Audio-visual biofeedback system for postural control

M Milosevic, K M V McConville

Electrical Engineering Department, Ryerson University
350 Victoria Street, Toronto, M5B 2K3, Ontario, CANADA

mmilosev@ee.ryerson.ca, *kmcconvi@ee.ryerson.ca*

ABSTRACT

This study presents an application of biofeedback in balance training, in particular an audio-visual balance rehabilitation system designed for training of the elderly. Motivated by the need to provide portable, cost-effective and accessible training devices, the system implements a MEMS accelerometer to quantify the balance board movements during a balancing task and use them to provide a real-time, synchronous audio-visual biofeedback. The visual feedback displays the offset and the overall performance of the balance board. The audio feedback is based on the sound localization cues that indicate the direction of the balance board movements using stereo sound. Initial results indicate a significant improvement in the postural stability when the audio-visual biofeedback is provided. The pilot study found significant improvements in maintenance and recovery of dynamic balance manifested through decreased variability of complex, lateral and front-to-back movements during a balancing task.

1. INTRODUCTION

Recent studies (e.g. Rubenstein, 2006) have shown that falls are the most frequent cause of injuries in the general populations and it is known that the incidence and severity of falls increases with age. It has been shown that falls are leading cause of some 300,000 hip fractures in the United States. The healthcare cost in the United States has been associated with the approximately $US 10 billion (Maki et al., 2003). It has been projected that falls will become an increasingly growing healthcare and societal problem because of the graying baby-boomer generation and projections indicate that the cost and the impact will quadruple in the next forty years. Our analysis (Milosevic and McConville, 2007a) of the 2005 Canadian Community Health Survey found that among Canadians, falls cause the most serious injuries in adults over 65 years of age. Also, this study found that slips, trips and stumbles frequently occur among the elderly and represent one of the major causes for falls-related injury.

Stevens and Olson (2000), advocate development of new approaches to prevention including behavioral and environmental changes as well as the development of new exercise programs aimed to improve strength and balance among the elderly. The reviews of evidence on falls and the prevention of falls (Rubenstein, 2006; Rubenstein and Josephson, 2006; Horak, 2006) indicate the existence of knowledge gaps related to clinical diagnostic procedures, cost-effective balance diagnostic equipment, and balance exercise programs. According to these studies, a highly important factor in the prevention of falls is the development of feasible and cost-effective tools along with the appropriate training programs for improvement of balance.

Balance is most affected by the visual, vestibular and proprioceptive system inputs, all of which deteriorate significantly with age. Balance control is a complex skill based process based on integrated sensory system re-weighing (Horak, 2006). The focus of rehabilitation strategies has gone from the compensatory to the neurorestorative recovery strategies. Thus it is important to consider the underlying neurological fundamentals and constraints. The specific strategies can also consider augmenting the compensatory mechanisms with adjacent strategies to have the most effect (Dobkin, 2003). This indicates that biofeedback can be an important tool, not only for neural rehabilitation, but for developing assistive devices for continual and portable feedback provision.

Studies, investigating audio and visual feedback modalities, found positive effects of audio-feedback and visual-feedback on improvements of balance. They suggest that audio and visual information can successfully provide feedback information during balancing tasks. Dozza, Chiari and Horak (2004) investigated a training system based on a portable audio-biofeedback (ABF) device that uses accelerometric signals encoded into stereo sound and demonstrated a significant balance improvement among healthy subjects. Another study (Dozza et al., 2005) examined the effects of the ABF systems on upright stance postural stability, in conditions of limited and unreliable sensory information among healthy subjects. They provided evidence that the audio-biofeedback system improves postural stability. In addition to the previously identified positive impact of biofeedback (BF) systems, a recent investigation of BF training using coding of audio and visual information for control of posture (Dozza et al., 2006) showed significant differences in the effects of audio and visual information cues on posture control. Results from this study showed that audio BF was more important for reducing center of pressure displacement while visual BF had a more important role in reducing trunk sway.

Our study examines a new system that uses both audio and visual feedback in balance maintenance through provision of different information for control of dynamic balance. The objective of the study was to develop a portable, cost-effective and accessible training device that uses biofeedback to provide audio and visual information about the balance performance during dynamic balancing.

2. METHODS

2.1 Subjects

The study examined four healthy participants who performed the experimental tasks consisting of three different tests with and without the audio-visual biofeedback. The mean age of the participants was 36.8 years and two are male and two are female. All of the participants were healthy middle-aged adults with no history of neurological or other disease, no history of falls, and vestibular or musculoskeletal impairments that might restrict them in participating.

2.2 Dynamic Balance Task

The effectiveness of the audio-visual biofeedback system was assessed during a dynamic postural stability balance task. The postural stability balance task consists of maintaining balance on an exercise balance board (PT Balance Board, PTfitness). The balance board is a simple yet valuable training and assessment device for use in therapeutic practice and in studies of dynamic postural balance. The balance board has been shown as a valuable training and assessment device (Dozza et al., 2006; Ferrell et al., 2004; Nordt et al., 1999). Mechling (1986) has demonstrated similar results between the measurements obtained from a force platform and a variable resistance balance board during stance. This study provides the evidence that balance boards are a valid and practical clinical assessment tool for diagnostic of dynamic balance.

The participants were tested on the three types of the balance boards with: (1) audio-visual biofeedback and (2) no biofeedback for each of the balancing tasks. The balance tasks include the balance board that can move in all direction: Radius; balance board that can move in the front-to-back directions only: Front-to-back; and the balance board that move in the left-right directions only: Lateral. The balancing tasks include quietly standing and trying to maintain balance with the arms positioned flat against the body. The effect of the audio-visual biofeedback for each balance board was recorded over a period of one-minute. The outcome measures included radius, and the lateral and front-to-back directions dynamics of the balance board movements.

2.3 Data Acquisition and Analysis

The balance board dynamics in the front-to-back and lateral directions were quantified using data from MEMS accelerometers (Kionix Inc., USA, model KXM52-1050, 3-axial accelerometer with a range of ±2.0g and sensitivity of 660 mV/g). Signals were sampled and acquired using a 12-bit data acquisition system (National Instruments, USA) for further processing on the personal computer. Signal processing was performed using LabVIEW 8.0 (National Instruments, USA) where the visual and audio analysis was performed and the feedback presented in real-time. The statistical analysis post-processing was performed using SPSS for Windows (SPSS, Inc.) and Statistica (StatSoft, Inc.).

2.4 Biofeedback Overview

The biofeedback system consists of real-time combined audio and visual feedback that indicates the position and direction of the balance board during the balancing task based on the accelerometer readings. In a study on audio-feedback Huang et al. found (2006), that sound is an effective feedback for temporal information, and that visual information works better for spatial feedback (Huang et al., 2006; Huang, Wolf and He, 2006). Also, several studies in the SPIRALL Laboratory at Ryerson University demonstrated a positive impact of virtual reality training on postural balance (McConville, Virk and Milosevic, 2007); Virk et al, 2007). This group of studies also found a beneficial effect of active use of arms and increased awareness about the role of arm movements for balance maintenance and recovery (Milosevic and McConville, 2007a; Milosevic and McConville, 2007b).

Specifically, the biofeedback system uses the visual information that shows balance board position and the audio information about the balance board dynamic. The combined processing and feedback was expected to provide an increased spatial orientation and improve maintenance and recovery of postural balance. The block diagram (Figure 1) presents the information flow from the sensor (accelerometer that is placed on the balance board and measures the dynamics of subject's movements), to the computer that process the acquired data, and provides the real time audio and visual biofeedback. In addition, the system stores the data in the database for further offline analysis.

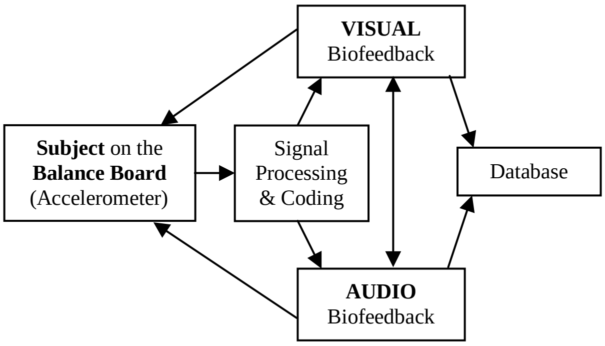

Figure 1. *Block diagram representation of the biofeedback system.*

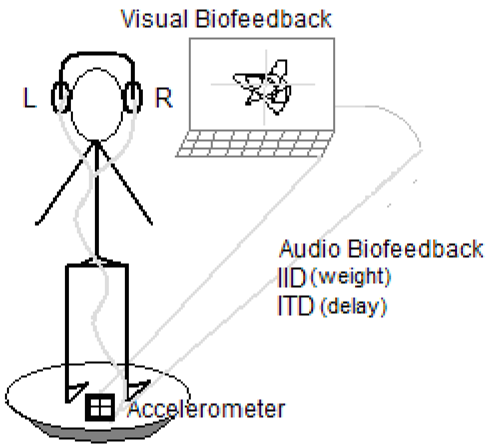

Figure 2. *System implementation for the audio-visual biofeedback. The subject is watching the visual display screen and at the same time receiving the stereo sound with the sound localization algorithm on the headphones.*

2.4.1 Visual Biofeedback. The visual biofeedback is displayed to the user on the PC station 15.4" flat-screen monitor. The visual display consists of a two-dimensional coordinate system plot that presents the position of the balance board related to the lateral (X) and front-to-back (Y) axes. Traces of the X and Y position indicate the dynamics of movement in the polar coordinate system and provide a visual display of the movements during the entire test session. The plot also keeps the position of all previous samples, for each reading, providing the overall performance feedback and the variance of the movement performance visually (Figure 2).

Considering the deteriorating sensory perception among the elderly the implemented display has the goal of augmenting the complex environment and as such helping improve balance. As the goal of the rehabilitation process is to provide the perceivable and simplified information about the often non-perceivable and complex environment for the elderly, the display is designed with this in mind. Moreover, based on the knowledge about the changing and increasingly symmetrical visual memory processes among the elderly (Dobkin, 2003, Dobkin, 2004, Peters, 2005) it is expected that the visual display will have a role in establishing new processes and can have implication in re-weighing the sensory inputs used for balancing

(Horak, 2006) through cortical plasticity induced by task-specific, repetitive, biofeedback training (Dobkin, 2003).

2.4.2 Audio Biofeedback. The audio biofeedback is provided to the user via stereo headphones. The feedback works by calculating the time difference offset and varying the amplitude of the left and the right headphone speaker, based on the algorithm for sound source localization. The Interaural Intensity Difference (IID) algorithm changes the amplitude of the delivered sound signal to each ear based on the position of the balance board. The intensity of the sound increases proportionally to the direction of the balance board. According to previous studies, the algorithm is the most effective when sound was transmitted with headphones (Dodge and Jerse, 1997). Furthermore, the Interaural Timing Difference (ITD) algorithm delivers a slightly delayed sound signal to the ear further away from the direction of the balance board, because of the apparent longer direction of travel providing the feeling that the virtual sound source is in the direction the balance board offset. The ITD has been shown to perform best in the lower frequency range (Dodge and Jerse, 1997). The IID and ITD algorithms were implemented on a constant sinusoidal sound source at 200 Hz and are presented to the subject to provide the audio-directional information. Figure 2 shows implementation of the audio biofeedback system.

Numerous studies on the risk of falls found than people prone to falls suffer from auditory impairment (Chu, et al., 2004; Sihvonen et al., 2004; Stevens et al., 2008) this study devotes particular attention to activation of the existing auditory sensory capabilities for supporting balance maintenance and recovery. The algorithm for the audio feedback used in this study is based on the neural mechanisms of encoding binaural localization cues in the auditory brainstem. According to theory, the auditory system is biologically important for vertebrates because it provides information about the direction and distance of sound. The algorithm for audio feedback is based on the principles of sounds encoding and interpreted through the integrative role of the CNS that gives meaning, localizes and interprets the source and meaning of sound. According to Yin (2002), sound localization is a critical task for the auditory system and the modern neurobiological research explains how vertebrates identify the source and localize sounds form the surrounding environment.

3. RESULTS AND DISCUSSIONS

The effectiveness of the audio-visual biofeedback system was tested in this study and shows promising results. The analysis includes comparison of repeated one-minute balancing tasks on the balance board with: (1) audio-visual biofeedback and (2) no biofeedback during the balancing tasks. All participants were introduced to the balancing tasks through a test practice run and were acquainted with the audio-visual system. The outcome measures include radius, and the lateral and front-to-back directions of the balance board dynamics (Table 1). The results indicate significant improvements in postural stability expressed through decreased variance of the balance board movements. Results show decreased mean of Radius ($F= 926.023$, $p<0.0001$), Lateral ($F= 125.973$, $p<0.0001$) and Front-to-back ($F=65.945$, $p<0.0001$) balance board movements. In addition to the decreased average movements the results show significant variance decrease among all participants (Fig. 3-5). The decreased radius of the balance board movements (Fig. 3) suggests an overall improvement in dynamic balance maintenance with the audio-visual biofeedback. The study also shows improvements in both, the front-to-back (Fig. 5) balancing task and the lateral (Fig. 4) balancing task which is particularly important for falls prevention among the elderly (Maki and McIlroy, 2006).

Table 1. *Descriptive statistics and ANOVA results for comparison of (1) Biofeedback and (2) No Biofeedback balance board dynamics.*

	Radius		**Lateral**		**Front-to-back**	
	Mean	SD	Mean	SD	Mean	SD
(1) Biofeedback	0.086446	0.026325	0.027684	0.022705	-0.07797	0.028405
(2) No Biofeedback	0.11534	0.050989	0.036869	0.043948	-0.08807	0.069697
ANOVA	F= 926.023 p<0.0001		F= 125.973 p<0.0001		F= 65.945 p<0.0001	

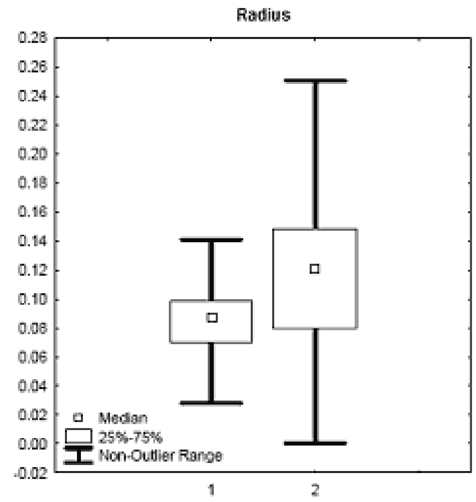

Figure 3. *Radius of the balance board movements*

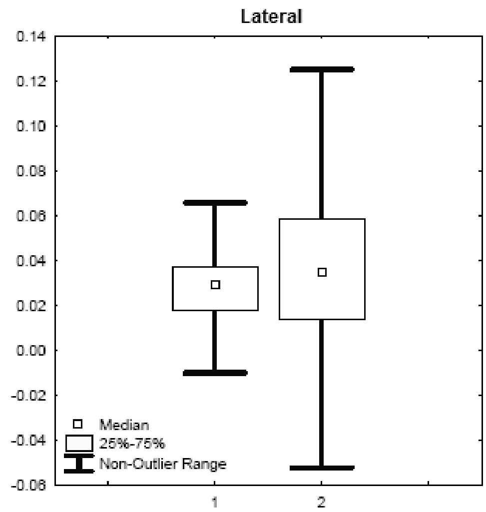

Figure 4. *Lateral balance board dynamics.*

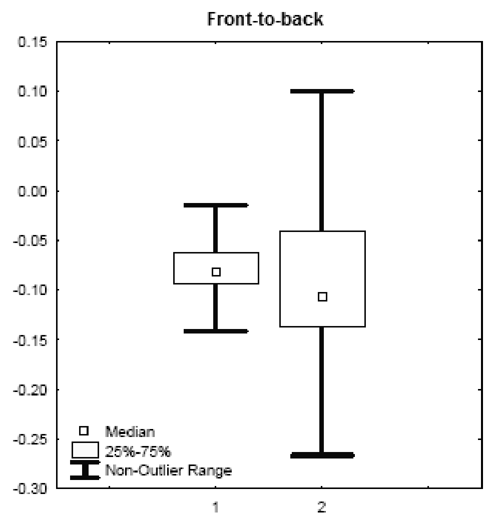

Figure 5. *Front-to-back balance board dynamics.*

4. CONCLUSION

The study presents the results during the implementation of a cost-effective and portable balance training system for the elderly. The initial results of this study indicate a significant positive impact of the combined audio-visual biofeedback on dynamic balance. Analysis shows a decrease in the overall variability of the balance board movements and better maintenance of balance when using the biofeedback. The results suggest that this system can provide a useful training tool for the elderly with an impaired sensory-motor control system. Further developments of this system and a more inclusive feedback, targeting specific movement strategies, may provide training for specific and more efficient balance maintenance strategies. Overall, the study presents promising results and calls for further investigation of the combined audio-visual feedback in improving balance in the elderly, as well as the temporal effects on balance improvements.

Acknowledgements: The authors acknowledge the Natural Sciences and Engineering Research Council (NSERC) of Canada (Grant No.54196), for supporting this work. The authors would like to thank Prof. Ling Guan of Ryerson University for his useful suggestions and help.

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