ORIGINAL ARTICLE

Age-related effect of visual biofeedback on human balance control

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Abstract

Real-time visual biofeedback (VBF) is a voluntary control mechanism of postural activity using additional visual information of the centre of pressure (CoP) position.

The aim of the study was to examine balance control performance in subjects of different age during the stance on different support surfaces with and without VBF.

The study was performed on 20 young and 13 older subjects during stance on firm and foam surface in the conditions with and without VBF. Body sway was measured by force platform (CoP) and by two accelerometers located on the upper (Th4) and lower trunk (L5).

Additional VBF showed the improvement of body balance with decreased CoP parameters RMS (root mean square), Ax (amplitude of postural sway in left-right direction) and Ay (amplitude of postural sway in forward-backward direction) in both age groups, but not with the same extent. Elderly subjects were able to improve their balance only during the stance on foam surface. Trunk tilts recorded by accelerometer at L5 level showed reduction of measured parameters only in the group of young subjects. Body tilts recorded by accelerometer placed at Th4 level showed no reduction of parameters.

The present results confirm knowledge about the stabilizing effect of additional VBF in stance control. Young subjects are able to improve their balance using additional VBF during the stance on both types of support surface more effectively than elderly subjects. However, the extent in which VBF of the CoP position can reduce postural sway is limited mainly on CoP displacements.

Introduction

Many aspects of postural control decline with age and then the postural deficits are a contributing factor to an increased likelihood for falls in many older adults (Shumway-Cook & Woollacott 2000). One third to one half of all people over the age of 65 years fall at least once per year (Geiger *et al* 2001) and a prolonged fear of falling as a result decreases their activity levels (Tinetti *et al* 1988). Subsequently, decreased mobility resulting from fear or injury can cause a decline in independence (Geiger *et al* 2001).

Sensory biofeedback offers the possibility to improve the postural stability in older people. Biofeedback system for postural control is aimed at providing additional sensory information to supplement the natural sensory information and improve human balance (Giansanti *et al* 2009). It consists of supplying individuals with additional artificial information about body orientation and motion to substitute or supplement the natural visual, somatosensory and vestibular information (Vuillerme *et al* 2008b).

Additional visual feedback is a control mechanism of postural activity using visual inputs. Visual biofeedback system is often used for treatment of balance disorders (Geiger *et al* 2001). Previous research has shown that standing sway can be reduced when real-time visual feedback of the centre of pressure (CoP) position is provided. Many studies reported improvements in postural stability after visual biofeedback-based training of balance in elderly (Rose & Clark, 2000; Sihvonen *et al* 2004; Hatzitaki *et al* 2009). However, the extent to which biofeedback information can improve balance has not been determined yet. It is unknown why additional sensory feedback is more effective for some subjects than others and in some environmental contexts than others (Dozza *et al* 2005; 2007). It is also still not clear whether any improvements in laboratory-based measures of balance and mobility are reflected in a larger reduction of falls and in a better ability to execute mobility tasks in the daily life environment (Zijlstra *et al* 2010).

Material & methods

Twenty young subjects (6 men and 14 women) within the range of 19–29 years (mean age 23.5 years) and thirteen elderly (6 men and 7 women) within the range of 66–82 years (mean age 72.9 years) participated in the study. None of the subjects reported previous or present diseases or injuries associated with gait and/or balance impairments and neurological diseases. All subjects gave written informed consent prior to participation and the local Science Ethical Committee approved the experimental protocol.

The balance control of young and older subjects was measured during the quiet stance in four conditions: stance on a firm surface with eyes open; stance on a foam surface (thickness 10 cm) with eyes open; stance on a firm surface with VBF and stance on a foam surface with VBF. The participants were informed to stand upright and relaxed on the platform barefoot with heels together and feet displayed at angle of about 30°. In conditions with eyes open subjects were instructed to keep eyes open fixing to a black point with a diameter 2 cm placed on a white scene in front of them at a distance of 2 m.

Visual feedback was realized by watching a screen situated in front of subject's eyes in a distance of 1 m. Subjects were informed about their body tilts as a moving red point on the screen (38 × 31 cm) controlled by a force platform. Signals (CoP positions) from a force platform provided the actual information about the body sway magnitude and direction for postural control during stance. Shift 1cm in reality was equal to shift 1cm of the light spot on the screen. Each trial lasted 50 s.

The body sway was quantified by displacements of the CoP in the forward-backward (FB) and left-right (LR) direction. The custom-made force platform with automatic subject's weight normalization was used.

Trunk tilts in FB and LR directions were measured by two ADXL203 dual-axis accelerometers with signal conditioned voltage outputs. Sensors measured both dynamic and static acceleration with a full-scale range of ±1.7 g. The acceleration output was low-pass filtered with cut-off frequency of 5 Hz and the output (trunk inclination) was calibrated in stationary conditions for ±10 degrees range of body tilt. The accelerometers were positioned at the spinal column of the upper trunk at the level of the fourth thoracic vertebra (Th4) and the lower trunk at the level of the fifth lumbar vertebra (L5).

The CoP displacements and the angle of trunk tilts were sampled at 100 Hz and recorded on MacPC. Obtained data were analyzed with MATLAB program. Three parameters were evaluated: Ay (amplitude of postural sway in FB direction), Ax (amplitude of postural sway in LR direction) and RMS (root mean square of the statokinesigram). RMS characterizes the overall stability of upright posture independently on the direction of postural sway (Hlavačka *et al* 1990). The values of parameters recorded from CoP displacements and trunk tilt angles were averaged for each subject in each experimental condition.

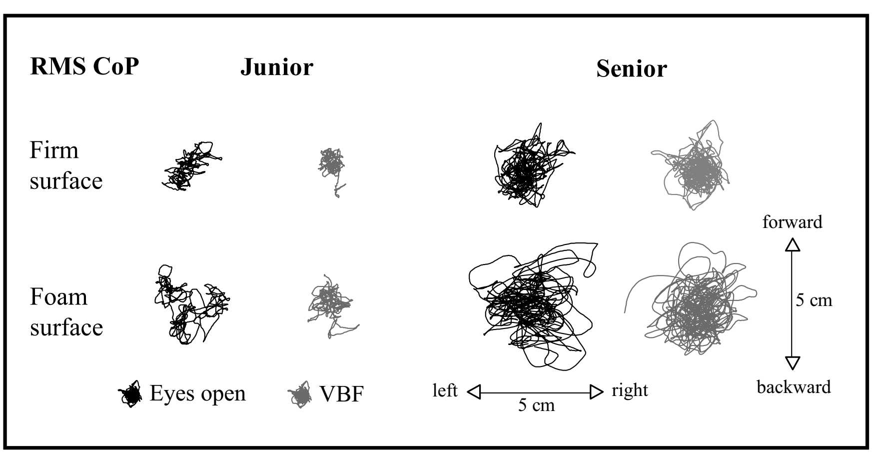

Fig. 1 Statokinesigrams of typical junior and senior subject in four tested conditions. The decrease of CoP displacement in the situations with VBF is mostly evident in a young person during the stance on foam support surface.

Tab. 1. F coefficients from 2-way repeated measures ANOVA of parameters RMS, Ax and Ay from CoP, lower trunk (L5) and upper trunk (Th4). *$p<0.05$, **$p<0.01$, ***$p<0.001$.

A

RMS	VBF	VBF - age	VBF - surface
Th4	0.817	5.795*	1.252
L5	8.721**	4.475*	5.230*
CoP	44.402***	13.426***	38.833***

B

Ax	VBF	VBF - age	VBF - surface
Th4	8.687**	4.282*	0.362
L5	3.737	6.578*	5.283*
CoP	14.877***	8.040**	30.726***

C

Ay	VBF	VBF - age	VBF - surface
Th4	0.000	3.995	1.005
L5	7.406*	1.746	2.239
CoP	40.391***	8.420**	22.102**

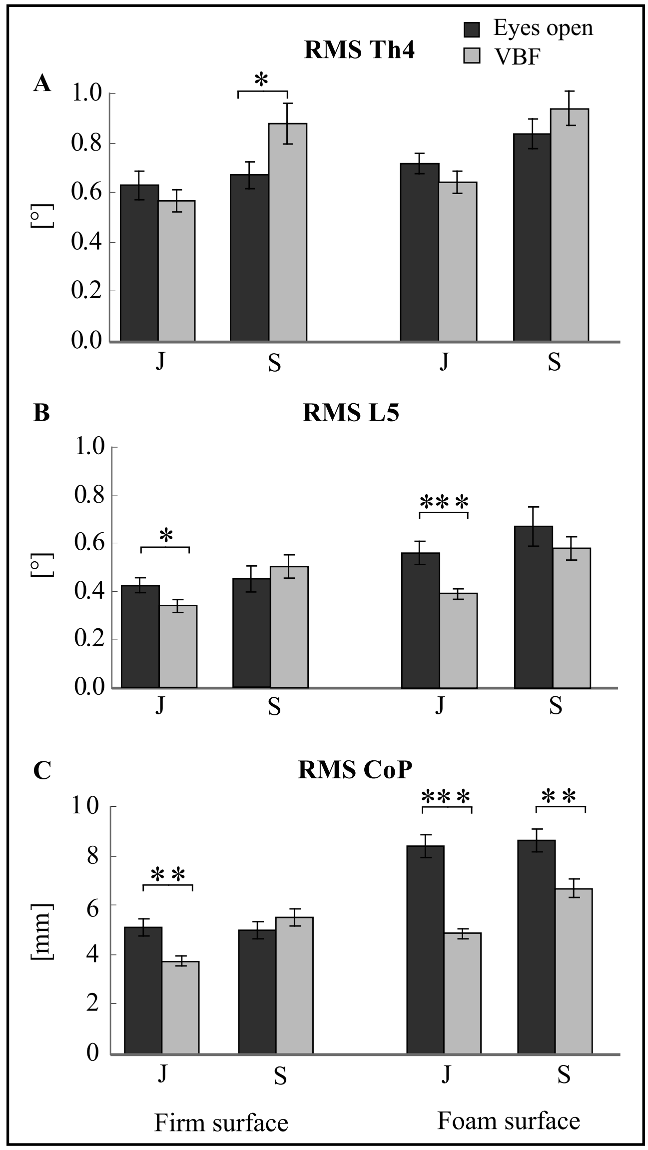

Fig. 2 The grouped averages of values of parameter RMS from CoP, lower trunk (L5) and upper trunk (Th4) during the stance with eyes open (black) and with VBF (gray) on firm and foam surfaces. The averaged data are presented as mean values ± SEM from the data of twenty juniors (J) and thirteen seniors (S). *$p<0.05$, **$p<0.01$, ***$p<0.001$

Data were statistically analyzed using 2-way repeated measures ANOVA with the within-subject factors: 1.) VBF – eyes open, 2.) foam support – firm support. The between-subjects factor was age. The differences between age groups and support surfaces were subsequently verified using Student's t-test, p-values < 0.05 were considered significant.

Results

The results showed that the postural improvement due to VBF was the most evident by decrease of CoP displacement. For the illustration see statokinesigrams of typical young and elderly subjects (***Fig. 1***).

The results from 2-way repeated measures ANOVA (***Tab. 1***) showed statistically significant influence ($p<0.001$) of additional visual information (VBF) on all measured parameters: RMS (***Tab. 1A***), Ax (***Tab. 1B***) and Ay (***Tab. 1C***) recorded by the force platform (CoP). All of these parameters decreased during the situations with VBF. Data from the accelerometer placed at lower trunk (L5) showed the statistically significant influence of VBF on parameters RMS and Ay. Data from the accelerometer placed at upper trunk (Th4) showed no statistically significant effect of VBF on reducing body sway. On the contrary we observed statistically significant increase of parameter Ax ($p<0.01$) during the situations with VBF (***Tab. 1B***, black cell).

We also observed a significant effect of age on postural sway during the situations with VBF. Decrease of values RMS, Ax and Ay was lower in older subjects than young subjects. The influence of age on postural sway for all measured parameters was the most evident on the CoP ($p<0.01$) and less but still significant for parameters RMS and Ax at lower trunk (L5) ($p<0.05$). Contrary, the statistically significant increase ($p<0.05$) of parameters RMS and Ax was observed at upper trunk (Th4) (***Tab. 1B***, black cell).

Significant interaction was also found between the factors: VBF – surface. VBF led to a larger reduction of RMS when subjects were standing on the foam surface than on the firm surface. The effect of support surface type on parameters RMS, Ax and Ay was the most significant ($p<0.01$) on CoP. It decreased at lower trunk (L5) but still had significant influence on parameters

RMS and Ax ($p<0.05$). The effect of VBF was practically negligible at upper trunk (Th4).

Subsequently Student's t-test was applied to clarify the differences between both age groups and support surfaces. For all three measured parameters were the results very similar with the same tendencies therefore only graphs of parameter RMS are represented for illustration (***Fig. 2***). The graphs show the influence of VBF depending on age and support surface. For CoP the statistically significant decrease of RMS values was observed in the group of young ($p<0.001$) and also in the group of older ($p<0.01$) subjects during the stance on foam surface with additional visual information. During the stance on firm surface only young subjects ($p<0.01$) were able to decrease their body sway due to VBF (***Fig. 2C***).

Data from the accelerometer placed at lower trunk (L5) showed the statistically significant decrease of RMS values during the stance on firm ($p<0.05$) and also on foam ($p<0.001$) surface only in the group of young subjects (***Fig. 2B***).

From the accelerometer placed at upper trunk (Th4) no reduction of body tilts in the situations with VBF was observed. Even statistically significant increase ($p<0.05$) of RMS in the group of older subjects during the stance on firm surface was found (***Fig. 2A***).

Discussion

The main purpose of this study was to investigate age-related changes in the postural responses to the additional visual information during upright stance. Our results are in agreement with previous studies about stabilizing effect of VBF on human stance control (Hlavačka & Šaling 1986; Hlavačka & Abrahámová 2009; Cawsey *et al* 2009). According to our results the postural effects of visual CoP feedback differed depending on the somatosensory inputs from the foot. Our findings about stabilizing effect of VBF during the stance on foam support surface in both age groups are not in a fully agreement with older findings of Hlavačka and Šaling (1986). They found out that the compensatory effect of visual biofeedback in stabilization of upright posture during stance on a foam surface was practically negligible. Possible reason for this disagreement could be due to using different method of visual feedback (oscillograph with afterglow 1 s) and small density of foam. The foam makes balance-related proprioceptive information less reliable and leads to greater postural sway during the stance with eyes open or closed (Abrahámová & Hlavačka 2008). Contrary, condition with foam support surface likely activates the brain function with sensory interaction and has a greater stabilizing effect on postural stability during the condition with additional visual information. Especially elderly people were relied upon to a greater extent on the visual feedback when standing on a foam surface. These findings are in agreement with recent studies of Vuillerme *et al* (2008a) and Cawsey *et al* (2009). They suggest increasing reliance on augmented sensory information for controlling upright posture in conditions of altered somatosensory input from the foot and ankle. Standing on a foam surface causes changes in sensory biofeedback that are not restricted to the proprioceptive system. The principle of sensory re-weighting causes increased reliance on augmented visual information. From vision alone it is not able to observe changes in standing balance due to unmagnified visual biofeedback. The balance control may be more responsive to VBF if balance is made more difficult by standing on a compliant surface.

Therefore it is likely that improvement of body sway during the stance on the foam surface in elderly may suggest a greater reliance on vision to maintain balance in the foam condition. However we found out the positive effect of VBF on stance control, the extent in which it reduced postural sway was limited mainly on CoP displacements. The postural parameters of upper trunk tilts were increased when the additional visual information was provided. When body tilts were recorded from upper parts of the body, the less significant reductions were observed. At the most distal part of the body (Th4) we even observed the opposite effect: statistically significant increasing of postural sway.

According to these results we can conclude that the CoP based VBF has the most stabilizing effect on CoP postural sway, less on lower trunk body tilts and disturbing effect on upper trunk body tilts. It seems VBF is the most effective in reducing postural sway mainly on the segment from which it is sensing. Further studies are needed to compare the effectiveness of visual biofeedback with sensor placed at different body segments to confirm these findings.

We also found out that older people are not able to utilize the additional visual information about their body tilts as effectively as young adults. We suggest that elderly may need greater magnification of additional visual information of CoP position. Likely, the real unmagnified display of the CoP position was adequate and beneficial for young subjects but it provided limited information for elderly. Slight impairment in sensory interaction in elderly is a consequence of natural aging process and it might cause small balance impairment.

Therefore more details are needed in understanding of how is biofeedback information combined with natural sensory information and which aspect of additional information in which situation is the most useful and relevant for improving balance in elderly population to adjust the biofeedback devices for their balance rehabilitation.

Acknowledgments

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Conflict of interest statement

All authors confirmed their agreement to submission and declared that they have no competing financial interests.

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