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# Directional effects of biofeedback on trunk sway during stance tasks in healthy young adults

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ABSTRACT

Biofeedback has been shown to improve balance in a number of different populations. As certain clinical populations have a tendency to fall in one direction, the provision of biofeedback in the impaired direction may improve balance in that direction but not in others. The purpose of this study was to determine the effects of uni-directional biofeedback on stance tasks in healthy young adults.

Trunk sway was measured in 40 healthy young adults as they performed nine stance tasks with and without biofeedback. Participants received biofeedback about their trunk sway in either the anterior–posterior (AP) or medial–lateral (ML) direction using a multi-modal head-mounted biofeedback device.

An overall effect of reduced sway angle and increased sway angular velocity was noted with biofeedback. Some of the effects of biofeedback were dependent on the direction in which biofeedback was given and whether vision was present during the stance task. These effects were strongest in the pitch direction for AP biofeedback with vision present.

This study showed direction specific effects of biofeedback are greatest in the sagittal plane. These results are important clinically as the use of biofeedback during stance tasks, similar to gait tasks, appears to work best in the AP direction when vision is present.



## 1. Introduction

Optimal balance control of stance requires the use and integration of a number of sensory inputs: visual, vestibular, and somatosensory. When this sensory information is degraded or absent, balance becomes more unstable [1]. Biofeedback has been shown to be a useful tool to improve balance in a number of different populations, including healthy young adults [2–7], healthy older adults [4], frail older adults [8], stroke patients [9,10], unilateral vestibular loss (UVL) patients [11–13], and bilateral peripheral vestibular loss (BVL) patients [5,6,11–14].

Usually only one sensory modality is used to provide biofeedback to participants, such as visual [10], auditory [2,5,8,14], or tactile [3,11–13] information. Recently, a multi-modal biofeedback system has been developed which uses vibrotactile, auditory, and visual modalities to provide biofeedback to individuals. Research has shown that this multi-modal system reduced trunk sway for selected gait tasks for both healthy young and older adults [4,7].

The majority of research has provided biofeedback to participants in both anterior–posterior (AP) and medial–lateral (ML) directions. However, certain populations have a tendency to fall in one direction, such as Parkinson's disease patients backwards [15] and UVL patients laterally [16]. In these populations, the provision of biofeedback, in the impaired direction only, may maximize improvements in balance, but with a possible risk of worsening balance in other directions.

Currently, only a few studies have investigated the directional effects of biofeedback [7,11,12]. Kentala et al. [12] examined the directional effects of vibrotactile biofeedback of body tilt when standing on a sway referenced support surface without vision or with sway referenced vision in UVL and BVL patients. A direction specific effect was found as AP biofeedback was able to decrease sway in that same direction, however, ML or directionless biofeedback, did not improve sway in the AP direction. The study of Kentala et al. [12] only measured sway in the AP direction. To fully examine the effects of uni-directional biofeedback, both directions of sway should be measured.

Janssen et al. [7] used a multi-modal biofeedback system and observed a decrease in both pitch and roll trunk movement for both AP and ML biofeedback conditions for a number of gait tasks in healthy young adults. The reductions were greatest in the pitch direction with AP biofeedback. It is still unknown whether or not the effects observed by Janssen et al. [7] are generalizable to stance tasks. Thus, the purpose of the present study was to determine for a variety of stance tasks in healthy young adults if biofeedback given

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**Table 1**
List of stance and gait tasks.

| |
|---|
| Stance tasks[a] |
| Standing shoulder width, eyes closed, on ground, 30 s[b] |
| Standing shoulder width, eyes open, on foam, 30 s[b] |
| Standing shoulder width, eyes open, on foam, 30 s[b] |
| Standing feet together, eyes open, on ground, 30 s[c] |
| Standing feet together, eyes closed, on ground, 30 s[c] |
| Standing feet together, eyes open, on foam, 30 s[c] |
| Standing feet together, eyes closed, on foam, 30 s[c] |
| Standing one-legged, eyes open, on ground, 30 s[c] |
| Standing one-legged, eyes open, on foam, 30 s[c] |
| Tandem stance, eyes open, on ground, 30 s[c] |
| Tandem stance, eyes closed, on ground, 30 s[c] |
| Tandem stance, eyes closed, arms folded on ground, 30 s[b] |
| Tandem stance, eyes open, on foam, 30 s[c] |
| Gait tasks[a,d] |
| Walking 8 m, eyes open, with a glass of water[b] |
| Walking 8 m, backwards eyes open[b] |
| Walking 4 m, eyes open, on foam[b] |

[a] The foam support surface was 10 cm thick, 44 cm wide and 4 m long and had a density of 25 kg/m$^3$.
[b] Tasks used only for training. During training every stance task was performed for 1 min and gait tasks four times each.
[c] Tasks used only for assessment. These tasks were used to compare with and without feedback conditions.
[d] For walking tasks participants started one foot behind the other and the heel raised on the back foot as if a step had already been taken.

in one direction improves sway in that direction only, or if the sway is increased in other directions, or if sway in general is improved in both pitch and roll directions.

## 2. Methods

### 2.1. Participants

Forty young healthy adults (16 males, 24 females, mean ± SD age = 22.6 ± 2.2 years) volunteered for this study. Exclusion criteria included any self-reported sensory, neurological, or musculoskeletal impairments that could interfere with balance or use of the biofeedback device. Participants provided informed consent prior to the start of any experimental procedures. This study was approved by the local university Research Ethics Board.

### 2.2. Procedure

Participants were tested twice. First, the balance performance of all participants was assessed on a battery of stance and gait tasks, comprising both training and second assessment test tasks (Table 1), to determine baseline values for customization of individual biofeedback thresholds (see Section 2.3). At the same time of day, one week following the first assessment, participants were provided with training with the biofeedback system with all directions of biofeedback active. Table 1 lists the training tasks. The training was used to familiarize participants with the biofeedback system and lasted 15–20 min. The training tasks were different from the test tasks of the second assessment such that the test tasks did not duplicate the training tasks (see Table 1). Directly after training, participants were assigned to one of two groups and were reassessed with the test tasks. One group was provided with biofeedback in the AP direction while the other group was provided with biofeedback in the ML direction. Participants were unaware that biofeedback was provided in only one direction of sway and were instructed that the biofeedback was based on trunk movement and that trunk sway should be reduced in order to eliminate the occurrence of the biofeedback signals.

### 2.3. Measurement system

Trunk sway was measured using a SwayStar™ system (Balance International Innovations GmbH, Switzerland) [17]. This device uses two angular velocity transducers that measure trunk angular displacement and velocity in the pitch and roll directions every 10 ms. The device is attached to the lower back (lumbar 2–3) of participants with an elasticized motorcycle kidney-belt. Based on a typical drift of 1°/h, maximal drift for stance tests of 30 s would be approximately 0.01°.

A BalanceFreedom™ system directly connected to the SwayStar™ system was used to provide biofeedback to participants [4,7]. Trunk velocities measured by the SwayStar™ device were converted to provide biofeedback regarding trunk angle, as this has been shown to be most effective for stance tasks [14]. Vibrotactile biofeedback was provided by eight vibrators spaced equally around the headband of the head-mounted device that became active when trunk sway exceeded a threshold in that direction. Auditory biofeedback was provided by two bone-conducting acoustic transducers placed over the mastoid bones. The left transducers or right transducers oscillated at 870 and 500 Hz if sway exceeded another larger threshold to the left and right, respectively. Both transducers oscillated at 250 and 1370 Hz if sway exceeded threshold for forwards or backwards sway, respectively. Visual biofeedback was provided by four lights on the brim of the head-mounted device such that the lights would blink at a frequency of 3 Hz if another even larger threshold was exceeded regardless of direction.

Feedback was limited to either the AP direction (AP biofeedback group) or the ML direction (ML biofeedback group) during the second assessment. The AP biofeedback group would receive biofeedback only if their trunk sway exceeded the established individualized threshold limit and if this sway was within segment zones of ±22.5° either side of pure forward sway or ±22.5° either side of pure backward sway. One potential limitation to this approach is that the limit of stability is greater for forward compared to backward sway. However, as biofeedback was provided around the participant's initial starting position, assumed to be shifted in front of the ankle joint, it was thought that sway in both directions would be approximately the same. A participant in the ML biofeedback group would receive biofeedback only if their trunk sway exceeded the established individualized threshold limit and if this sway was within segment zones of ±22.5° either side of pure rightward sway or ±22.5° either side of pure leftward sway.

Feedback thresholds were customized for each participant and derived from the baseline values collected during the first assessment of 90% peak-to-peak ranges for pitch and roll angle. 90% ranges were obtained by dividing the peak-to-peak range into 40 bins and from a histogram of the values in the bins deriving the 5% and 95% values. Feedback was activated cumulatively with increasing thresholds such that vibrotactile (factor of 40%) was activated first, followed by auditory (factor of 80%), and lastly, visual (factor of 150%). For example, a 90% peak-to-peak roll angle of 1° would correspond to a vibrotactile peak-to-peak threshold value of 0.4° divided equally left 0.2°, right 0.2°, auditory threshold of 0.8°, and visual threshold of 1.5°. These values and progressions were based on previous research [4,7].

### 2.4. Data analysis

First, to determine if there was an effect of biofeedback, four multivariate analyses of variances (MANOVAs) were performed on the difference scores (first assessment–second assessment) for each of the trunk sway measures across the nine stance tasks. Paired *t*-tests were then performed to compare each trunk sway measure without and with biofeedback for the stance tasks. To determine differences in the effects of AP and ML biofeedback, a one-way ANOVA was performed, with post hoc comparisons performed to determine the nature of the differences when appropriate. To determine if the effects of biofeedback were truly

**Table 2A**
Effects of biofeedback.

| Task | ΔRA in° (SEM) | ΔRV in°/s (SEM) | ΔPA in° (SEM) | ΔPV in°/s (SEM) |
|---|---|---|---|---|
| Feet together EO | 0.18[a] (0.07) | −0.16[a] (0.07) | 0.11 (0.08) | −0.28[a] (0.10) |
| Feet together EC | 0.10[a] (0.05) | −0.16[a] (0.08) | 0.10 (0.13) | −0.14 (0.14) |
| Feet together EO foam | 0.21[a] (0.08) | −0.31[a] (0.11) | 0.11 (0.11) | −0.31[a] (0.15) |
| Feet together EC foam | 0.09 (0.08) | −0.41[a] (0.15) | 0.19 (0.12) | −0.23 (0.12) |
| Tandem EO | 0.37[a] (0.08) | 0.22 (0.11) | 0.73[a] (0.18) | 0.10 (0.17) |
| Tandem EC | 0.26 (0.15) | 0.39 (0.25) | 0.34[a] (0.16) | 0.18 (0.33) |
| Tandem EO foam | 0.31[a] (0.13) | 0.77[a] (0.24) | 0.32[a] (0.14) | 0.26 (0.25) |
| 1 leg EO | 0.88[a] (0.23) | 0.71[a] (0.27) | 0.51[a] (0.15) | 0.20 (0.21) |
| 1 leg EO foam | 0.68[a] (0.21) | −0.01 (0.40) | 0.12 (0.21) | −0.67 (0.34) |

A positive result indicates a reduction in sway variable for second assessment compared to the first.
[a] Main effect of biofeedback comparing pre to post.