Orthotic interventions to improve standing balance in somatosensory loss

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Foot and ankle compression improves joint position sense but not bipedal stance in older people

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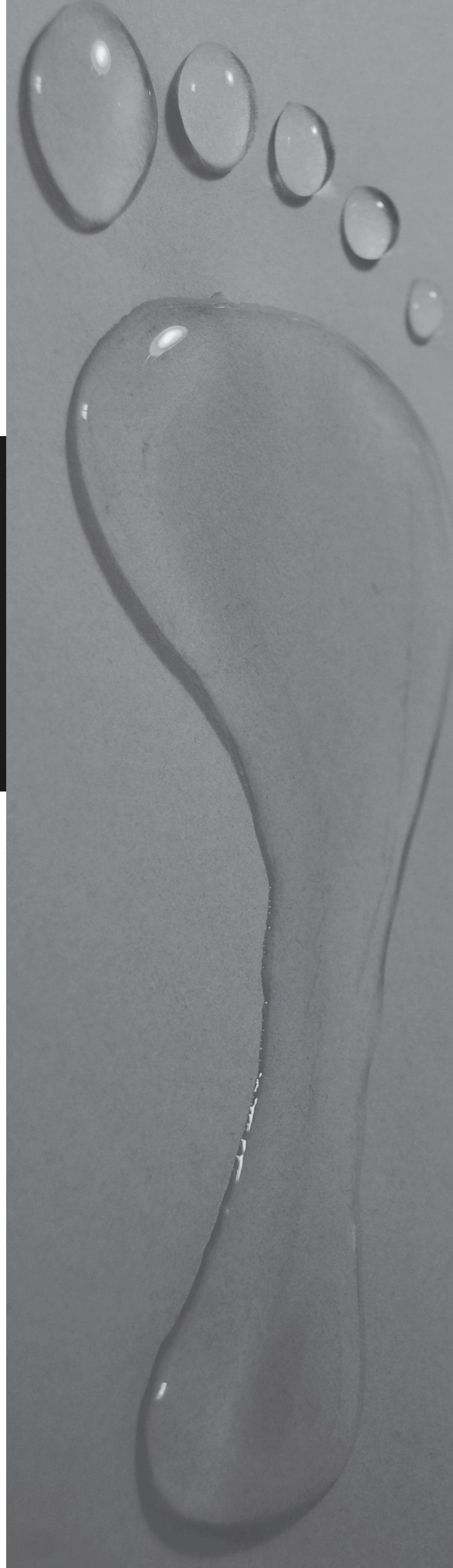

Abstract

This study investigates the effects of foot and ankle compression on joint position sense (JPS) and balance in older people and young adults. Twelve independently living healthy older persons (77-93y) were recruited from a senior accommodation facility. Fifteen young adults (19-24y) also participated. Compression was applied at the ankles and feet using medical compression hosiery. The mean velocity of the centre of pressure (COP) displacements and the root mean square of the COP velocity, in both anteroposterior and mediolateral directions, were measured with a foot pressure plate. In older people, ankle compression was associated with an improvement of JPS towards normal values. However, a concurrent deterioration of their balance was found. In young adults compression had no effect on either JPS or balance.

Introduction

Balance disorders in older people are often associated with impaired somatosensory input from the lower limbs [1-5]. Somatosensory feedback is thought to provide the central nervous system (CNS) with joint position sense (JPS) and information concerning pressure distribution on the plantar surface of the feet [6;7]. It has been argued that postural control can be improved by enhancing the somatosensory input from the ankles and feet [8].

The application of ankle foot orthoses (AFOs) and compression of the ankle and foot have been shown to have an association with improvement of ankle JPS [9-15]. Due to compression, additional feedback from mechanoreceptors in the skin could contribute to the improvement in JPS. In healthy people ankle JPS plays little role in balance control [16]. Whereas in older people and those with disabilities JPS plays a greater role. Evidence is available about the immediate effects of an appliance providing compression at the ankle on JPS and balance [9-13]. However, these studies were on healthy young people or young athletes with ankle instability. No studies were found that described the effects of compression on balance or JPS in older people. In people with polyneuropathy, AFOs were associated with improved balance apparently due to additional somatosensory cues from the skin [14]. To some extent this population is comparable to older people who can experience problems in both JPS and balance [17]. To date there is no data showing whether compression improves JPS in older people or whether improvement of JPS is associated with improvements in balance in older people.

This study investigates whether JPS is enhanced by the application of compression by an elastic bandage (medical compression hosiery (MCH)) and whether enhanced JPS is related to enhanced standing balance in older people. In healthy young adults it is expected that MCH has no effect on either balance or JPS, given that they do not have sensory impairments.

Methods

All residents of a senior accommodation facility in Groningen, the Netherlands, were invited to a lecture about balance and falls which took place in their common room. During the lecture they were invited to participate in research concerning the effects of compression on balance in older people. Residents were eligible to participate in this study if they were between 75 and 95 years of age and could stand and walk without assistive devices. People with diabetes, rheumatoid arthritis, foot wounds, an endoprosthesis, amputation of their lower limbs, deformities of ankles or feet, or history of stroke were excluded. They were also excluded if they used a lower limb orthosis, orthopaedic footwear, or MCH on a daily basis. A group of students (age 18-25y) were invited to participate as a control, matched on gender.

Participants

Nineteen older people who attended the lecture volunteered to participate (out of an approximate 50 attendees). One person was excluded because she was unable to stand without assistance. Two were excluded because they had obvious deformities of the foot and four were excluded because they used MCH on a daily basis. Twelve older people (10 female, 2 male), aged between 77 and 93 were included. Fifteen healthy students (11 female, 4 male) aged between 19 and 24 were included in the control group. All participants signed an informed consent and the study was approved by the medical ethics committee of the University Medical Center Groningen (UMCG) (METc2006/205). Participant details are summarised in Table 1.

Measurements

Tactile sensitivity was tested by pressing a 5.07/10g Semmes Weinstein Monofilament [18] three times at each test location (plantar side of: first toe, MTP1, MTP5 and heel of both feet). Vibrotactile sensitivity was tested with a 128Hz tuning fork pressed at both the medial and lateral malleolus (Table 1).

JPS was defined as the ability to indicate the steepness of a slope by standing on it with one foot. JPS was measured with a modified slope box [19-21], as a functional way of measuring JPS. In contrast with other JPS measures [11], the participant stood on a slope and estimated the angle. The slope box used in this study consisted of two parts: a flat surface; and an adjustable surface, in steps of 2.5° (Figure 1). The participant was asked to sense the steepness by stepping on the slope with their preferred foot. After the first step, the investigator made sure that every following step was with the same foot.

Each participant had to score the steepness of the slope on a -10 (plantar flexion) to 10 (dorsal flexion) scale for 10 times. A maximum score of 10 corresponded with the maximum angle of the slope box of 25°. Before the actual measurements, slopes with a score of 8 (20° dorsal flexion), 0 (horizontal) and -8 (20° plantar flexion) were presented to the participants as reference scores. During the actual measurements, ten different slopes were presented in a random order, varying 20° and -20°.

During the measurements the participants were asked to either close their eyes or to use special glasses that made it impossible to see the slope. All participants were allowed to hold on to the wall for stability. For safety, the investigator also supported the older participants by holding their arm. Only JPS in the plantar/dorsal flexion direction was measured. The perception error, expressed as the mean absolute error in degrees, was used as the primary outcome. JPS measurements were repeated two times, once with and once without MCH. Because compression was applied only once, the first measurement with compression (either the balance or the JPS measurement) was directly followed by the other measurement with

Table 1. Characteristics and sensitivity test results of the participants.

	Older participants (n = 12)		Younger participants (n = 15)	
Mean age in years ±SD	85.3±4.6		22.1±1.6	
% female (n)	83% (10)		73% (11)	
Mean mass in kg ±SD	68.9±10.1		69±10.9	
	Left	Right	Left	Right
% 5.07 / 10g SWM correctly located at first toe (n)	42% (5)	42% (5)	100% (15)	100% (15)
% 5.07 / 10g SWM correctly located at MTP1 (n)	33% (4)	50% (6)	100% (15)	100% (15)
% 5.07 / 10g SWM correctly located at MTP5 (n)	67% (8)	42% (5)	100% (15)	100% (15)
% 5.07 / 10g SWM correctly located at heel (n)	67% (8)	33% (4)	100% (15)	100% (15)
% correct response to 128Hz tuning fork (n)	25% (3)*	25% (3)*	100% (15)	100% (15)
Mean pressure under the MCH above medial malleolus in mm Hg ±SD	22.0±3.5	22.0±4.3	26.1±3.7	26.3±4.0

SD= standard deviation; SWM = Semmes Weinstein Monofilaments; MTP = metatarsophalangeal joint; MCH = medical compression hosiery; * 2 older participants responded correctly to the tuning fork at both sides

compression. The remaining measurements (without compression) were presented in a random order.

Balance was defined as the displacements of the COP and was measured with a foot pressure plate (RSscan footscan® 2D Balance 0.5m system). Pressure plate data were sampled at 17 Hz and low-pass filtered (Butterworth) with a cut-off frequency of 6 Hz. The mean velocity of the COP displacement (vCOP) over a period of 40s was used as the primary outcome. Secondary outcomes were the root mean square of the COP velocity in anteroposterior (rmsAP) and mediolateral (rmsML) directions. The measurement protocol consisted of standing for 60s (first and last 10s were not taken into consideration) on the foot pressure plate in four different conditions. During the first condition, the participants were asked to stand with their arms relaxed at the side of their body, looking straight ahead at a dot on the wall (2.5m away), with the feet placed parallel and 7cm apart. The other three conditions were standing with the eyes closed, performing an attention demanding task (continuously

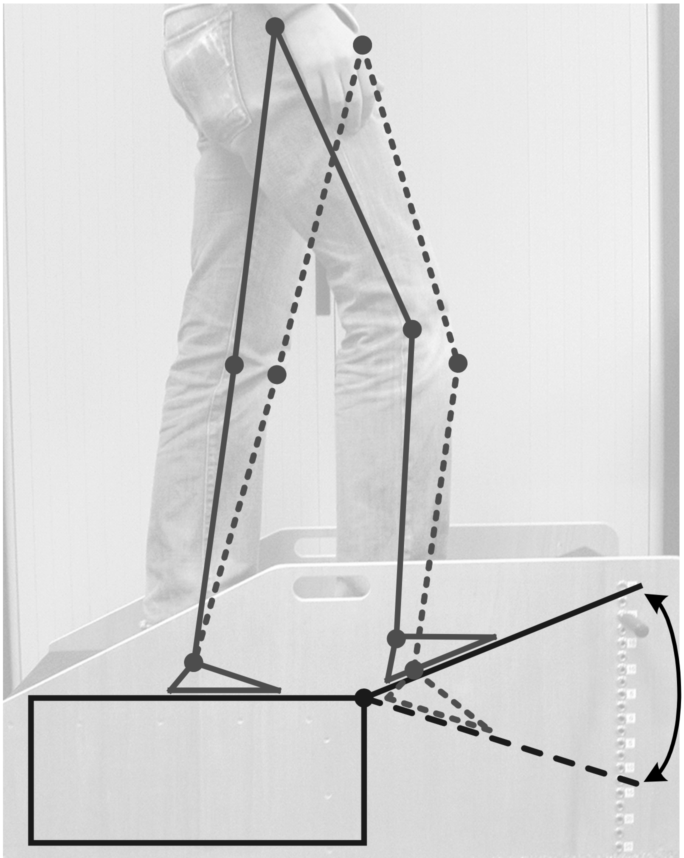

Figure 1. Modified slope box. The slope of the slope box on the right side of this figure can be altered between -25 ° and 25 ° in steps of 2.5 °. The participant has to step on the slope with the preferred foot, is allowed to use the wall for stability, and is not allowed to see the slope.

subtracting six from a randomly chosen number) and standing in the Romberg position (feet placed against each other). These three conditions were presented in a random order.

JPS and balance of the older participants were measured in a room at their residence. The foot pressure plate was placed in a standardized position, 2.5m from a wall. The control group was measured with the same foot pressure plate at the Laboratory for Human Movement Analysis of the Center for Rehabilitation, UMCG.

Compression

Compression was applied with MCH type AB compression bandage class II (Varitex, Haarlem, the Netherlands). Type AB corresponds with an ordinary sock without toes.

According to the CEN European standard[1], compression class II corresponds with pressure under the MCH of 23-32mm Hg. Three different sizes of bandages were used. The applied size was chosen based on the circumferential of the thinnest part of the lower leg. Pressure under the MCH was measured with a pressure monitoring device (Kikuhime, Harada Company, Japan) [26] about 3cm proximal to the medial malleolus (Table 1).

Statistics

Differences in perception errors with and without compression were tested using the Wilcoxon signed rank test. Differences in perception errors between the two groups were tested with a Mann Whitney U test. The effects of compression on balance were tested with a multivariate analysis of variance (MANOVA) with repeated measures. SPSS software (version 14.0) was used for all statistical analyses.

Results

In older participants a significant difference ($p = 0.025$) in perception error was found between conditions with ($3.2^{\circ} \pm 1.0$) and without ($4.8^{\circ} \pm 1.7$) compression. In younger participants no differences ($p = 0.93$) in perception errors were found ($3.0^{\circ} \pm 0.9$ and $3.1^{\circ} \pm 1.1$ with and without compression respectively). The difference in JPS between the older and younger participants when no compression was applied was significant ($p < 0.01$). When compression was applied, no differences in JPS between the two groups were found.

Table 2 shows the mean vCOP, rmsAP, and rmsML, with and without compression. A MANOVA, with repeated measures, showed a significant ($p = 0.03$) main effect of compression on balance in the older participants, with balance significantly disturbed. Univariate tests did not show significant main effects of compression on the vCOP ($p = 0.11$), rmsAP ($p = 0.09$), or rmsML ($p = 0.26$). In the younger participants no main effects of compression on balance were found.

In one case, the participant (older) was not able to stand in the Romberg position for 60 s. For this participant, calculations of the outcomes were based on the first 30s (which the participant completed both with and without compression).

Discussion

This study demonstrated that JPS improved towards normal values as a result of the application of compression in older participants yet not in younger adults who had no impairment of JPS. The mean perception errors in this study while standing barefoot (younger: 3.1°; older: 4.8°) are comparable to earlier research reporting errors of 2.9° - 3.4°

1 CEN European Prestandard. ENV12718. Medical compression hosiery. European Committee for Standardization. Brussels,2001;1–43.

Table 2. Mean ± standard error of the mean (SEM) of the mean velocity of the COP displacements, the RMS of the COP velocity in AP and ML direction, with and without compression, in older and younger participants, during four different conditions.

		Stance		Stance + Eyes closed		Stance + Attention demanding task		Stance in Romberg position	
		Comp	No-comp	Comp	No-comp	Comp	No-comp	Comp	No-comp
Mean velocity of the COP displacements (mm/s)	Older n = 12	10.2±1.86	8.8±1.05	15.6±2.53	12.5±2.13	13.5±1.93	11.7±1.19	23.8±3.60	20.6±2.53
	Younger n = 15	6.2±0.47	6.7±0.41	7.7±0.46	7.1±0.56	8.5±0.73	9.5±1.34	12.2±0.59	11.9±0.77
RMS of the COP displacement velocity in AP direction (mm/s)	Older n = 12	9.9±1.85	7.7±0.97	15.4±2.38	12.2±2.28	12.7±2.02	10.9±1.10	15.2±1.96	14.6±1.62
	Younger n = 15	4.9±0.49	5.6±0.43	6.8±0.52	5.8±0.40	7.4±0.71	8.8±1.93	8.7±0.66	8.9±0.76
RMS of the COP displacement velocity in ML direction (mm/s)	Older n = 12	7.7±1.79	7.1±1.09	10.7±2.33	9.0±1.46	9.4±1.49	9.4±1.45	25.0±4.30	21.3±2.67
	Younger n = 15	5.1±0.37	5.1±0.28	5.8±0.37	5.6±0.55	6.4±0.66	6.7±0.65	12.1±0.59	11.2±0.75

Comp = with compression; No-comp = without compression; COP = centre of pressure; RMS = root mean square; AP = anteroposterior; ML = mediolateral in young adults; 3.9° in older people (mean age 73y); and 3.9° - 4.2° in young adults with unstable ankles [19-21]. Interestingly, although JPS improved, balance deteriorated in older participants with the application of compression. Compared to barefoot standing, with the application of compression, all balance parameters deteriorated in all four balance conditions.

Several possible explanations can be given for this deterioration of balance in older participants. First, the role of JPS on balance during bipedal stance may be limited, because the angular rotations at the ankle were minimal (<0.5°). Many studies have shown that with the application of compression, balance during unipedal stance improved in young athletes with ankle instability [8-15]. As few older people can [23] stand on one foot, unipedal stance was not an option in our study. More angular rotations at the ankle are present during unipedal stance. Improving the detection of these rotations (in other words improved JPS) may enhance unipedal balance control [12]. Compared to bipedal stance, the role of JPS in balance control during unipedal stance seems to be more important.

A possible explanation for the deterioration of balance in older people shown in this study, may be that the MCH on the plantar side of the foot reduced tactile feedback from plantar mechanoreceptors. Plantar mechanoreceptors play an important role in the detection of changes in plantar pressure distribution. These changes are directly related to changes in upright stance [6;7]. Possibly, compression of the dorsal part of the foot and the lower leg, provides the CNS with additional information, whereas compression of the plantar foot impairs the detection of plantar pressure changes. This deterioration may complicate balance control. Continuous pressure applied to plantar mechanoreceptors may result in an adaptation of these receptors [24]. This may cause a reduced ability to detect changes in pressure distribution, which in turn affects the control of upright stance. This explanation supports the idea that plantar pressure distribution, when compared to ankle JPS, is a more important source of information for balance control in upright stance [8].

Previous research provides an alternative explanation, suggesting that older people have problems in rapidly resolving the conflicting sensory information required for balance control [25]. A change in this sensory feedback may occur when compression is applied. Re-weighting of the gains for sensory feedback systems in the CNS must then take place in order to optimally control balance [26]. As this re-weighting takes place, balance may temporarily deteriorate. However, after the re-weighting process, balance may be restored or even improved. Whether this occurs after long-term use of compression cannot be analysed based on our data.

Some weaknesses of this study need to be acknowledged. Firstly, participants were chosen selectively. The older participants in our study may not represent the average population between 75 and 95 years of age. People with a better physical condition are likely to live more independently, and people with a poorer physical and mental condition need more help in daily living and therefore, may live in a facility where more care is provided. Secondly, it may be possible that the MCH does not affect balance due to additional somatosensation alone; rather, it also may have a limited mechanical effect on stance. If a mechanical effect would have been present, however, effects in both populations would have been expected. Thirdly, the slope box and the related protocol were modified in our study compared to earlier work [23-25]. The older age of the participants was the main reason to apply the modifications. Finally, in this study we only used static balance measures. Although the inclusion of measures for dynamic balance would have provided a more comprehensive assessment of balance function, we decided to focus on a static balance task because the role of JPS in quiet standing tasks is thought to be relatively important.

In conclusion, in older people, ankle compression applied by MCH, was associated with an improvement of JPS towards normal values. However, a concurrent deterioration of their balance was evident. In young adults compression had no effect on either JPS or balance.

References

1. Diener HC, Horak FB, Nashner LM. Influence of stimulus parameters on human postural responses. J Neurophysiol 1988;59:1888-1905.
2. Manchester D, Woollacott MH, Zederbauer-Hylton N, Marin O. Visual, vestibular and somatosensory contributions to balance control in older adult. J Gerontol 1989;44:M118–M127.
3. Jeka JJ, Ribeiro P, Oie KS, Lackner JR. The structure of somatosensory information for human postural control. Motor Control 1998;2:13-33.
4. Fukuoka Y, Nagata T, Ishida A, Minamitani H. Characteristics of somatosensory feedback in postural control during standing. IEEE Trans Neural Syst Rehabil Eng 2001;9:145-53.
5. Meyer PF, Oddsson LI, De Luca CJ. The role of plantar cutaneous sensation in unperturbed stance. Exp Brain Res 2004;156:505-12.
6. Bloem BR, Allum JH, Carpenter MG, Honegger F. Is lower leg proprioception essential for triggering human automatic postural responses? Exp Brain Res 2000;130:375-91.
7. Kavounoudias A, Roll R, Roll JP. The plantar sole is a 'dynamometric map' for human balance control. Neuroreport 1998;9:3247-52.
8. Hijmans JM, Geertzen JHB, Dijkstra PU, Postema K. A systematic review of the effects of shoes and other ankle or foot appliances on balance in older people and people with peripheral nervous system disorders. Gait Posture 2007;25:316-23.
9. Calmels P, Escafit M, Domenach M, Minaire P. Posturographic evaluation of the proprioceptive effect of ankle orthoses in healthy volunteers. Int Disabil Stud 1991;13:42-5.

10. Feuerbach JW, Grabiner MD. Effect of the aircast on unilateral postural control: amplitude and frequency variables. J Orthop Sports Phys Ther 1993;17:149-54.

11. Jerosch J, Hoffstetter I, Bork H, Bischoff M. The influence of orthoses on the proprioception of the ankle joint. Knee Surg Sports Traumatol Arthrosc 1995;1:39-46.

12. Baier M, Hopf T. Ankle orthoses effect on single-limb standing balance in athletes with functional ankle instability. Arch Phys Med Rehabil 1998;79:939-44.

13. You SH, Granata KP, Bunker LK. Effects of circumferential ankle pressure on ankle proprioception, stiffness, and postural stability: a preliminary investigation. J Orthop Sports Phys Ther 2004;34:449-60.

14. Rao N, Aruin A. Automatic postural responses in individuals with peripheral neuropathy and ankle–foot orthoses. Diabetes Res Clin Pract 2006;74:48-56.

15. Kaminski TW, Gerlach TM. The effect of tape and neoprene ankle supports on ankle joint position sense. Phys Ther Sports 2001;2:132-40.

16. Feuerbach JW, Grabiner MD, Koh TJ, Weiker GG. Effect of an ankle orthosis and ankle ligament anesthesia on ankle joint proprioception. Am J Sports Med 1994;22:223-9.

17. Robbins S, Waked E, Allard P, McClaran J, Krouglicof N. Foot position awareness in younger and older men: the influence of footwear sole properties. J Am Geriatr Soc 1997;45:61-6.

18. International Working Group on the Diabetic Foot. International consensus on the diabetic foot and practical guidelines on the management and the prevention of the diabetic foot. Amsterdam; 2007.

19. Robbins S, Waked E, McClaran J. Proprioception and stability: foot position awareness as a function of age and footwear. Age Ageing 1995;24:67-72.

20. Halasi T, Kynsburg A, Tallay A, Berkes I. Changes in joint position sense after surgically treated chronic lateral ankle instability. Br J Sports Med 2005;39:818-24.

21. Kynsburg A, Halasi T, Tallay A, Berkes I. Changes in joint position sense after conservatively treated chronic lateral ankle instability. Knee Surg Sports Traumatol Arthrosc 2006;14:1299–306.

22. Van den Kerckhove E, Fieuws S, Massagé P, Hierner R, Boeckx W, Deleuze JP, Laperre J, Anthonissen M. Reproducibility of repeated measurements with the Kikuhime pressure sensor under pressure garments in burn scar treatment. Burns 2007;33:572-8.

23. Bohannon RW, Larkin PA, Cook AC, Gear J, Singer J. Decrease in timed balance test scores with aging. Phys Ther 1984;64:1067-70.

24. Vedel JP, Roll JP. Response to pressure and vibration of slowly adapting cutaneous mechanoreceptors in the human foot. Neurosci Lett 1982;34:289-94.

25. Bugnariu N, Fung J. Aging and selective sensorimotor strategies in the regulation of upright balance. J Neuroeng Rehabil 2007;4:19.

26. Horak FB, Shupert CL, Mirka A. Components of postural dyscontrol in the elderly: A review. Neurobiol Aging 1989;10:727-38.