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Vibrotactile feedback of mediolateral trunk tilt or foot pressure increases locomotor performance in healthy older adults - a pilot study*

Conrad Wall III, Diane Wrisley, Lars Oddsson

Abstract–**Sensory substitution devices can provide body orientation and somatosensory information through vibrotactile feedback. This pilot study compares the effects of two vibrotactile feedback devices during a locomotor task using similar groups of elder subjects.**

I. Introduction

The body uses visual, vestibular, and somatosensory information to maintain balance while standing and walking. Normal subjects integrate vestibular and somatosensory information to control balance differently depending upon the situation to optimize their performance and stability. Subjects who have reduced or missing information due to vestibular or somatosensory loss are unable to achieve the performance or stability of normal subjects and face an increased risk for falls. Sensory substitution, providing information normally obtained by one sense to the body through a different sense, can improve subject's ability to control their balance and their stability. Sensory substitution devices can provide vestibular (body trunk tilt orientation in space) and somatosensory (pressure distribution on the bottom of the feet) information through vibrotactile feedback.

Two newly developed devices are used in this pilot study. The vibrotactile tilt feedback (VTTF) belt or "vest" provides magnitude and direction of trunk tilt relative to the vertical via an array of tactile vibrators (tactors) that ring the torso. The vibrotactile pressure feedback (VTPF) "sock" provides magnitude and the direction of pressure distribution under the feet via an array of tactors that ring the lower leg.

One application is for falls prevention in the elderly. About 7.5 million persons between 65 and 85 years of age fall two or more times per year in the US [1]. Thus, this is a significant National health problem. It has been estimated that about 1/3 of these fallers[2] can be helped by providing them with sensory cues that can enhance or replace natural cues that are lost due to ageing, disease or accidents. Since the majority of falls occur during challenge activities including walking [3] we chose a well-known clinical test of locomotor performance, the dynamic gait index (DGI) [4] ,to measure community dwelling subjects' performance while walking with, and without feedback from the two devices.

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C. Wall is with the Department of Otology and Laryngology, Harvard Medical School, and the Jenks Vestibular Diagnostic Laboratory, Massachusetts Eye and Ear Infirmary, Boston, MA, phone: 617 573 4153; fax: 617 573 4154; e-mail: cwall@mit.edu

D. Wrisley was with the Department of Rehabilitation Science, University at Buffalo, Buffalo, NY. She is now with the Department of Physical Therapy, Lynchburg College, Lynchburg, VA, e-mail: Wrisley.D@lynchburg.edu

L. Oddsson was with the Neuromuscular Research Center, Boston University, Boston, MA. He is now at the Sister Kenny Research Center, Minneapolis, MN, e-mail: lars.oddsson@allina.com

II. Methods

A. Sensory substitution vest

The VTTF vest is a completely wearable, battery-powered research prototype device consisting of a body-mounted 6-degree-of freedom motion sensor package (3 rate gyroscopes and 3 linear accelerometers), a PC 104 computer with peripherals, and a 3 x 16 array of tactile vibrators (tactors) with amplifiers to drive them (Figure 1). The tactors are model VBW 32, from Audiological Engineering, Somerville, MA. The wide white elastic band that rings the torso contains the array of 48 tactile vibrators. Direction is displayed by selecting one of the 16 columns of tactors, while magnitude is displayed by selecting one of three rows in that column. The motion sensor package is mounted at the small of the back. The signals from the motion sensor unit are processed by the

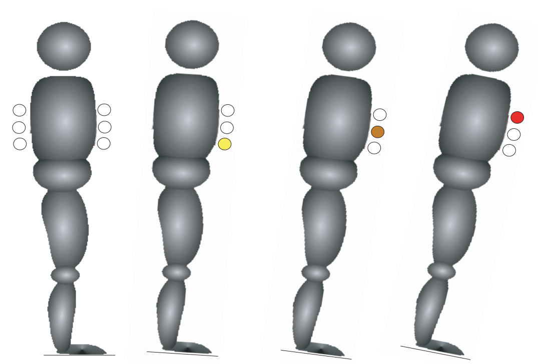

Fig. 1. Position-base tilt magnitude coding for VTTF vest.

computer that activates individual amplifiers connected to each tactor in the array. When activated, the tactor provided a continuous 250 Hz vibratory stimulus to the skin. Tilt direction is coded by activating a tactor in the column whose orientation is nearest to that of the computed tilt direction. Tilt magnitude is coded by changing the position of the activated tactor in a given column. The electronic components and their battery power are mounted in two black leather holsters worn around the waist. The details are published elsewhere [5].

B. Sensory substitution sock

The VTPF sock consists of three modules; a Pressure Sensor Module that directly connects to a Signal Processor Module that sends feedback commands to the Vibrotactile Feedback Module. For these locomotor tests, the device was set up to provide information about the symmetry of the mediolateral pressure distribution on the sole of each foot to the calf of that same foot. For example, a greater pressure on the outside portion of the sole of the left foot is displayed as a vibrotactile signal on the left side of the left calf.

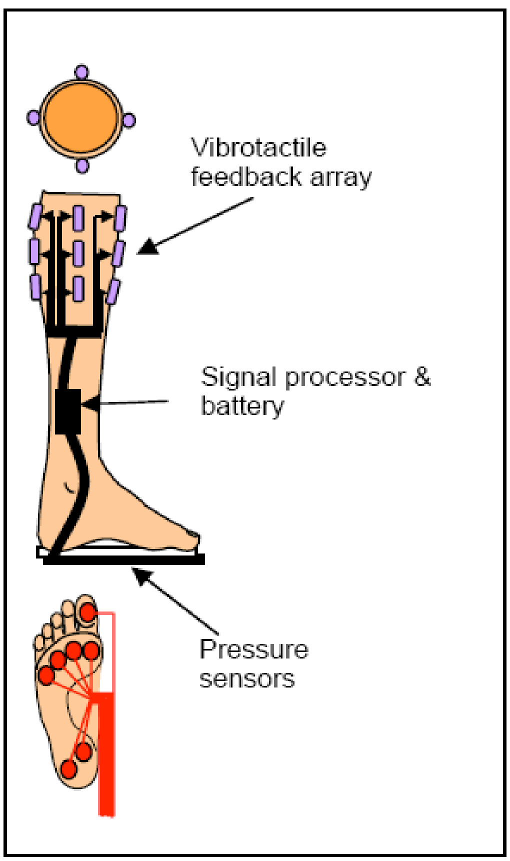

Fig 2. Vibrotactile pressure feedback sock.

C. Dynamic Gait Index (DGI)

This test is comprised of 8 short subtests or items: 1. Gait on a Level Surface; 2. Change in Gait Speed; 3. Gait with Horizontal Head Turns; 4. Gait with Vertical Head Turns; 5. Gait and Pivot Turn; 6. Step over Obstacle; 7. Step Around Obstacles; and 8. Stair Stepping (up and down). Each item is scored on a 4-point scale (0 to 3) and the points for each item are then summed for a total score. A total score of 19 or less indicates increased risk of fall [6], while a score change of 3 is considered to be clinically significant [4].

D. Subjects and protocol

The experiments were conducted in Dr. Wrisley's lab at the University of Buffalo. Nine healthy elderly subjects (5 males and 4 females, age: 75.2±2.2 yrs) were tested with each device in two separate sessions. Community dwelling older adults were recruited from a university community and senior living facility. Subjects were included if they were between the ages of 65 and 90 years of age, had no neurological or orthopedic impairment that would limit their ability to stand and walk, were able to stand independently for 5 minutes, and perceived they had balance problems. Each subject completed a neurological screen to ensure that they met all the inclusion criteria and to document the subject's lower extremity range of motion, muscle strength and sensation. During the first session the DGI was measured for 6 subjects with and without VTTF. Subjects were characterized as healthy elderly based on the Activities-specific Balance Confidence Scale [7], (ABC, 73.2±8.3) Vestibular Disorders Activities of Daily Living Scale [8] (VDAL, mean 2.11), and Berg Balance Scale [9] (BBS, 52.0±0.6). A baseline DGI without VTTF was measured for each subject. After 30 minutes of VTTF training, a second DGI was measured for each subject while receiving VTTF information about their mediolateral body tilt from the device. During the second session one month later the DGI was measured for the original 6 plus 3 additional subjects with and without VTPF. ABC (74.3±7.19), VADL (mean, 1.92), and BBS (51.2±1.4) scores were measured. A baseline DGI without VTPF was measured for each subject. After 30 minutes of VTPF training a second DGI was measured for each subject while receiving VTPF about foot pressure from the device.

III. RESULTS

A. DGI results with vest

DGI scores increased by 3.7±1.7 from 17.1±0.4 to 20.8±0.3 with VTTF. This change was significant at the p =0.001 level. Each of the 8 DGI items showed an increase in the average score, with the increase in item 3 being significant ($p < 0.05$), Table I.

Table I. DGI Scores by DGI subtest item.

DGI	Vest OFF		Vest ON		Difference	Sock OFF		Sock ON		Difference	Biggest
item	Mean	*SD*	Mean	*SD*		Mean	*SD*	Mean	*SD*		Change
1	2.00	*0.60*	2.33	*0.50*	0.33	2.11	*0.60*	2.44	*0.70*	0.33	equal
2	2.33	*0.50*	2.67	*0.50*	0.34	2.44	*0.00*	2.67	*0.50*	0.23	vest
3	1.50	*0.50*	2.33	*0.50*	**0.83**	2.11	*0.80*	2.44	*0.40*	0.33	vest
4	2.17	*0.80*	2.67	*0.50*	0.50	2.11	*0.60*	2.78	*0.40*	**0.67**	sock
5	2.83	*0.40*	3.00	*0.00*	0.17	1.89	*1.20*	2.44	*0.90*	0.55	sock
6	1.83	*1.20*	2.67	*0.50*	0.84	2.22	*0.40*	2.56	*0.50*	0.34	sock
7	2.50	*0.50*	3.00	*0.00*	0.50	2.89	*0.30*	2.89	*0.30*	0.00	vest
8	2.00	*0.00*	2.17	*0.40*	0.17	2.11	*0.30*	2.33	*0.50*	0.22	sock
Total	17.17	*1.50*	20.83	*1.20*	**3.66**	17.89	*2.50*	20.56	*2.65*	**2.67**	

B. DGI results with sock

DGI scores increased by 2.2±0.5 from 17.7±0.8 to 20.2±0.9 with VTPF. This change was significant at the $p<0.01$ level. Each of the 8 DGI items showed an increase in the average score, with the increase in item 4 being significant ($p < 0.05$). The DGI items showing the most improvement of vest versus sock are shown in the last column of Table I.

C. Score improvement versus subject sensory deficit

Subjects' DGI scores improve with both vestibular and proprioceptive information, but there was a tendency for more improvement when the sensory feedback matched the compromised sense. Two subjects with bilateral vestibular hypofunction improved with both kinds of feedback, but improved more with vest (4.5 points from 16.5 to 21) than with the sock (3 points from 18 to 21). Two subjects with peripheral neuropathies that affected the pressure sensitivity of the sole of the foot improved with both kinds of feedback, but improved more with sock (3.5 points from 18 to 21.5) than vest (3-points from 18.5 to 21.5). One subject with combined vestibulopathy and peripheral neuropathy improved with both, more with vest (6 points from 15 to 21) than sock (4 points from 18 to 22).

V. CONCLUSIONS

Shortcomings of the study include no control group and no randomization of the order of VTTF and VTPF. Previous studies have shown that the reaction time to a vibrotactile stimulaion is about 30 msec [10]. Despite this delay, subjects were able to make use of the feedback from an excursion quickly enough to use the feedback in one step to make a correction in the next step. Based upon our limited pilot data we make the following predictions. In subjects with normal sensory function there will be better performance when either orientation or proprioceptive sensory substitution information is provided. There will be even further improvement with both modalities enhanced. In subjects with vestibulopathies and peripheral neuropathies there will be some performance improvement when information is added to the intact modality, but better performance when information is added to the missing modality. We would predict even further improvement when information is added to both missing and intact modalities.

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