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Effectiveness of different visual biofeedback signals for human balance improvement

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ABSTRACT

The aim of this study was to examine the effectiveness of visual biofeedback (VBF) signals from a force platform and accelerometer sensors placed on different body segments. The study was performed on 20 young subjects during standing on a firm and foam support surface with a VBF signal sensed from CoP, lower trunk (L5) and upper trunk (Th4). The VBF signal was controlled by 2D-movement of chosen body segment, which was presented as a red point on a monitor screen. Location of VBF signal had a significant effect on each postural parameter of CoP and trunk segments. RMS and amplitudes of postural sway in medial–lateral and anterior–posterior directions decreased during standing on both types of support surface due to VBF. L5-VBF and CoP-VBF significantly reduced CoP displacements and lower trunk tilts. Th4-VBF reduced upper trunk tilts. Frequency analysis of postural sway revealed a decrease of power spectral density (PSD) values in low frequency range (0.02–0.3 Hz) and an increase of PSD values in higher frequency range (0.5–1.4 Hz) in the VBF conditions during the stance on the firm surface in anterior–posterior direction. Reduction of body sway was the most significant in the body segment from which the VBF signal was sensed. The CoP position and L5 position provided the best signals for VBF. Changes in frequency ranges of body sway suggest voluntary activation of balance control. The results open new opportunities to optimize VBF system for balance improvement using accelerometers.

1. Introduction

Undisturbed upright stance control is a complex task based on an integration process involving visual, vestibular and proprioceptive information [1]. Postural stability is often evaluated by outputs from the force platform, which measures the centre of foot pressure (CoP) variability. However, posturography has its limitations because human body is multi-segmental and does not always act as an inverted pendulum. Upper body segments are often more independent from lower body segments, especially in challenged situations [2].

Visual biofeedback (VBF) consists of supplying individuals with additional artificial visual information about body motion to supplement the natural visual information and improve human balance [3]. The use of real-time visual biofeedback (VBF) from CoP during a standing task is a common tool incorporated in evaluation and training of the postural control [4]. The CoP position is presented in real time on a monitor screen and the subject is required to confine it to the narrowest possible zone [5].

The sensor of body motion is, besides the processor and interface, one of the main components of each biofeedback device [6]. The question of optimal sensor location for VBF has not been examined yet, despite the fact that accelerometers allow to measure inclination of body segment with respect to the vertical position. They can be attached to any part of the body. Body tilts measured by the accelerometer could be displayed on a monitor screen as well as outputs from a force platform. That offers new possibilities for VBF experiments.

In the present study, the effectiveness of VBF sensed from accelerometers attached to upper and lower trunk and VBF sensed from CoP were investigated. It was hypothesized that VBF from accelerometer attached to lower trunk would have similar influence on the body sway as VBF from CoP, because both reflect similar postural activities.

2. Methods

Twenty young subjects (9 men and 11 women) within the range of 20–33 years (mean age 22.6 years, mean BMI 21 kg m^{-2}) participated in the study. Subjects did not report any neurological, orthopaedic, or balance impairments. They gave their informed

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consent in agreement with the Declaration of Helsinki. The study was approved by the local Ethics Committee.

Balance control was measured in eight conditions: standing on a firm (EO)/foam (thickness 10 cm) surface (FEO) with eyes open (control conditions); standing on a firm/foam surface with VBF based on the force platform outputs (CoP-VBF) or 2D signals from accelerometers attached on lower trunk (L5-VBF) and upper trunk (Th4-VBF). The participants stood on the platform barefoot with heels together and feet positioned at an angle of about 30°. During control conditions, subjects were instructed to fix the gaze on the black point placed in a white scene in front of them at a distance of 1 m, to sway as little as possible and to breathe normally. In conditions with VBF, they were instructed to minimize the extent of the red point movements around the centre of the monitor (38 cm × 31 cm) placed at a distance of 1 m in front of the subject (Fig. 1). Participants were informed which body segment is actually displayed on the monitor screen and they had time for practicing before each VBF condition. VBF was magnified twice: 1 cm shift of CoP in real was equal to 2 cm shift on the screen. Each trial lasted for 50 s.

CoP displacements in the anterior–posterior (AP) and medial–lateral (ML) directions were measured by the custom made force platform with 3 force transducers inbuilt, equipped with automatic weight correction for direct output of CoP. Trunk tilts were measured by two ADXL203 (Analog Devices, Inc., MA, USA) dual-axis accelerometers with signal conditioned voltage outputs. The sensors measured in particular the static acceleration (gravitational part) with a full-scale range of ±1.7 g. The output was low-pass filtered with cut-off frequency of 10 Hz and the output (trunk inclination) was calibrated in stationary conditions for ±10° range of body tilt. The accelerometers were positioned at the spinal column at the level of the fourth thoracic vertebra (Th4) and at the level of the fifth lumbar vertebra (L5) using an adhesive tape and flexible belt. The CoP displacements and the angle of trunk tilts were sampled at 100 Hz and directly recorded on a MacPC. The obtained data were analyzed with MATLAB programme. Three parameters from CoP, lower trunk (L5) and upper trunk (Th4) were evaluated: root mean square (RMS), amplitudes in AP direction (A_{ap}) and amplitudes in ML direction (A_{ml}).

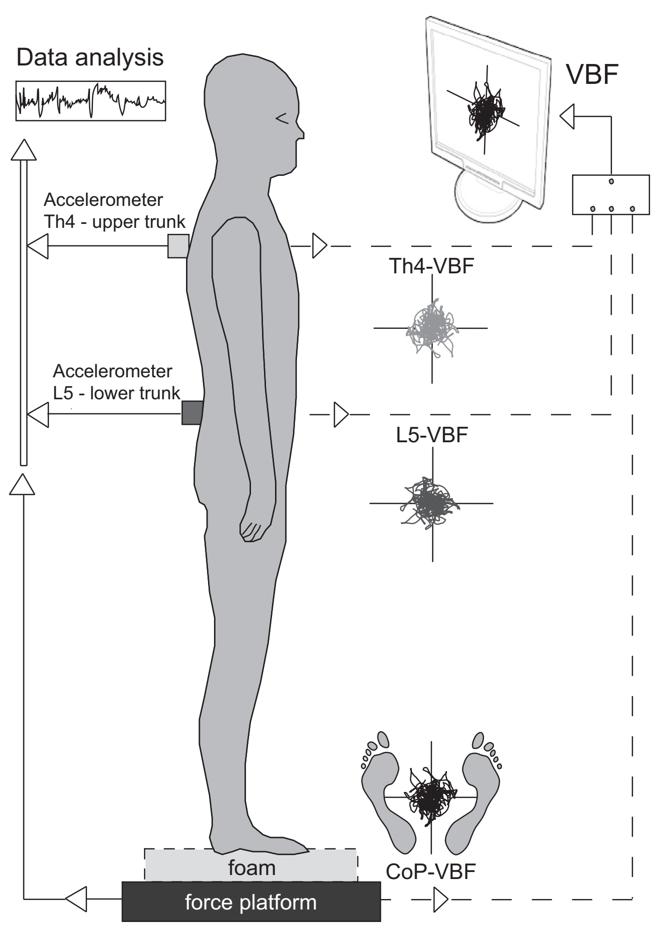

Fig. 1. Schematic illustration of the VBF system. A signal either from CoP, L5 or Th4 is presented on a monitor screen. Simultaneously, all measured data from a force platform and both accelerometers are recorded and analyzed on a PC.

Repeated measures ANOVA (main factors: surface and VBF location) were performed on each variable and body segment separately. Greenhouse–Geisser adjustments were performed in the cases, where the assumption of sphericity was violated. *Post-hoc* pairwise comparisons with Bonferroni adjustments were performed on each level of surface for further exploration of differences between VBF conditions and control conditions.

For direct comparison between VBF conditions, RMS values were normalized to control conditions as 100%. Repeated measures ANOVA were performed for three factors: surface, VBF location and body segment. Pairwise comparisons and simple contrasts were used to further explore differences between the means.

Power spectral density was evaluated during the standing on the firm surface in all conditions for CoP and trunk tilts in AP direction. PSD data were normalized to the control condition (EO) by mean values of PSD. Repeated measures ANOVA were performed for mean values of PSD in two selected frequency ranges (0.02–0.3 Hz and 0.5–1.4 Hz) separately to explore the effect of VBF location on different body segments. The frequency ranges were chosen as follows: when the statistically significant difference between PSD values of EO and PSD values of VBF condition appeared/disappeared, we marked the beginning/end of frequency range. We performed this process for all VBF situations and body segments. *Post-hoc* pairwise comparisons and simple contrasts were used. The level of significance was set at $p < 0.05$.

3. Results

The results showed a decrease of body sway amplitudes and RMS characterized by CoP displacements and trunk tilts during the condition with VBF. Repeated measures ANOVA revealed a significant effect of VBF location for each evaluated parameter and body segment. There was also a significant interaction between the VBF location and support surface for each parameter of CoP displacements and for some parameters of trunk tilts (Table 1).

Post-hoc comparisons were performed for each VBF condition (CoP-VBF, L5-VBF, Th4-VBF) and control condition for both support surfaces (EO, FEO) separately. We observed a decrease of RMS and body sway amplitudes during the conditions with VBF. The decrease was the most evident in the body segment from which the inputs were sensed for real-time VBF. Results of parameters A_{ml}, A_{ap} and RMS showed similar tendencies. RMS characterizes the overall stability of upright posture independently on the direction of postural sway, therefore only the graphs of parameter RMS are represented (Fig. 2A). CoP-VBF and L5-VBF led to significant reductions in CoP displacements and lower trunk tilts. They were not effective in reducing upper trunk tilts. On the other hand, Th4-VBF was effective only in decreasing upper trunk tilts.

Repeated measures ANOVA performed for normalized RMS values revealed a significant effect of VBF location, $F(2,38) = 12.62$; $p < 0.001$. Pairwise comparisons showed significant differences between CoP-VBF and Th4-VBF ($p = 0.019$) and between L5-VBF and Th4-VBF ($p = 0.001$). There was a significant effect of body segment, $F(1.23, 23.31) = 11.52$; $p = 0.001$. *Post-hoc* comparisons showed significant differences between CoP and Th4 ($p = 0.012$)