Original article

Effects of plantar foot sensitivity manipulation on postural control of young adult and elderly

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A B S T R A C T

Introduction: Subjects with sensorial losses present balance deficits. Although such condition is often observed among elderly, there is discussion concerning the dependence on sensorial information for body sway control in the elderly without sensorial losses.
Purpose: We investigated the effects of foot sensitivity manipulation on postural control during upright standing in young adults and independent elderly ($n = 19$/group).
Methods: Plantar sensitivity was evaluated by esthesiometry, and speed of center of pressure shift data during upright posture were evaluated for each foot using a baropodometer while the subjects were standing with eyes open or closed. The young adult group was evaluated for center of pressure in normal conditions and after plantar sensitivity disturbance, by immersing their feet in water and ice.
Results: Young adults did not show alterations in their center of pressure after sensorial perturbation and presented, even under sensorial perturbation, better postural control than elderly subjects. The elderly showed lower foot sensitivity and greater center of pressure oscillation than young adults.
Conclusion: Elderly subjects seem to rely more on foot sensitivity for control of body sway than young adults. In the elderly, a clinical intervention to improve foot sensitivity may help in upright posture maintenance.

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Efeitos da manipulação da sensibilidade plantar sobre o controle da postura ereta em adultos jovens e idosos

R E S U M O

Introdução: Pessoas com perdas sensoriais apresentam déficits de equilíbrio. Embora esse quadro seja comum em idosos, ainda se discute o quanto idosos sem doenças que afetam as vias sensoriais dependem dessa informação para controlar oscilações corporais durante o controle da postura.
Objetivo: Investigar os efeitos da perturbação da sensibilidade plantar sobre o controle da postura ereta em adultos jovens e idosos independentes (n = 19/grupo).

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Métodos: A sensibilidade plantar foi avaliada com estesiômetro e dados de velocidade e deslocamento do centro de pressão durante a postura de pé foram avaliados para cada pé com um baropodômetro, em condições de olhos abertos e fechados. O grupo de adultos jovens foi avaliado quanto ao centro de pressão nas condições normal e pós-perturbação da sensibilidade plantar, pela imersão dos pés em água e gelo.

Resultados: Adultos não apresentaram alterações no centro de pressão em resposta à perturbação sensorial e tiveram, mesmo na condição de perturbação sensorial, melhor controle postural do que idosos. Idosos apresentaram menor sensibilidade plantar e maior oscilação do centro de pressão do que os adultos jovens.

Conclusão: Idosos pareceram depender mais da sensibilidade plantar para manter o controle postural do que adultos jovens. Em idosos, intervenções clínicas que melhorem a sensibilidade plantar podem auxiliar na tarefa de manter a postura de pé.

Introduction

The control of upright posture is a skill required daily and which depends on constant neuromuscular adjustments to keep the center of pressure (CoP) within the stability limits of the supporting base.[1] These adjustments suffer deterioration by the aging process.[2] One reason for the occurrence of these deficits may be the loss of sensory function or usability of this sensory information. When subjected to situations where proprioceptive functions of the foot and ankle are compromised, young adults have a lower length and area of CoP shift *versus* elderly subjects, suggesting an improved ability to compensate for sensory loss.[3,4]

Billot et al.[5] suggest that plantar sensitivity is not a primary function for posture control in adults, since this information can be compensated by other proprioceptive pathways, for example, vision or vestibular system. However, posture control seems to be associated with plantar sensitivity in the elderly, where other systems also have deficits in response to aging, for example, losses in vestibular system function, vision and muscle strength.[3] Ducic et al.[6] showed that the reduced plantar sensitivity relates to deficits in postural control of elderly patients with peripheral neuropathy. In addition, plantar sensitivity contributes to the control of plantar pressure during upright posture in the elderly.[7] This helps to explain the fact that older people sometimes show greater reliance on vision, especially for the control of CoP velocity, than young adults.[8] However, there is still doubt as to the degree of contribution of this kind of sensory information from the plantar region for the regulation of postural control in healthy elderly.

Experimental studies have developed protocols that reduce temporarily the adult sensory function, for example, the activity of mechanoreceptors, in order to mimic sensory decline of aging and facilitate a comparison between this intact *versus* impaired afferent resource. One strategy that has proved valid in some studies consists in the immersion of the lower limbs in water and ice, in order to reduce plantar sensitivity, two-point touch discrimination ability, and sensitivity to vibration.[9]

In this study, our aim was to assess changes in the position of CoP under each foot, which is considered as an indicator of postural control in the elderly and in young adults in normal sensory condition and in response to a sensitivity disturbance.

Considering that aging can promote heterogeneous losses in different sensorimotor (cognitive and sensory/perceptual processing) components,[10] our hypothesis was that reduced plantar sensitivity would exert different impact for the elderly compared to young adults, because young adults would have the capacity to regulate CoP satisfactorily, even under conditions of disturbance in the sensory characteristics of their feet, indicating that this type of information is more important for the elderly than for young adults.

Materials and methods

Participants

Thirty-eight participants invited from the local community were divided into two groups matched for height and body mass. The group of young adults included 19 subjects with mean (SD) age of 35 (5) years, height of 1.65 (0.08) m, and body mass of 63 (10) kg. The elderly group consisted of 19 independent elderly subjects with mean (SD) age of 79 (6) years, height of 1.55 (0.05) m, and body mass of 68 (9) kg. The group of young adults was evaluated in two conditions: one pre- and the other post-sensory disturbance, making a total of three groups in the final analysis: adults without sensory disturbance, post-sensory disturbance adults, and elderly subjects. All participants signed an informed consent in accordance with the Declaration of Helsinki and this study was approved by the Human Research Ethics Committee of the local institution (opinion 082 011). All participants ought to be in a physical condition to walk and to stand on their own feet with no orthosis or prosthesis; moreover, they should be available to visit the laboratory to be part of the evaluations. Exclusion criteria included the presence of cerebellar disease, plantar skin lesions, lower limb traumatic injury history, neuropathy or inability to perform the proposed tasks.

Assessment of plantar sensitivity

Before engaging in the assessment of plantar sensitivity, participants had 10 min of rest, sitting in a chair. The plantar sensitivity was evaluated according to a clinical protocol using a Semmes-Weinstein pressure esthesiometer
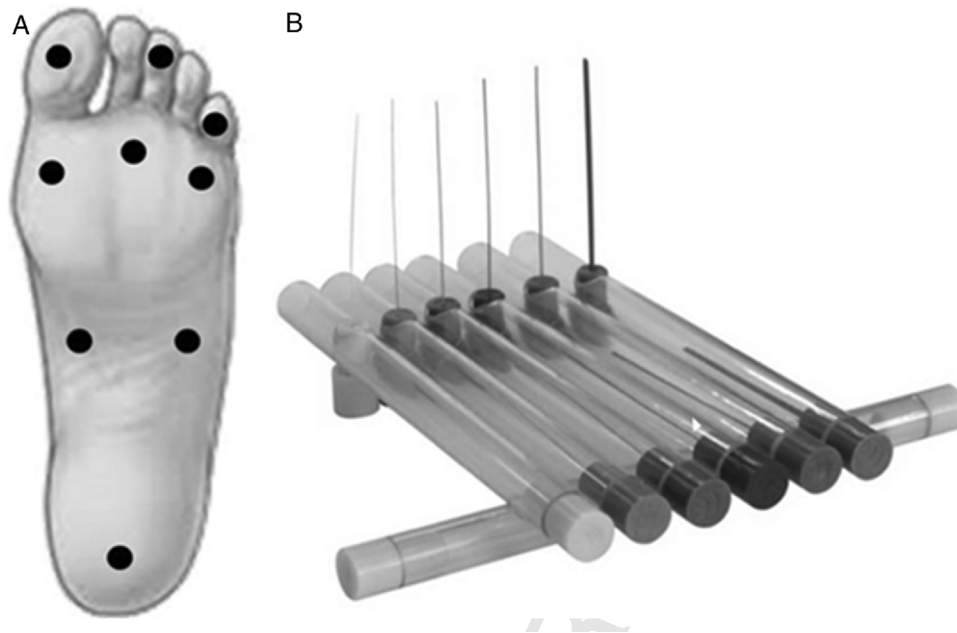
Fig. 1 – Illustration of the points where plantar sensitivity was evaluated and the esthesiometer used in the study.

(Semmes-Weinstein Monofilaments, San Jose, USA).[11,12] The esthesiometer consisted of 6 nylon filaments of equal length (Fig. 1A) with varying diameters, able to produce a standardized pressure on the skin surface (considering six values from 0.05 gf to 300 gf) in accordance with calibration and recommendation for use.[13]

During the assessment, all participants were blindfolded and in a supine position in a quiet and distraction-free environment. All participants were evaluated by the same evaluator. Plantar sensitivity was evaluated in nine different locations of the foot (Fig. 1A) in a randomized order, with an alternation of feet in the evaluation of each participant. Participants indicated in their palm the area where they perceived the tactile stimulus on their feet. All evaluations were performed in the same period of the day. Plantar sensitivity was determined by the initial application of the thin filaments, progressing to the thick filaments until the participant would be able to detect the touch.[14] These touches were performed during 1 second and with two repetitions, so that the filament would take a C-shaped form.

Each filament corresponded to a classification based on their colors, in which green and blue corresponds to a normal sensitivity; violet corresponds to some difficulty of shape and temperature discrimination; red denotes slight loss of a vulnerable to injury, protective sensation; orange denotes a slight loss of protective sensation; pink denotes loss of protective sensation and no response at all.

To determine the sensitivity of the entire foot, the sum of the values for each region was calculated. Thus, the higher the score, the lower the plantar sensitivity.

Postural control assessment

Data acquisition for the evaluation of CoP was made during the standing posture with bipedal support, feet positioned in an abduction of 30° [15] with the heels kept 5 cm apart and arms relaxed beside the upper body in two situations: (a) looking toward a fixed point 4 meters ahead and at eye level; (b) with closed eyes.[3]

For each visual condition, three attempts of 30 s each were made, the first condition alternating between open and closed eyes in each participant assessed. For all participants, a 30-second interval was observed between attempts. CoP data were collected for each foot with the use of a baropodometer (Tekscan Inc., Boston, MA), with a sampling rate of 100 Hz The following variables were measured: average speed of CoP (CoPsp), anteroposterior (CoPap) and mediolateral (CoPml) amplitude, considering the contact area of each foot with the surface.

Plantar sensitivity disturbance

The plantar sensitivity disturbance protocol was applied only to young adult participants, and aimed to simulate a sensory decrease in foot area – a common finding in the elderly. The disturbance protocol was conducted through hypothermia, similar to the protocol previously used.[9,16] For the generation of the disturbance in order to obtain the plantar sensorial information, participants completed the protocol in a comfortable sitting position and kept their feet immersed in a container with ice and water, at a controlled temperature between 5 °C and 8 °C for 15 min.[3] For the evaluation of CoP after immersion in ice, participants moved immediately from the position described to the standing position on the baropodometer.

Data analysis

Data were grouped (mean and standard deviation) for each group. Data normality was verified with Shapiro–Wilk test.

Table 1 – Plantar sensitivity scores (data expressed as mean and standard deviation) in each foot. The sum of all points for each foot represents the sensitivity of the whole foot. Higher values represent worse sensitivity.

	Young adults		The elderly	
	Right foot	Left foot	Right foot	Left foot
Mean	24.7	25.2	46.2[a]	46.6[a]
Standard deviation	4.0	5.3	12.1	14.1

[a] Statistically significant difference among groups verified by paired t test ($p < 0.05$).

Plantar sensitivity was compared between right and left feet of young adults using the paired t test; in the elderly, the Wilcoxon test was applied. The independent t test was used to compare groups. To obtain an analysis of asymmetries and the effect of vision on CoP data, for all groups and conditions the Wilcoxon test was used. From CoP measurements, young adults, post-sensory disturbance young adults, and elderly groups were compared by analysis of variance, with the *post hoc* Bonferroni test. In all tests, a 0.05 significance level was set.

Results

The normality test for sensitivity showed a parametric distribution in young adults for the right ($p = 0.064$) and left ($p = 0.177$) leg; and for the elderly, a parametric distribution for the right leg ($p = 0.175$), and a non-parametric distribution for the left leg ($p = 0.018$) were observed. The sensitivity data were analyzed only for the right foot, as there were no asymmetries in these observations in young adults [t (18) = –0.529; $p = 0.603$] and in the elderly [$Z = –0.393$; $p = 0.694$]. The plantar sensitivity results showed that young adults had a better sensitivity than the elderly for both feet (Table 1). As to the analysis of CoP (Fig. 2), it was found that the visual deprivation did not change any variable of CoP; furthermore, no asymmetries were observed (Fig. 3). Thus, subsequent comparisons were performed using data of the analysis of trials with eyes open and using data from the right foot.

Analyzing the amplitude of CoP shift, a group effect was not observed in the anteroposterior direction [$F(2) = 2.348$; $p = 0.105$]. On the other hand, in the assessments of CoP shift in the mediolateral direction, a group effect was observed [$F(2) = 5.622$; $p = 0.006$]. The *post hoc* analysis indicated similarity among young adults *versus* young adults after sensory disturbance ($p = 1.000$). However, elderly subjects had greater mediolateral shift of CoP *versus* young adults ($p = 0.017$), and young adults after sensory disturbance ($p = 0.015$).

In the same line, a group effect was observed for CoP speed [$F(2) = 7.587$; $p = 0.001$]. The *post hoc* analysis indicated that the group of young adults after sensory disturbance was not different from the "without sensory disturbance" condition ($p = 1.00$). However, young adults prior to ($p = 0.006$) and after ($p = 0.003$) plantar sensitivity disturbance showed lower values *versus* the elderly.
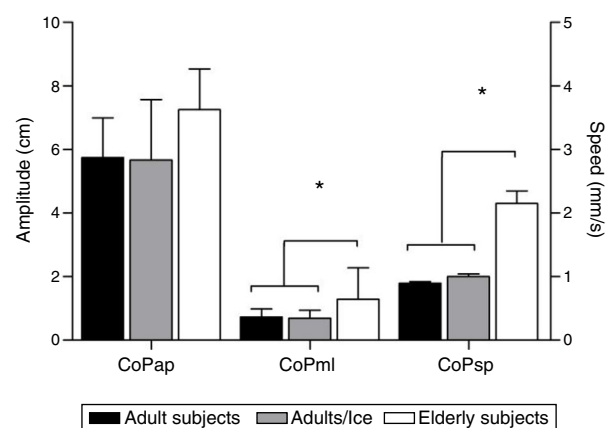

Fig. 2 – CoP amplitude values in anteroposterior (CoPap) and mediolateral (CoPml) directions, in centimeters, on the left vertical axis, and CoP speed (CoPsp) in millimeters per second (mm/s) on the right vertical axis for each group ($n = 19$ per group). *It indicates statistically significant difference between groups, confirmed by an analysis of variance with *post hoc* Bonferroni ($p < 0.05$).

Discussion

Trying to simulate in young adults the losses in plantar sensitivity experienced by the elderly, we conducted a sensitivity disturbance protocol for plantar sensitivity in young adults. Although this same sensory disturbance protocol has generated changes in plantar sensitivity of adults in a previous study,[3,9] the impact of this acute disturbance cannot be regarded as equivalent to that experienced by the elderly, in whom these deficits are present in a continuous and progressive manner.[11] However, this is not a specific limitation of our study, but of all studies which seek to investigate this type of question. In addition, differences can also depend on the ability of adults to use information coming from other afferent pathways, possibly the vestibular system, to control CoP.[17]

There was no asymmetry between the feet with respect to the sensitivity or the oscillation of CoP, which indicates that the evaluated participants showed no influence of functional lateralization in a simple task such as the proposed protocol. Deprivation of visual information and the change in plantar sensitivity did not lead to changes in postural control standards measured in young adults. Nevertheless, some literature findings indicate that individuals of all ages depend on the
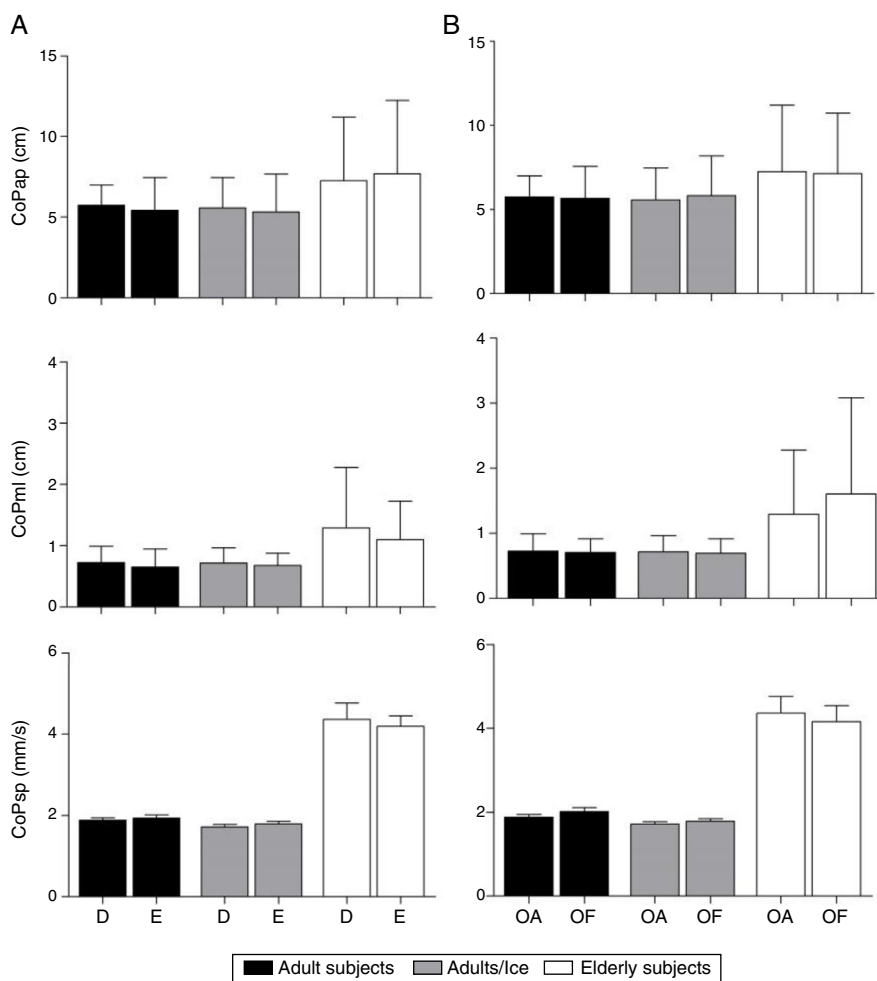
Fig. 3 – Mean (bars) and standard deviation of anteroposterior amplitude of the center of pressure (CoPap) and mediolateral amplitude of the center of pressure (CoPml) in centimeters, and center of pressure shift speed (CoPsp) for each group ($n = 19$ per group) in millimeters per second (mm/s). The left column (column A) displays values for both feet, where R indicates right foot and L indicates left foot. In the right column (column B), values are presented for visual conditions with open eyes (OE) and closed eyes (CE). For both analysis of comparison between right and left foot, the Wilcoxon test was used, with a significance level of 0.05.

plantar sensitivity to maintain balance in the standing posture, and old age leads to an increased body sway.[18] Ueda et al.[3] found an increase in anteroposterior shift of CoP of the whole body in the elderly, compared to young adults, and our evaluation of CoP for each foot showed that the mediolateral amplitude of CoP is greater in older subjects than in young adults (with or without sensory disturbance). This result is relevant, since the measurement of the mediolateral amplitude is important for predicting the risk of falls in the elderly population[19]; thus, our result is an indicator of vulnerability to falls in elderly patients with compromised plantar sensitivity. The same happened with CoP velocity, which remained higher in elderly *versus* young adults before and after sensory disturbance, meaning a worse performance in controlling the standing posture. This variable is described by Hewson et al.[20] as being useful in the classification of elderly people with and without risk of falls. Again, we find a variable that can indicate

the negative influence of reduced sensitivity on the stability of the elderly.

Our results corroborate the findings of a recent study[21] that also found no increase in CoP shifts when visual information was not available, or with disturbance of the sensitivity of adult feet.[22] This recent study has shown that sole cooling does not alter the balance control either with or without vision information available. In our study, even when visual information was unavailable and the sensory plantar information was disturbed, young adults continued to have better postural control than the elderly. This can be explained by the possibility that, for adults, decreases in the temperature of the plantar area induce a readjustment in the use of sensory information, in the search for preservation of postural control in the face of the experienced deficits, with special attention to other afferent pathways, such as vestibular information.[21]

Yasuda et al.[17] point out that the major mechanism contributing to the control of orthostatic posture is the vestibular system. Knowing that this system is impaired with advancing age,[23] it can be inferred that adults get better postural control values that the elderly because, even with the deprivation of vision and in a scenario of plantar sensitivity disturbance, the young adults maintained a body adjustment system in better condition. On the other hand, knowing that vestibular problems are one of the most common causes of dizziness and imbalance in the elderly,[24] and considering that the loss of plantar sensitivity in elderly people is related to the greater fluctuation of the CoP, it may be suggested that interventions that aim to maintain or reduce losses in plantar sensitivity can help maintaining postural balance to compensate for compromises in CoP under the acute effect of the disturbance. We did not evaluate post-hypothermia sensitivity because studies show that the effect of the immersion of the feet in water and ice on postural control can be compensated for shortly after the end of the immersion.[9] An evaluation of sensitivity after immersion in water and ice would require a time that would cancel the effects of sensory change sought by our group. On the other hand, other studies were published indicating that this type of protocol is effective for plantar sensitivity disturbance.[12,25] In our study, we considered the measurement of CoP in each foot, because the determination of plantar sensitivity is done on each foot. While this may not be a limitation in our discussion, our procedure still leaves room for an investigation that also monitor the shift of the center of gravity, allowing a broader view of postural stability in response to disturbances in plantar sensitivity.

Conclusion

The elderly and young adults differ in relation to their dependence on plantar sensitivity in order to maintain the upright posture, on the basis of CoP measures, wherein the plantar sensory information appears more important for the elderly. It is possible that clinical interventions that improve the plantar sensitivity in the elderly can contribute to improve the control of orthostatic posture.

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Conflicts of interest

The authors declare no conflicts of interest.

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