could potentially enhance the sensitivity of the cutaneous and mechanoreceptors in elderly females, reducing their falls risk, by indirectly enhancing their postural regulation capacity.

Therefore, the current study sought to understand whether wearing compressive knee length socks (KLS) would enhance the stimulation of mechanoreceptors in the lower limbs of elderly men and women, helping these community-dwelling individuals to achieve better postural regulation, and potentially forming a strategy to reduce risk of falling. We sought to add to the literature by discerning the impact of low cost, easily implemented compression materials, on somatosensory function and postural regulation in elderly males and females. The specific aim of this study was to examine immediate effects of wearing KLS of various compression levels on postural regulation under four levels of performance difficulty, in community-dwelling healthy elderly men and women, during double-limb standing, balancing task. It was hypothesized that wearing compression KLS would reduce postural sway, with gender-based differences being observed in these community-dwelling elderly men and women.

2.0 Methods

2.1 Participants

A total of 46 (Male = 23) community-dwelling elderly individuals (Table 1), were randomly selected based on specific inclusion criteria, from the profiling of Singapore community-dwelling elderly people project [20]. Specific inclusion criteria were ability to walk independently without using any assistive devices (e.g., walking stick; umbrella), no history of falling in the past 12 months, Berg Balance task Score > 40 (normal), and Mini-Mental State Examination (MMSE) score > 24 (normal). Exclusion criteria were: evidence of muscular and neurological diseases, recent stroke events (< 18 months), and brain injuries. Voluntary and informed consent was obtained from all 46 participants, and the procedures used in the study were approved and in accordance with the ethical guidelines of the research ethics committee of Nanyang Technological University, Singapore.

Insert Table 1 about here

2.2 Apparatus and Tasks

Three treatment interventions (wearing clinical compression KLS; wearing non-clinical compression KLS; wearing commercial KLS) and one control condition (barefoot), in a counterbalanced order, were administered to participants while they performed a double-limb standing balance task. In testing we used KLS with clinical level compression KLS (CC) of 20-30 mmHg pressure (Zeropoint, Finland), KLS with non-clinical level compression (NCC) of 8-15mmHg (X-bionic, Switzerland), and non-compression (NC) models commercial KLS (Mizuno, Japan) of similar thickness. The purpose of including different types of KLS was to gain insights into effects of wearing garments of varying compression levels. We sought to discern whether the degree of contortion of lower limb tissue, by different compression properties, might influence postural regulation function in elderly males and females. The tasks required participants to perform a 30-s Romberg test on a balance platform (Hur, Finland) under two vision conditions (eyes open and closed) and on two standing surfaces (stable and foam) inside a laboratory. The dimension of the foam was 50 x 50 x 10 cm and the density was at 30 kg/m^3.

The four levels of performance difficulty task conditions were standing on: (1) a stable surface with eyes open (SO); (2) a stable surface with eyes closed (SC); (3) a foam surface with eyes open (FO); and (4), a foam surface with eyes closed (FC). All treatment interventions and task conditions were presented in a random order for each participant.

2.3 Procedure

A repeated-measures design was used to determine effects on balance and postural control of four different treatment conditions – wearing CC KLS; wearing NCC KLS; wearing NC KLS; barefoot. The sequences of the testing interventions and the task conditions were randomised by using Microsoft Excel to prevent carryover/order effects.

For the 30-s Romberg test, participants were instructed to stand upright and as still as possible with feet together and the arms by the side. For the eyes open condition, participants were asked to look straight ahead to a reference point on a blank wall, marked at eye level, and it was about 1.5 m away from the balance platform. For the unstable surface, a 10-cm thick foam pad was placed on top of the balance platform to create a more challenging surface for the participants.

Before data collection, participants undertook two trials of the static balance task to familiarize themselves with each of the four task conditions– SO, SC FO, FC. For every treatment intervention, participants were required to perform 2 trials for each of the task conditions. Participants were given a sufficient rest period (~ 2 minutes) between each treatment intervention. The tests were repeated if participants lost balance on the platform.

2.4 Data processing and Statistical analysis

Centre of pressure data were collected at a sampling frequency of 100Hz, accumulating to 3000 data points for each condition. The parameters were the 90% confidence elliptical area (C90 sway area), trace length (TL, the total length of the CoP path), sway velocity, range of anterior–posterior (AP) and medial–lateral (ML) CoP displacement, AP and ML standard deviation (SD). Observed increases in value of these parameters were associated with a greater risk of falling [21]. It has been reported that the sway area, trace length, and sway velocity are the most reliable CoP stabilometric parameters in measuring postural stability [6]. All data were analyzed by using nonparametric statistical tests due to abnormal data distributions. SPSS software (version 24.0) was used for statistical analysis. All measurements across the treatment interventions were compared using a Friedman test – K related samples. If statistically significant results were found during the Friedman test, Wilcoxon sign test was conducted to further identify which treatment intervention resulted in a significant effect. Results were reported as means and standard deviation (SD). Alpha level was set at <0.05 for all statistical analyses.

3.0 Results

3.1 Postural sway (C90) area

For the female group, the Friedman test revealed significant differences across the treatment interventions on the foam surface with eyes open ($p = 0.007$) (Figure 1). Post hoc analysis showed that the sway area in that group was significantly lower while wearing the NCC ($p = 0.013$) and NC ($p = 0.016$) KLS compared to the barefoot condition. No statistically significant effects were found across the treatment interventions in men.

Insert Figure 1 about here

3.2 Trace length

For the female group, the Friedman test revealed significant differences across the treatment interventions on the foam surface with eyes open (p = 0.007), but not in the other three task conditions – SO, SC and FC (Figure 2). Post hoc analysis showed that trace length was significantly shorter while participants wore the NCC KLS (p = 0.013), compared to the barefoot condition for the FO task condition. No statistically significant effects were found across the treatment interventions in men.

Insert Figure 2 about here

3.3 Sway velocity

The Friedman test revealed significant differences across the treatment interventions (p = 0.027) in the female group in the FO task condition (Figure 3). Post hoc analysis showed that sway velocity was significantly lower while wearing the CC and NCC KLS (p = 0.013) compared to the barefoot condition. No statistically significant effects were found across the treatment interventions in men.

Insert Figure 3 about here

3.4 Anterior–posterior (AP) postural sway and AP SD

There were significant differences across the treatment interventions in AP sway on both stable (p = 0.043) and foam (p = 0.027) surfaces, with eyes open (Table 2) in the elderly males. In the SO task condition, post hoc analysis revealed that CC KLS significantly decreased AP sway compared to when wearing NCC KLS (p = 0.013) and when standing barefoot (p = 0.039) in the elderly men. The same beneficial effect of wearing CC KLS was observed in the FO condition. A significant difference across treatment interventions was observed on APSD ($p = 0.012$) in the SC condition. However, no significant differences were found in all treatment interventions and all task conditions on AP sway and AP SD values in the women.

3.5 Medial–lateral (ML) postural sway and ML SD

There were no differences across the treatment interventions on ML sway and ML SD in the elderly men (Table 2). A significant difference across treatment conditions was observed in MLSD ($p = 0.012$) in SC task in the women.

Insert Table 2 about here

4.0 Discussion

The aim of this study was to examine immediate effects of wearing KLS of various compression levels on somatosensory function, during a double-limb standing balancing task. The results of this study support our hypothesis on the beneficial effects of wearing compression KLS on postural regulation in community-dwelling elderly men and women. In elderly men, wearing CC and NCC KLS decreased postural sway, mainly in the AP direction in both SO and FO task conditions. Similarly, wearing KLS, particularly non-clinical compression, reduced sway area, trace length and sway velocity while standing on the foam surface with eyes open (FO) in the elderly women. There were no significant beneficial effects of all levels of KLS observed in the FC condition in both elderly men and women.

Consistent with findings of previous studies, use of lower-limb stimulation strategies decreased postural sway for elderly participants wearing textured insoles (see Qiu et al., 2012) [2] and hard insoles [17]. Our results support the idea that compression wearable garments can enhance the functioning of the postural regulation system by reducing sway

[8,14,16,22]. Wearing CC and NCC KLS are deemed to be beneficial perhaps due to their capacity to support exploitation of the available "sensorimotor system noise" to enhance perception of proprioceptive and haptic information during performance of complex tasks (for example, maintaining upright stance while standing on an unstable surface). Furthermore, wearing compression KLS yielded similar effects as balance training interventions (electrical stimulation) in improving postural stability in elderly people [23,24]. Perhaps wearing compression KLS may increase motorneuron excitability of H-reflex, as suggested by Nishikawa and Grabiner (1999) [10] and down-modulated the Hoffmann Reflex (H-reflex). Therefore, wearing compression KLS, which covered most of the lower legs, seemed to stimulate the various cutaneous mechanoreceptors, motor neurons, and muscle proprioceptors along the shanks, and could potentially form a strategy to ameliorate negative effects of ageing on the postural control system and reduce risk of falling.

The amplitude and conduction velocity of motor and sensory nerves have been found to significantly differ with gender [25]. This effect could be potentially attributed to the gender-based differences observed from wearing the compression KLS in our study. In agreement with our findings, Olchowik et al. (2015) [26] found that men displayed less postural sway than women in the AP direction. Our findings provided new insights, indicating that wearing compression KLS, is beneficial to men, as supported by the decrease in the sway distance in the AP direction. Furthermore, we found that women displayed positive performance outcome in many COP variables such as sway area, trace length, and sway velocity. This observation could be due to the possibility that women use the ankle strategy (to regulate balance) more effectively than men [25,26]. Wearing compression KLS seems to aid the ankle control strategy by stimulating the cutaneous and mechanoreceptors around the ankle joint. An issue requiring further research concerns the suggestion that compression garment manufacturers may improve sock design, by concentrating the stimulating material (by increasing textured undulations) surrounding the ankle and at the anterior-posterior aspects of the compression socks.

In this study, KLS enhanced postural regulation performance in a challenging condition – during upright balance on a foam (unstable) surface with eyes open (i.e., availability of vision), supporting findings with textured insoles reported by Qiu et al. (2012). The role of somatosensory feedback is assumed to be more important when standing on an unstable surface [1,3]. In the current study, wearing compression KLS seemed to provide necessary sensory information to the Central Nervous System (CNS) and facilitated the perceptual regulation of stance [3] when the somatosensory system is compromised. In contrast to data of Qiu et al. (2017) [2], our study showed no immediate beneficial effects of wearing compression KLS when both vision and somatosensory are compromised [i.e., standing on a foam surface with eyes closed (FC)]. Effects of these sensory perturbations seemed to be too severe for mediation by wearing compression garments, although potential long term effects may need to be assessed. This finding could imply that the somatosensory system stimulation provided by wearing compression KLS is not sufficient to yield beneficial effects when both vision and somatosensory systems are compromised. However, more studies are needed to confirm the beneficial effects of wearing compression KLS on postural regulation in the FC condition.

To summarise, our study showed that wearing compression KLS significantly improved the balance performance in FO task condition. It was observed that men and women responded differently to the effects of wearing compression KLS on postural regulation. Wearing compression KLS could be used as a medium to reduce risk of falling and enhance postural control and function of the perceptual-motor systems. A limitation of this study includes the absence of an assessment of the muscle strength capacity of our participants and it is unknown whether individual variations in lower limb muscle strength affected performance outcomes, if at all. Future studies could include some form of measurement of muscle strength to determine the effect of muscle strength coupled with the use of KLS on the balance tasks. In addition, there could also be an emphasis on examining the long-term effects of wearing compression KLS on postural regulation and dynamic tasks (e.g., walking, sliding), and the immediate effects of wearing compression KLS in specific groups of elderly individuals with debilitating conditions, such as diabetes, Parkinson Disease and peripheral neuropathy.

Conflict of interest statement

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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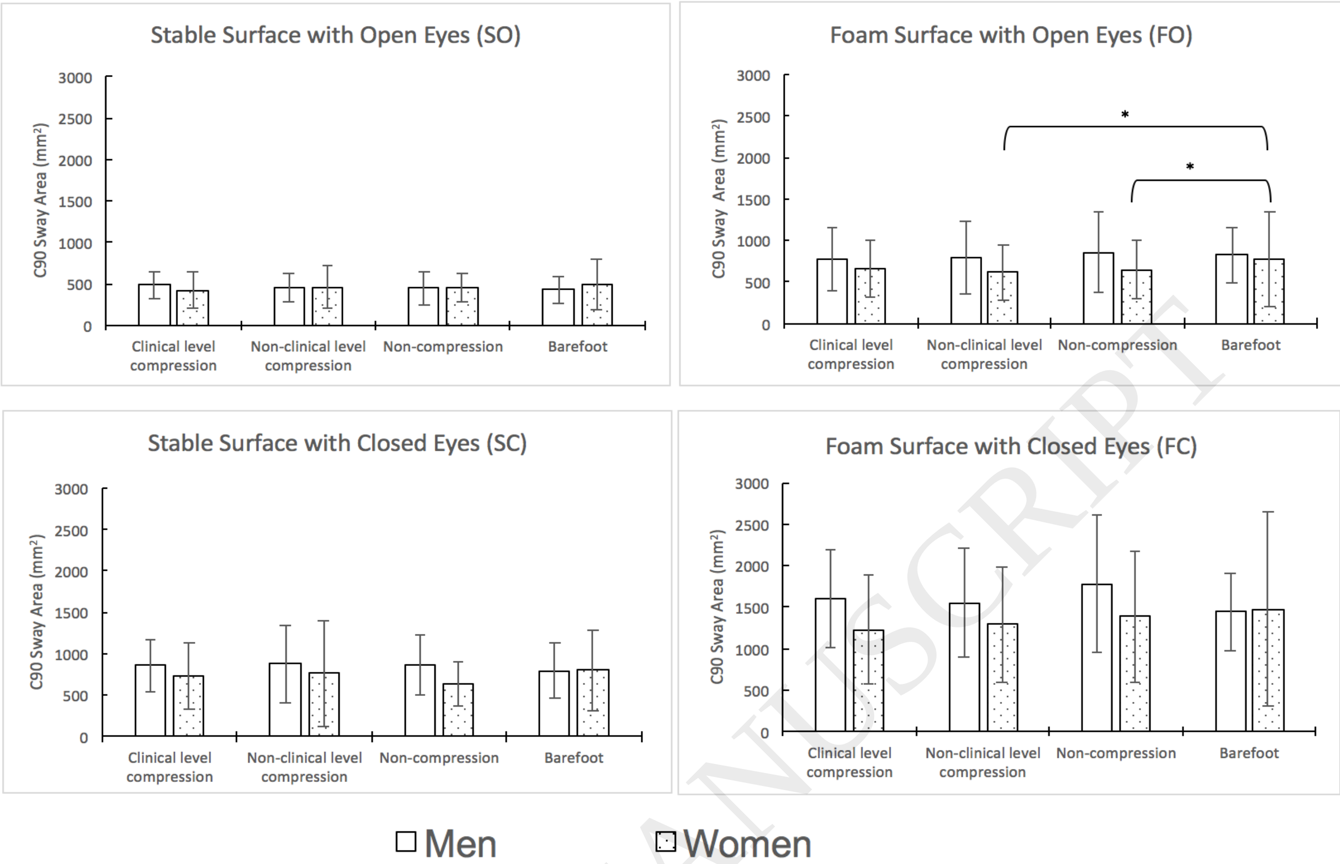
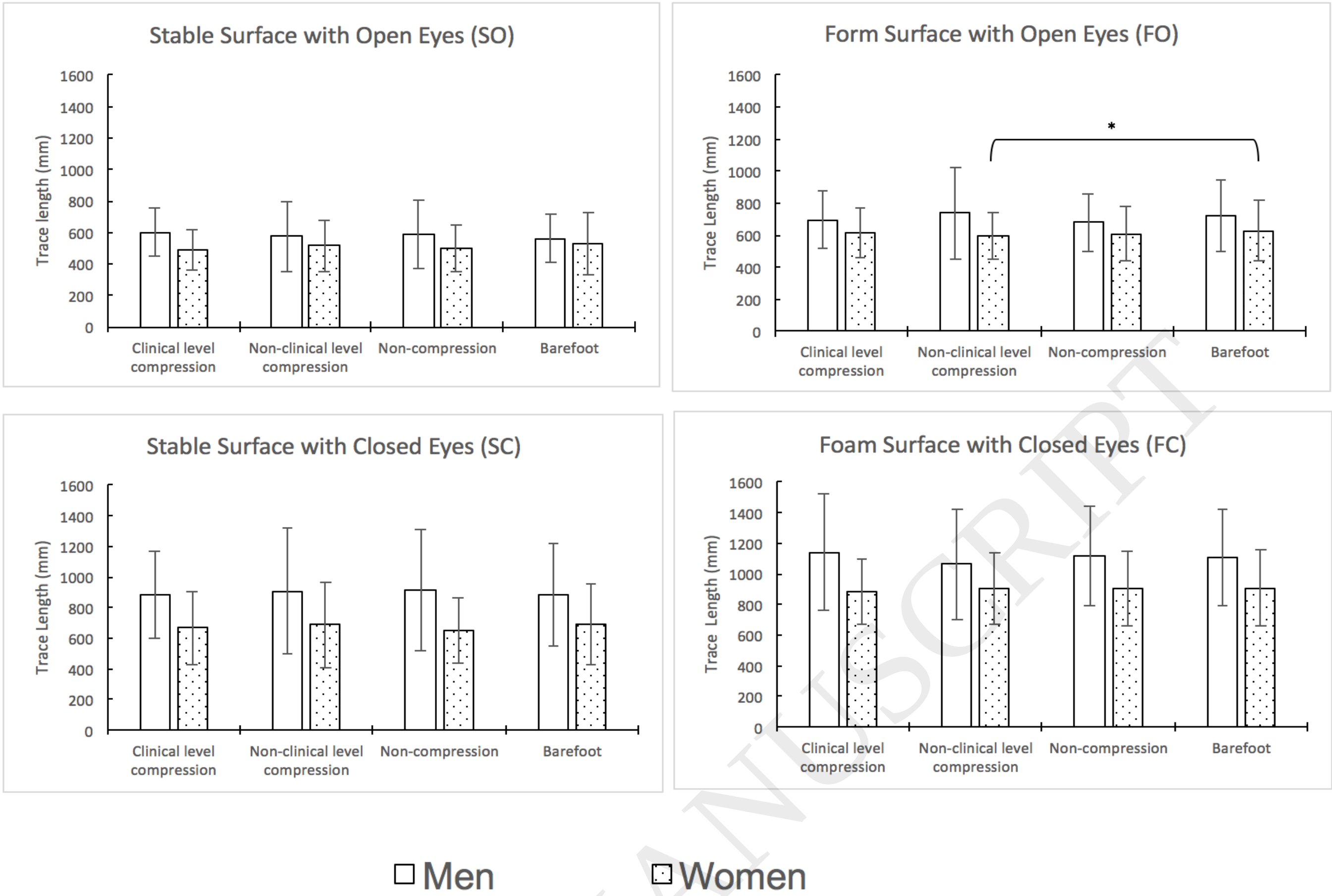


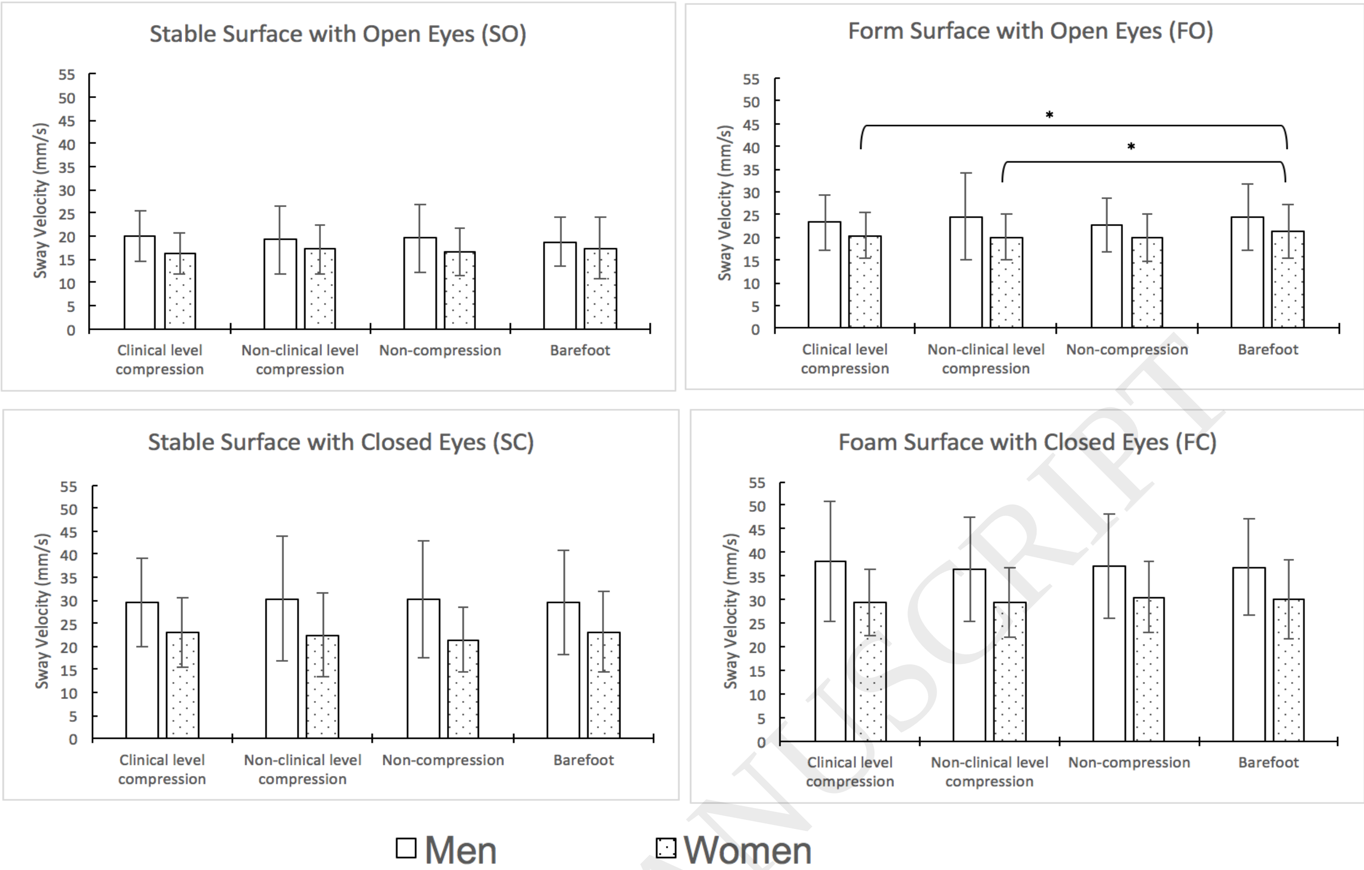
* Significantly lower than barefoot

Fig. 1. Mean (SD) C90 area for the elderly men and women during the four task conditions



* Significantly lower than barefoot

Fig. 2. Mean (SD) trace length for the elderly men and women during the four task conditions.



* Significantly lower than barefoot

Fig. 3. Mean (SD) sway velocity for the elderly men and women during the four task conditions.

Table 1.
Participants' Demographic

	Men (N =23)	Women (N = 23)
Age (years)	75.2 ± 5.1	72.8 ± 5.8
Height (cm)	162.3 ± 6.4	153.7 ± 6.2
Weight (kg)	57.9 ± 9.5	59.8 ± 11.2
Berg Balance Scale (Scores)	50.9 ± 4.3	50.6 ± 4.4
Mini-Mental State Examination (Scores)	25.7 ± 1.4	26.4 ± 1.9

Table 2.
Balance Measures of postural difficulty levels in elderly men and women (Mean ± SD).

	Men (N = 23)					Women (N = 23)				
	Clinical level compression (> 20mmHg)	**Non-clinical level compression (8 - 15mmHg)**	**Non-compression**	**Barefoot**	**p-value**	**Clinical level compression (> 20mmHg)**	**Non-clinical level compression (8 - 15mmHg)**	**Non-compression**	**Barefoot**	**p-value**
(a) Stable Surface with Eyes Open (SO)										
Anterior–posterior (AP) Sway (mm)	33.4 ± 14.67*	38.66 ± 16.28	35.93 ± 15.47	36.75 ± 17.25	<0.05	46.45 ± 19.67	42.67 ± 17.62	42.23 ± 19.9	42.13 ± 21.03	>0.05
Anterior–posterior (AP) SD (mm)	5.3 ± 1.29	5.08 ± 1.12	4.98 ± 1.27	4.99 ± 1.12	>0.05	5.06 ± 1.46	5.07 ± 1.54	5.22 ± 1.26	5.36 ± 1.96	>0.05
Medial–lateral (ML) Sway (mm)	6.18 ± 5.43	6.63 ± 4.64	7.34 ± 4.93	7.09 ±5.53	>0.05	7.21 ± 4.25	6.72 ± 5.23	7.76 ± 5.76	7.6 ± 5.43	>0.05
Medial–lateral (ML) SD (mm)	6.26 ± 0.97	6.22 ± 1.32	6.27 ± 1.75	5.91 ± 1.12	>0.05	5.67 ± 1.4	6.28 ± 1.69	6.06 ± 1.16	6.35 ± 1.52	>0.05
(b) Form Surface with Eyes Open (FO)										
Anterior–posterior (AP) Sway (mm)	53.67 ± 27.38**	66.44 ± 26.31	60.04 ± 28.12	57.56 ± 27.95**	<0.05	67.14 ± 30.04	67.55 ± 29.61	70.49 ± 25.42	66.07 ± 31.86	>0.05
Anterior–posterior (AP) SD (mm)	7.06 ± 2.01	6.92 ± 1.91	7.64 ± 3.01	7.49 ± 2.34	>0.05	6.23 ± 1.69	6.13 ± 1.7	6.32 ± 1.52	6.83 ± 2.32	>0.05
Medial–lateral (ML) Sway (mm)	10.45 ± 5.75	9.99 ± 5.82	8.98 ± 5.06	9.37 ± 5.21	>0.05	9.25 ± 6.23	11.59 ± 6.77	9.44 ± 6.8	9.08 ± 6.66	>0.05
Medial–lateral (ML) SD (mm)	7.58 ± 1.52	7.75 ± 2.14	7.62 ± 1.77	7.73 ± 1.77	>0.05	7.07 ± 1.58	7.03 ± 1.88	7 ± 1.72	7.29 ± 2.17	>0.05

(c) Stable Surface with Closed Eyes (SC)										
Anterior–posterior (AP) Sway (mm)	29.98 ± 13.75	34 ± 15.28	33.4 ± 16.85	33.4 ± 15.49	>0.05	44.93 ± 20.97	43.35 ± 18.43	35.65 ± 18.07	41.11 ± 20.47	>0.05
Anterior–posterior (AP) SD (mm)	7.12 ± 1.22	6.93 ± 1.83#	7.18 ± 1.82	6.55 ± 1.54#	<0.05	6.5 ± 1.82	6.35 ± 2.22	6.07 ± 1.53	6.53 ± 2.28	>0.05
Medial–lateral (ML) Sway (mm)	7.13 ± 4.15	7.8 ± 4.67	7.35 ± 5.18	7.07 ± 4.43	>0.05	5.78 ± 3.21	6.71 ± 2.89	6.74 ± 4.08	7.17 ± 6.38	>0.05
Medial–lateral (ML) SD (mm)	8.32 ± 2.31	8.54 ± 2.27	8.1 ± 1.93	8.35 ± 2.18	>0.05	7.91 ± 2.46	7.68 ± 2.72	7.21 ± 2.06##	8.26 ± 2.46	<0.05

(d) Foam Surface with Closed Eyes (FC)										
Anterior–posterior (AP) Sway (mm)	56.13 ± 24.84	66.07 ± 26.37	62.46 ± 27.31	60.68 ± 30.67	>0.05	67 ± 28.08	67.7 ± 28.31	68.71 ± 24.42	65.12 ± 24.89	>0.05
Anterior–posterior (AP) SD (mm)	10 ± 2.18	9.5 ± 1.98	10.25 ± 2.77	9.34 ± 1.84	>0.05	8.58 ± 3.03	8.95 ± 2.66	9.2 ± 2.71	9.31 v 3.51	>0.05
Medial–lateral (ML) Sway (mm)	11.07 ± 5.79	10.13 ± 5.34	10.25 ± 4.61	8.83 ± 4.77	>0.05	10.41 ± 6.01	13.81 ± 7.62	9.57 ± 5.71	10.09 ± 6.41	>0.05
Medial–lateral (ML) SD (mm)	10.97 ± 2.16	11.11 ± 2.95	11.73 ± 3.15	10.8 ± 2.42	>0.05	9.43 ± 2.39	9.89 ± 2.38	9.74 ± 3.07	10 ± 3.1	>0.05

* A significant difference between Non-clinical level compression and barefoot

** Significantly lower than Non-clinical level compression

Significantly lower than Non-compression

A significant difference between non-compression and barefoot