

Novel Supplementary Tactilebiofeedback System Providing Online Center of Foot Pressure Displacement for Balance Training Rehabilitation: A Preliminary Study

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Abstract

Objective: The present study is a preliminary investigation of whether balance training intervention using a tactilebiofeedback system, providing supplementary vibratory sensory cues related to center of foot pressure displacement, contributes toward improved stability of upright posture as measured post-intervention.

Methods: Twelve young adults (age 27.6 ± 4.2 years) were assigned to two groups: tactilebiofeedback and control. In the tactilebiofeedback group, the participants tried to minimize postural sway while standing on a foam rubber mat with their eyes open and wearing the tactilebiofeedback system around the pelvic girdle. In the control group, participants performed the same postural task without the tactilebiofeedback system.

Results: Pre and post measurements of postural stability (i.e., sway area, mean velocity of sway) using a force plate showed significantly improved stability of bipedal posture in the tactilebiofeedback compared with the control group. This beneficial effect was maintained for 10 min after the retention test.

Conclusions: A tactilebiofeedback system, providing supplementary vibratory sensory cues related to center of foot displacement, was effective in improving postural stability in cases where somatosensory input was not entirely unreliable, and this beneficial effect had a brief carry-over effect.

Keywords: Postural control; Biofeedback system; Sensori motor training

Introduction

Biofeedback systems for postural control entail providing individuals with artificial sensory cues about body position or motion to supplement sensory information [1,2], and their utility is currently being investigated to serve as a balance training tool for older adults and patients with sensory disorders [3,4]. Although visual, tactile, and auditory biofeedback systems are all effective means of conveying spatial orientation information [5-8], supplementary sensory information, particularly, in the form of tactilebiofeedback appears preferable because tactile stimulation does not interfere with activities that require visual and auditory information. As an example, Vuillerme et al. reported that the provision of supplementary information on head orientation with respect to gravitational effects through electrical stimulation of the tongue improved postural control, which was indicated by decreased surface area and length of center of foot pressure (CoP) displacements using biofeedback relative to non-biofeedback [9]. Another study demonstrated that healthy participants reduced the extent of lateral postural sway using head tilt information provided by an inertial sensor and vibrotactile display located either on the shoulder or the side of the trunk [10]. The afore mentioned studies have demonstrated the effectiveness of tactilebiofeedback in improving upright postural control as a sensory supplementation system.

Because CoP is a reliable and commonly used output measure of the postural control system that is indicative of postural stability [11-13], we developed a CoP biofeedback system providing supplementary tactile sensory cues related to CoP displacement using a vibrator applied to the lower back. We found that the provision of supplementary online tactile feedback on CoP displacement decreased sway area in the biofeedback in comparison with the control group (unpublished observation). However, because clarification of whether this feedback system offers any training or carry-over effects is still awaited, we aimed to investigate the training and carry-over effects

of the tactilebiofeedback system in providing supplementary sensory cues related to CoP displacement using a vibrator as compared with an identical training method without biofeedback in young healthy participants. Various body parts are used to record tactilebiofeedback, such as the tongue [9], trunk [10], and head [7]. In the present study, we chose the pelvic area to provide tactilebiofeedback because the center of gravity is located at the S2 level [14,15]. We speculated that the participants would readily appreciate their orientation and CoP changes. Overall, we hypothesized that the provision of supplementary cues about CoP displacement from the pelvic belt during balance exercise would contribute to improved postural stability.

Experiment

Method

Participants: Twelve young adults (10 males, 2 females; ages 27.6 ± 4.2 years) participated in the study. Participants were randomly assigned to either the biofeedback training or the non-biofeedback comparison group. Table 1 summarizes participants' background data. As the table illustrates, there were no significant differences ($p < 0.05$) between the groups at pre-test with regard to age, height, weight, foot length, and percentage of female participants. Inclusion criteria were (a)

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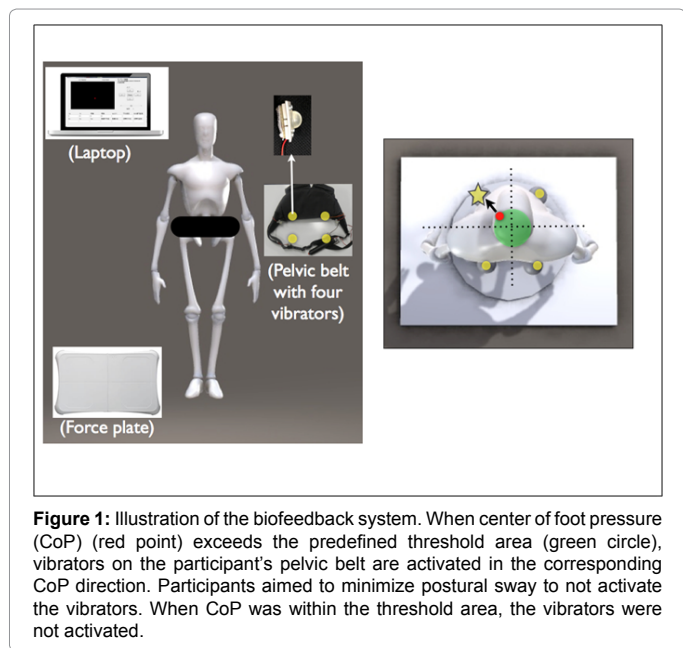
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	Feedback group(n=6)	Control group(n=6)	p-value*
Age (years)	27.50 ± 3.3927	27.17 ± 6.67	0.92
Gender (% woman)	17	17	1.00
Height (cm)	164.5 ± 6.38	165.8 ± 10.13	0.79
Weight (kg)	58.83 ± 6.24	64.17 ± 5.41	10.15
Foot length	26.17 ± 0.93	26.42 ± 0.97	0.65

n=number of participants. *Significance was assessed by Student's t-test (p<0.01).

Table 1: Participant characteristics.



no sensory or motor impairments that could influenced balance and (b) ability to maintain balance in bipedal stance on a foam rubber mat for >30 s. All participants provided written informed consent prior to their participation.

Experimental set-up and postural task: The biofeedback system consisted of a force plate (Wiiboard, Nintendo, JAPAN) to capture CoP data, a belt with four vibrators worn around the pelvic girdle to display CoP motion, and a personal computer (PC)with custom-programmed software (Visual studio, Microsoft, USA) to record and manipulate biofeedback threshold (Figure 1). A circular-shaped rubber foammat (Balance mat, Sanwa Kako Co.Ltd, JAPAN; diameter:320 mm, thickness:30mm, density:95 kg/m³) was correctly placed at the center of the force plate.

The participants wore the pelvic belt with vibrators while standing bare foot on a rubber foam mat with their eyes open (the foam rubber mat compromises the reliability on somatosensory data). The vibrators were attached bilaterally at anterior superior iliac spine (ASIS) and posterior superior iliac spine (PSIS). CoP in the anteroposterior and mediolateral directions was obtained by force plate measurements. The direction of CoP motion was displayed by the four tactile vibrators worn around the participant's pelvis (Figure 1), and the vibrator was activated when CoP exceeded a pre defined circular threshold. Predefined circle threshold was defined according to the following two criteria: First, we measured the 95% confidence circle area [11] during five 30s pre-tests. Then, the target area was reducedby 10% from the pre-measured minimum 95% confidence circle area (i.e., the participants were required to surpass the existing best performance

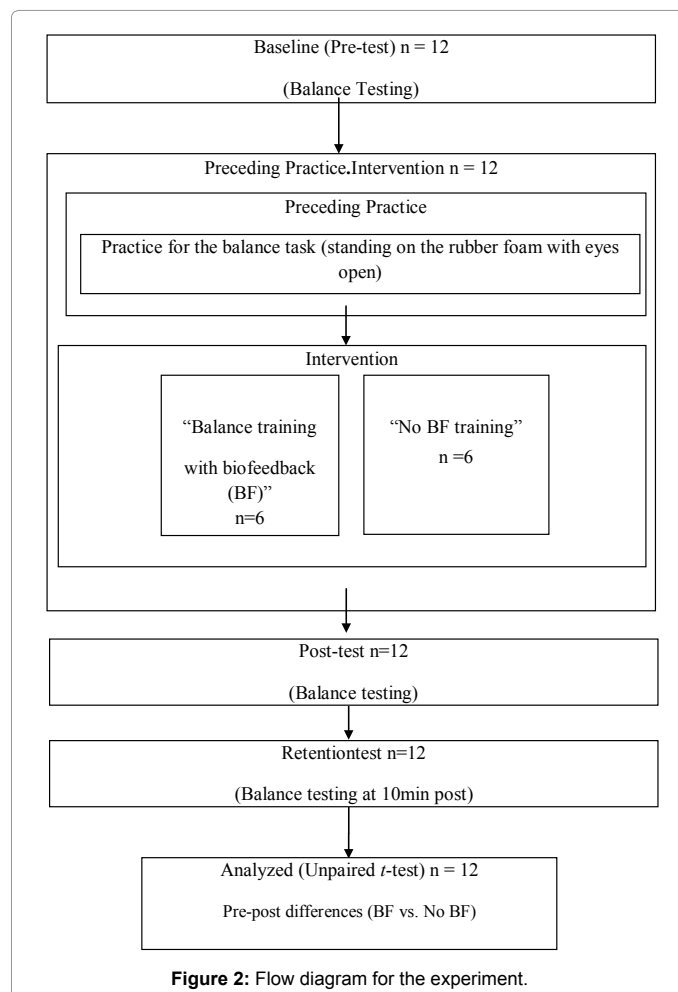
during the pre-test). The participants aimed to minimize postural sway to not activate the vibrators.

Procedure

Procedure and interventions: Waseda University's Ethics Committee for Human Research approved the procedures employed in the study.The entire procedure (Figure 2) was performed in an experimental room.

Measurement of postural sway comprised four phases: five performances (30s each) of pre-test, intervention, post-test, and retention test, with rest intervals of 2 min between each stage. Before pre-test evaluation, participants were given five practice sessions (30 s each) for familiarization with the postural task. After this practice session, baseline measurement of postural sway in bipedal stance was conducted as a pre-test. The participants stood bare foot on a rubber foam mat with their eyes open while looking at a fixed eye-level target at a distance of approximately 2m.

After the end of pre-test, the participants moved onto a further training session. Training session comprised five performances (30 s each),with a rest interval of 1 min between each performance. For the biofeedback group, the participants were asked to minimize postural sway to not activate the vibrators. For the control group, the participants performed the same postural task while aiming to minimize postural sway without biofeedback.



After the training session, we measured postural sway as both post-test and delayed test (approximately 10min after intervention). The protocol of these measurements was identical to that used in the pre-test.

Outcome measurements: Two dependent variables were used to describe participants' postural stability:

Confidence ellipse area (95%) as a measure of CoP spatial variability [11], which is defined as the area of 95% bivariate confidence ellipse expected to enclose approximately 95% of the points on the CoP path.

Mean velocity of CoP displacement (mm/s), representing the total distance covered by CoP (total swaypath) divided by the duration of the test period [16].

To examine the level of change in postural sway between pre-test and post-test, the values of each measurement at post-test were subtracted from those at pre-test (i.e., a negative value means that posture had stabilized at post-test). These values were then used as postural stability measures. The average value for each phase was calculated for analysis of change among phases.

Statistical analysis: Student's *t*-test was used to compare differences in pre and post postural stability values between the biofeedback and control groups, with the level of significance set at $p < 0.05$.

To verify the presence of the carry-over effect, one-way ANOVA with repeated measures was performed on average values in each phase, with a 0.05 level of significance. Posthoc comparison was performed to determine differences.

Results

Pre-test and post-test data of each individual are shown in Table 2. Mean and standard deviations of the difference between measurements

	Biofeedback group (n=6)		N Control group (n=6)	
	Pre-test	Post-test	Pre-test	Post-test
95% elliptical area (cm²)				
Participant 1	5.99 ± 1.39	4.27 ± 0.88	4.44 ± 0.70	4.73 ± 0.96
Participant 2	6.35 ± 0.71	4.65 ± 0.55	12.67 ± 3.08	10.54 ± 2.26
Participant 3	7.06 ± 2.23	6.20 ± 1.33	9.44 ± 0.83	11.15 ± 1.92
Participant 4	8.36 ± 1.27	7.17 ± 1.19	7.40 ± 1.55	7.29 ± 1.69
Participant 5	5.82 ± 0.64	4.47 ± 0.97	8.92 ± 1.26	10.12 ± 3.08
Participant 6	7.81 ± 1.15	5.83 ± 1.03	5.91 ± 1.45	5.16 ± 1.26
Mean sway velocity (cm/sec)				
Participant 1	4.49 ± 0.16	4.51 ± 0.24	4.28 ± 0.11	4.12 ± 0.18
Participant 2	4.71 ± 0.23	4.76 ± 0.36	4.08 ± 0.12	3.89 ± 0.13
Participant 3	4.24 ± 0.26	4.27 ± 0.16	4.74 ± 0.23	4.51 ± 0.15
Participant 4	5.07 ± 0.54	4.79 ± 0.08	4.47 ± 0.05	4.44 ± 0.18
Participant 5	4.24 ± 0.14	4.36 ± 0.18	5.74 ± 0.17	5.52 ± 0.58
Participant 6	4.45 ± 0.19	4.44 ± 0.20	4.63 ± 0.30	4.58 ± 0.35

Table 2: Pre- and post-test data of individuals in the biofeedback and control groups (mean ± SD).

	Mean velocity of sway (cm/sec)	Control group (n=6)
95% elliptical area (cm ²)	0.04 ± 1.38	0.04 ± 1.38
Mean velocity of sway (cm/sec)	-0.01 ± 0.14	-0.14 ± 0.08

n=number of participants.

Negative values mean that the posture became stable at the post-test

**p*-values were derived from unpaired *t*-test ($p < 0.05$).

Table 3: Parameters measured in the biofeedback and the control group (mean ± SD).

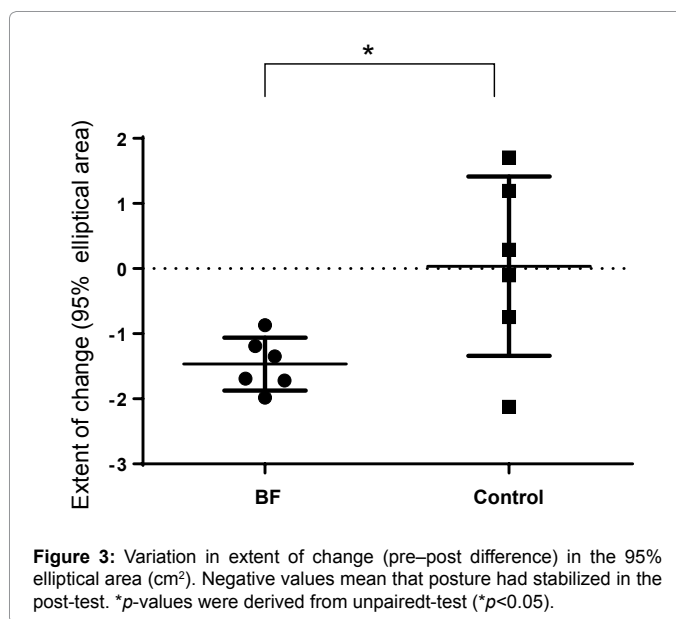


Figure 3: Variation in extent of change (pre-post difference) in the 95% elliptical area (cm²). Negative values mean that posture had stabilized in the post-test. **p*-values were derived from unpaired *t*-test (* $p < 0.05$).

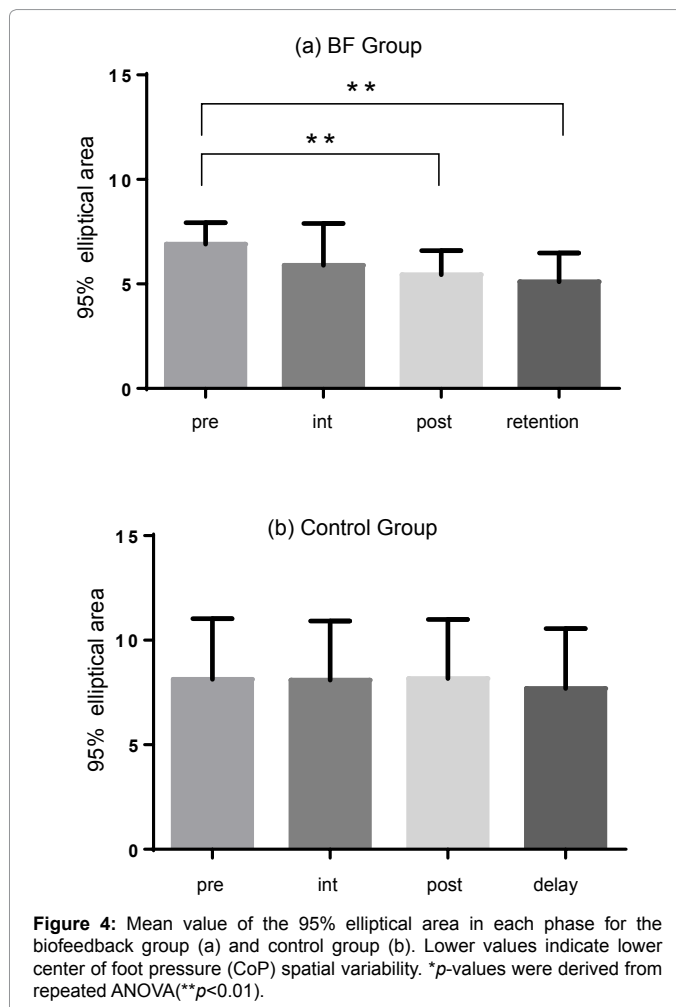


Figure 4: Mean value of the 95% elliptical area in each phase for the biofeedback group (a) and control group (b). Lower values indicate lower center of foot pressure (CoP) spatial variability. ***p*-values were derived from repeated ANOVA (** $p < 0.01$).

at pre-test and post-test are shown in table 3. *t*-test showed that the 95% elliptical area was significantly lower in the biofeedback group than in the control group ($p < 0.05$). This effect was demonstrated by

a consistent reduction in 95% elliptical area for all six participants in the biofeedback group (Figure 3). There was no significant difference in mean velocity of sway between the biofeedback and control groups.

For the biofeedback group, one-way ANOVA showed that the main effect of phase was significant with regard to the 95% elliptical area ($F = 9.73, p < 0.05$). The posthoc test showed that the 95% elliptical area was smaller in the post-test and retention test phases than in pre-test ($p < 0.01$) (Figure 4a). For the control group, one-way ANOVA showed that there was no significant primary effect with regards to the 95% elliptical area (Figure 4b).

Discussion

In the present study, we investigated the effectiveness of the tactilebiofeedback system in providing supplementary sensory cues related to CoP displacement in improving upright postural control in young healthy participants, with eyes open and somatosensation partially unreliable. Analyses of the pre-post 95% elliptical area showed that the sway area was significantly reduced in the biofeedback group compared with the control group. These results are congruent with those of previous studies demonstrating the effectiveness of the tactilebiofeedback system in improving upright postural control as a sensory supplementation system [9,10]. Furthermore, for the biofeedback group, the beneficial effect (i.e., reduced surface area) was maintained for 10 min after the retention test.

Regarding the sway area results, although some of the participants in the control group could also reduce the sway area after training, the biofeedback effect was demonstrated by a consistent reduction in the 95% elliptical area in "all six participants." Thus, it is possible that the biofeedback system is effective in inducing steady effect, regardless of his or her ability. Of note, in our study, the sway area, but not the mean velocity of sway, was improved by prior training with the biofeedback system. There is general consensus on the role of visual, vestibular, and proprioceptive senses in the maintenance of upright posture [17,18]. Particularly in humans, equilibrioception is mainly sensed by the detection of acceleration, which occurs in the vestibular system [19]. Several studies suggested that the vestibular system is the main monitor of sway area (extent of CoP spatial variability), whereas proprioception is the principle monitor of velocity and length of sway [20,21]. Although the exact mechanism is still unknown, the study participants took advantage of the supplementary sensory information to inhibit sway area by their awareness of orientation of the CoP.

In terms of clinical implication, the biofeedback training may be helpful for older individuals or those requiring balance training. Our results showed that improvement occurred with regard to sway area. The area of body sway increases more than length in patients with vestibular disorder [20], this being the characteristic that causes most balance difficulties in such patients. Therefore, it is possible that offering biofeedback particularly to such patients may have potential in improving balance control. However, further evidence is required on the clinical implications of the effectiveness of our newly developed biofeedback system.

There is a methodological issue that limits the conclusions to be drawn from this study. Because the experiments were conducted on a very small group of young participants, with the gender ratio biased toward males, we could not exclude the potential for bias occurring in this group of participants. In addition, we need to determine whether the carry-over effect persists for several days after training intervention. Further studies are necessary that include a larger sample and greater diversity of individuals to validate our conclusions and findings in a clinical setting.

In conclusion, the present study showed that balance training with the biofeedback system, providing supplementary tactile sensory cues related to CoP displacement by the use of vibrators attached to a pelvic belt, has beneficial effects on the improvement of postural stability. Furthermore, the system induced a short carry-over effect during the subsequent retention test period. This conclusion supports the efficacy of the tactilebiofeedback system when performing balancing exercises. Because only young healthy participants were tested in the present study, a greater diversity of individuals should be tested to validate our conclusions.

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