

Evaluation of a Smartphone-based audio-biofeedback system for improving balance in older adults – A pilot study

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Abstract— This study was designed to assess the effectiveness of a Smartphone-based audio-biofeedback (ABF) system for improving balance in older adults. This so-called “iBalance-ABF” system that we recently developed is “all-inclusive” in the sense that its three main components of a balance prosthesis, (i) the sensory input unit, (ii) the processing unit, and (iii) the sensory output unit, are entirely embedded into the Smartphone. The underlying principle of this system is to supply the user with supplementary information about the medial-lateral (ML) trunk tilt relative to a predetermined adjustable “dead zone” through sound generation in earphones. Six healthy older adults voluntarily participated in this pilot study. Eyes closed, they were asked to stand upright and to sway as little as possible in two (parallel and tandem) stance conditions executed without and with the use of the iBalance-ABF system. Results showed that, without any visual information, the use of the Smartphone-based ABF allowed the older healthy adults to significantly decrease their ML trunk sway in the tandem stance posture and to mitigate the destabilizing effect induced by this particular stance. Although an extended study including a larger number of participants is needed to confirm these data, the present results are encouraging. They do suggest that Smartphone-based ABF system could be used for balance training and rehabilitation therapy in older adults.

I. INTRODUCTION

It is now well recognised that human balance and posture control during standing involve the integration of sensory information from diverse sources including visual, somatosensory and vestibular systems (e.g., [1]).

One way to improve balance, especially when one of the above-mentioned sensory inputs becomes unavailable,

undermined or degraded, is to provide individuals with supplementary information regarding their body’s displacements and orientations, in addition to these usual sensory cues. Based on the concept of sensory substitution initially introduced by Paul Bach-y-Rita [2], various biofeedback systems have been developed during the past decades (see [3-4], for recent reviews).

We recently developed an original Smartphone-based audio-biofeedback (ABF) system for improving balance [5]. Interestingly, this so-called “iBalance-ABF” system is “all-inclusive” in the sense that the three main components of all balance prosthesis, (i) the sensory input unit (i.e., inertial motion unit), (ii) the processing unit, and (iii) the sensory output unit (i.e., earphones) are here entirely embedded into the smartphone. The underlying principle of this system is to supply the user with supplementary information about the medial-lateral (ML) trunk tilt relative to a predetermined adjustable “dead zone” (DZ) through sound generation in earphones (see section II). In a pioneering proof-of-concept study [5], the effectiveness of this system in improving the control of bipedal posture in absence of visual cues and in a stance which enhances lateral postural instability, was assessed in twenty young healthy individuals. By showing diminished trunk tilt in the ML direction when the iBalance-ABF was in use relative to when it was not, results of this study showed that young healthy individuals were able to efficiently use ABF on sagittal trunk tilt to improve their bipedal stance in the ML direction. Now, from clinical and rehabilitative perspectives, investigating whether the beneficial effect observed in young healthy adults also occurs across people showing less accurate postural capacities and for whom the consequences of an impaired balance could be more dramatic, becomes crucial.

The present study was specifically designed to address this issue by assessing the effects of iBalance-ABF system on upright postural control in older adults, known to constitute one of the largest groups of patients at risk for falls [6-8].

This paper is organized as follow. Sections II and III present the experimental procedure and results of this study designed to assess the effectiveness of the iBalance-ABF system on older adults population, respectively. Section IV discusses the obtained results and draws conclusions and some directions to extend our work.

II. MATERIALS AND METHODS

A. Participants

Six healthy elderly (age: 62.7 ± 2.7 kg; height: 173.0 ± 9.1 cm; weight: 86.2 ± 9.1 kg, mean \pm SD)

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volunteered for the present study. They gave their written informed consent to the experimental procedure as required by the Declaration of Helsinki and the local Ethics Committee after the nature of the study had been fully explained.

Inclusion criteria consisted of people who were 60 years of age and older, able to stand and walk without any assistance and living independently in their own accommodation.

Participants were characterized as *healthy* older adults based on the Activities-specific Balance Confidence Scale [9], the Berg Balance Scale [10] and the Mini Mental State Examination [11]. Persons with musculoskeletal problems, defects in the peripheral sensory system of the lower extremities, vascular pathology, neurologic disorders, vestibular impairment, or hearing deficits were excluded, as were those with current use of medication that could affect their balance and those with a history of falls. A fall was defined as an event resulting in a person inadvertently coming to rest on the ground or another lower level.

B. Tasks and procedures

Participants wore the Smartphone mounted in a belt on the posterior low back at the level of L5 vertebra and a pair of earphones throughout the experiment.

The iBalance-ABF system used in the present experiment has recently been developed [5] as a home-based balance Telemonitoring and Telerehabilitation system which allows accomplishing the following three complementary tasks:

- (1) quantitatively and objectively assessing the individual's balance ability remotely and in real-time in his home environment ;
- (2) automatically and adaptively creating a customized balance training program by adaptively configuring and tuning the system BF parameters based on each individual's ability/progress/needs/preferences and/or goals ;
- (3) tracking individual's progress history and compliance in order to improve quality of care (see figure 1 of [5]).

The architecture and the functioning principle of the iBalance-ABF system used in this study have been detailed in a previous report [5]. Only the main points will thus be evoked here. In summary, as mentioned above, the underlying principle of this system is to provide the user additional information about his/her ML trunk tilt relative to a predetermined adjustable "dead zone". In the present experiment, ML bounds of the DZ were set to 1° around the mean of the participant's trunk position in the ML direction recorded for 5 s preceding each experimental trial.

The three-dimensional trunk motions were computed, using Kalman filtering over the 9 dimensions of the signals from the 3 MEMS sensors (a 3D accelerometer, an integrated 3D gyroscope and a 3D magnetometer) embedded in the Smartphone (Apple iPhone 4).

Furthermore, as illustrated in Fig. 1, to avoid an overload of sensory information presented to the user, a simple and

intuitive coding scheme for the ABF, consisting in a "threshold-alarm" type of feedback rather than a continuous feedback about ongoing trunk orientation, was used:

(1) when the ML trunk orientation was determined to be within the DZ, no ABF was provided to any of the two earphones;

(2) for the entire time the ML trunk orientation was determined to be outside the DZ, ABF provided a sound to either the left or the right earphone depending on whether the actual trunk orientation was exceeding the DZ in either the left or right direction, respectively.

Participants were asked to stand barefoot with their arms close to their trunk and their eyes closed. Participant's task was to sway as little as possible in two stance conditions: (1) feet parallel 10 cm apart ("Parallel stance" condition) and (2) feet heel to toe ("Tandem stance" condition). These two stance conditions were executed under 2 experimental conditions: (1) No audio-biofeedback ("No-ABF" condition) and (2) Audio-biofeedback ("ABF" condition). The No-ABF condition served as a control condition. In the ABF condition, participants executed the postural task using the iBalance-ABF system. Our aim here was to assess the effectiveness and the usability of the iBalance-ABF system by elderly persons.

Before the experiment, participants performed two practice trials in the Parallel stance and Tandem stance, with and without the use of ABF. The purpose of these practice trials was for the participants to ensure that they had become familiar with standing with the postural stances and that they had understood how the trunk information was coded into the ABF sound. Data from these practice trials were not considered in the analyses.

Three 30-s trials for each experimental condition (1) Parallel / No-ABF, (2) Parallel / ABF, (3) Tandem / No-ABF and (4) Tandem / ABF were performed. The order of presentation of the 4 experimental conditions was randomized. Participants were not informed about their postural performances.

D. Data analysis

Three parameters were used to describe participant's postural behavior:

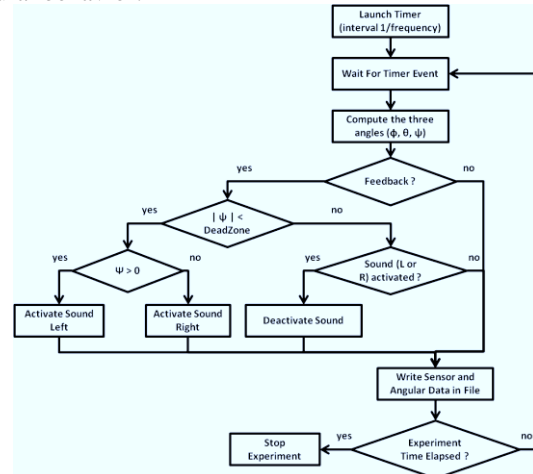


Fig. 1. Algorithm of measurement and biofeedback activation [5].

(1) the percentage of time that the trunk tilt was within the specified angle limits (%Time-DZ in %);

(2) the root mean square of trunk tilt in the ML and AP (Anterior-Posterior) directions (RMS in degree) as a measure of the amount of trunk sway ; and

(3) the mean power frequency of trunk tilt in the ML and AP directions (MPF in Hz) calculated from the power spectral density of trunk tilt.

E. Statistical analysis

The means of the three trials performed in each experimental condition were used for statistical analyses. To evaluate the effect of ABF on the control of posture during bipedal standing, %Time-DZ, ML RMS, AP RMS, ML MPF and AP MPF were subjected to separate two-tailed paired-samples t-tests. The threshold for statistical significance was set to $P < 0.05$.

III. RESULTS

A. Percentage of time within the DZ

As illustrated in Fig. 2, analysis of the %Time-DZ showed: (1) in the Parallel stance condition, no significant difference between the No-ABF and the ABF experimental conditions ($P > 0.05$), whereas (2) in the Tandem stance condition, a significant increased %Time-DZ value in the ABF relative to the No-ABF experimental condition ($P < 0.01$).

Analysis of the %Time-DZ further showed, in both No-ABF and ABF experimental conditions, significant decreased %Time-DZ values in the Tandem stance condition relative to the Parallel stance condition ($P < 0.05$), with this effect being less pronounced in the ABF ($P < 0.01$) than in the No-ABF experimental condition ($P < 0.001$).

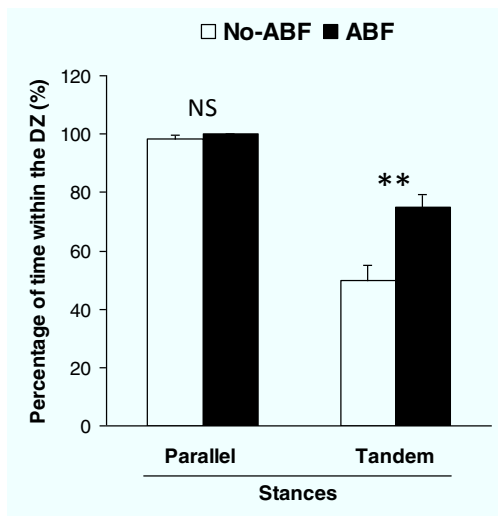


Fig. 2. Mean and standard error of mean of the percentage of time that the trunk tilt was within the DZ (%) measured in the two stances (parallel and tandem) and the two ABF conditions (No-ABF and ABF) (P values for comparison between No-ABF and ABF conditions are reported: NS: $P > 0.05$; **: $P < 0.01$.)

B. Root mean square of trunk tilt

As illustrated in Fig. 3, analysis of the ML RMS showed: (1) in the Parallel stance condition, no significant difference between the No-ABF and the ABF experimental conditions ($P > 0.05$), whereas (2) in the Tandem stance condition, a significant decreased ML RMS value in the ABF relative to the No-ABF experimental condition ($P < 0.05$).

Analysis of the ML RMS further showed, in both No-ABF and ABF experimental conditions, significant increased ML RMS values in the Tandem stance condition relative to the Parallel stance condition ($P < 0.05$), with this effect being less pronounced in the ABF ($P < 0.01$) than in the No-ABF experimental condition ($P < 0.001$).

Analysis of the AP RMS showed no significant difference in both Parallel and Tandem stance condition ($P > 0.05$).

C. Mean power frequency of trunk tilt

As illustrated in Fig. 4, analysis of the ML MPF showed: (1) in the Parallel stance condition, no significant difference between the No-ABF and the ABF conditions ($P > 0.05$), whereas (2) in the Tandem stance condition, significant increased ML MPF value in the ABF relative to the No-ABF experimental condition ($P < 0.05$).

Analysis of the ML MPF further showed, in both No-ABF and ABF experimental conditions, significant increased ML RMS values in the Tandem stance condition relative to the Parallel stance condition ($P < 0.05$), with this effect being less pronounced in the ABF ($P < 0.01$) than in the No-ABF experimental condition ($P < 0.001$).

Analysis of the AP MPF showed no significant difference between the No-ABF and the ABF experimental conditions in both Parallel and Tandem stance condition ($P > 0.05$).

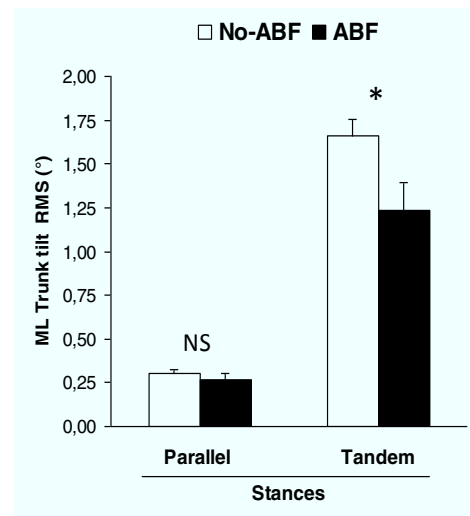


Fig. 3. Mean and standard error of mean of the trunk tilt root mean square in the medio-lateral direction (°) measured in the two stances (parallel and tandem) and the two ABF conditions (No-ABF and ABF) (P values for comparison between No-ABF and ABF conditions are reported: NS: $P > 0.05$; *: $P < 0.05$.)

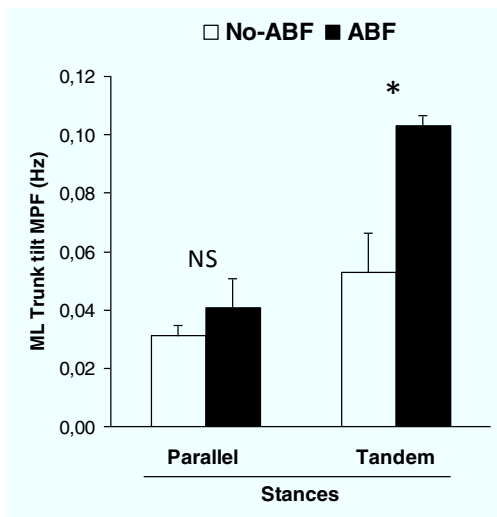


Fig. 4. Mean and standard error of mean of the trunk tilt mean power frequency in the medio-lateral direction (Hz) measured in the two stances (parallel and tandem) and the two ABF conditions (No-ABF and ABF) (values for comparison between No-ABF and ABF conditions are reported: NS: $P > 0.05$; *: $P < 0.05$.)

IV. DISCUSSION

Following the goal of assessing the effectiveness of a Smartphone-based audio-biofeedback system on the control of bipedal posture, six healthy older adults were asked to stand upright with their eyes closed and to sway as little as possible in 2 parallel and tandem conditions, executed without and with the use of the so-called iBalance-ABF system.

On the whole, results showed that, in the absence of visual information, the use of the Smartphone-based ABF on sagittal trunk tilt allowed the older healthy adults to significantly decrease their ML trunk sway in the Tandem stance posture and to mitigate the destabilizing effect induced by the adoption of this particularly challenging stance relative to a more natural parallel stance.

Regarding the immediate effect of ABF on the control of bipedal posture, our results are in line with the existing literature. Indeed, it has previously been reported that auditory information related to trunk movement allowed healthy individuals and labyrinthine-defective patients to increase postural stability when sensory information from both vision and the surface were compromised by eye closure and stance on foam [12-13]. Our results extended this existing literature to a population of healthy older adults. At this point, a key limitation of the present study is the small sample size and an extended study including a large number of participants is crucially needed to confirm these preliminary data. However, we strongly believe that the present findings are promising. They hence suggest that the augmented sensory information about the ML trunk tilt relative to a predetermined adjustable DZ through sound generation in earphones could substitute for the absence of visual spatial reference system, known to play a major role in

the balance control and prevention of falls, especially in elderly [7,14-15] to ensure adequate bipedal posture in healthy older adults. They further suggest that this innovative Smartphone-based audio-biofeedback system could be used for balance training and balance rehabilitation therapy in older adults. Work is currently underway to address these issues.

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