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Applications of Vibrotactile Display of Body Tilt for Rehabilitation

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Abstract **Body-mounted motion sensors have been shown to decrease subject sway when a tilt estimate is fed back to the user by means of an array of tactile vibrators which display estimated tilt magnitude and direction. Vestibulopathic subjects who are tested using computerized dynamic posturography show significantly reduced sway in both the sensory motor and the motor control portions of that test. This result suggests potential application as an assistive balance aid. Another potential application of vibrotactile tilt feedback is in rehabilitation. Two lines of research have yielded promising, albeit very preliminary, supporting results. The first of these is the response of subjects to a toes-up pitch maneuver. At critical pitch velocities, vestibulopathic subjects are unable to maintain stability during or after a perturbation without tilt feedback, but are able to stand when feedback is provided. The second line of research involves perturbations during locomotion. Vibrotactile tilt feedback again reduces subjects sway. Preliminary results of both of these on-going experiments indicate that this increase in performance may be retained.[1]**

Keywords **Balance, Prosthesis, Sensory Substitution, Vibrotactile Display**

I. Introduction

The U.S. Navy has successfully used vibrotactile displays to help orient pilots by providing them with navigational cues from the aircraft avionics[1, 2]. We have extended this concept to human postural and locomotor control by using body mounted motion sensors, and by optimizing the display for this specific application[3]. A simple tethered 1-axis apparatus allowed us to show proof-of-concept by demonstrating that vestibulopathic subjects were able to use vibrotactile display of body anterior-posterior (A/P) tilt to improve their performance in a widely-used clinical test of postural control [4]. The preliminary rehabilitation data shown in this report was taken with the 1-axis device. A second generation 6 degree of freedom, completely wearable vibrotactile display apparatus has recently been developed [5], and is now in use. It will allow much more flexibility for locomotion experiments and represents the application of this new technology for rehabilitation.

II. Methodology

The device used for the preliminary experiments has three components. An instrumentation unit consisting of a micro-mechanical rate gyroscope (gyro) and a micro-mechanical linear accelerometer is mounted on the small of the back of the subject. The sensitive axis of the gyro measures A/P angular rate (pitch). The sensitive axis of the accelerometer measures linear acceleration and gravitational force in the A/P direction tangential to the subject s rostro-caudal axis. Theses two signals are processed using a laptop computer, then combined to provide an estimate of A/P body tilt. The gyro signal is high pass filtered, then integrated. This eliminates drift in the signal due to bias, but does not provide DC information. The latter is provided by low pass filtering the linear accelerometer signal to greatly reduce the tangential acceleration, while still keeping the gravity component. The resulting body tilt estimate is then displayed to the subject using 4 vertical columns of vibrotactile elements called tactors. Each column of tactors has 3 rows which are used to display tilt magnitude. Two columns are mounted on the front of the torso, approximately two inches on each side of the navel. The other two columns are mounted on each side of the backbone. If the subject stays within a dead zone of approximately plus or minus 1 degree, no tactors are activated. A tilt of between 1 and about 3 three degrees activates the lowest tactors on the two front columns. As tilt increases to between about 3 and about 8 degrees, the first row of tactors is shut off and the second row is activated, and so on, in a stair-like manner. Rearward tilt is similarly displayed on the columns of tactors mounted on the back. Actual switching levels are determined on an individual subject basis and are scaled based upon that subject s limits of stability. The device is described in detail elsewhere [6]. Subjects can be taught to use the vibrotactile display to control their body tilt in approximately 15 minutes [4]. The device was used to test vestiblopathic subjects in two experiments whose results are described below.

III. Results

A. *Vibrotactile feedback of body tilt during toes up pitch in bilateral hypofunction subjects*

In collaboration with Drs. Horak and Wrisley, we compared the response to toes up pitch during quiet standing of a bilateral vestibular hypofunction subject with and without the balance aid. Our preliminary study using the balance aid demonstrated increased stability of the trunk in space and center of mass in one patient with bilateral vestibular loss at velocities of surface rotation that normally require vestibular information. Our preliminary study using the vibrotactile

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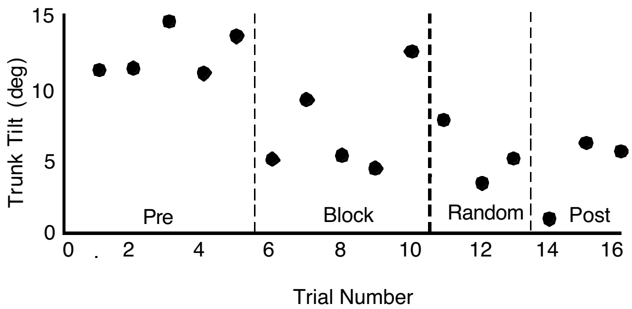

Fig. 1. Maximum trunk tilt by trial in a subject with bilateral vestibular loss. Pre-trials: Without vibrotactile feedback before training. Block: Practice trials blocked by velocity of surface rotation with the device. Random: Practice trials with the device on and with surface rotation velocity randomized. Post: Trials with the device after training. Note that the average trunk tilt decreases after training even without the device.

feedback device for a postural control experiment demonstrated increased stability of both the trunk in space and center of mass in a patient with bilateral vestibular loss at velocities of surface rotation that normally require vestibular information. Fig. 1 shows peak backward tilt of the trunk in response to toes up surface tilts for a series of trials. The peak tilt of more than 10 deg during the pre-training trials (Pre) was reduced by blocks of trials in which the same tilt velocity was repeatedly presented (Block). Tilt reduction with sway feedback also reduced peak tilt responses when the stimuli were presented in random order (Random). The surprising result was that this bilateral vestibular loss subject maintained improvements even after the device was removed. This implies there may be a long-term benefit from periodic training with the vibrotactile device.

*B. **Vibrotactile feedback of tilt during perturbations of locomotion***

We next investigated the effect of vibrotactile feedback of tilt on a vestibulopathic subject who was given perturbations during locomotion using a standard Balance Disturber protocol [7, 8]. We again used pre-test trials with no feedback where perturbation and control (no perturbations) trials were presented in random order. This was followed by blocks of vibrotactile feedback training trials. Each block repeated the same condition five times. We then presented perturbation and control trials in random order but with vibrotactile feedback. Finally, we ran post-test trials as per the pre-test protocol (Fig. 2). The means of the Random and Post-test trials are significantly less than the pre-test ones ($p < 0.05$). This reduction in body sway after training with vibrotactile feedback is much larger than effects we have observed in repeated perturbation trials of vestibulopathic subjects who had no vibrotactile tilt feedback. These responses for perturbations of locomotion are similar to the responses to perturbations of postural sway shown above.

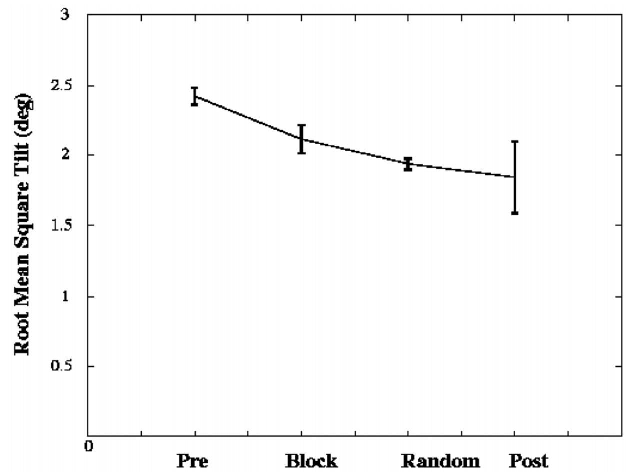

Fig. 2. Average root mean square mediolateral body tilt in response to perturbations of locomotion for a vestibulopathic subject. Pretest and Post-test trials have with no vibrotactile feedback of mediolateral body tilt, which is displayed on the subject's right and left sides for the Block and Random trials

These preliminary results suggest that we will be able to use vibrotactile feedback to control the M/L body tilt of vestibulopathic subjects' responses to perturbations during locomotion.

IV. Discussion

Both of these preliminary experiments suggest that the vibrotactile display of body tilt has potential utility for rehabilitation applications. Our continuing studies will examine whether there is a true effect due to retention.

V. Conclusion

The technology of micro mechanical inertial instrumentation which can be used to measure motions of the body is rapidly advancing in that high accuracy, low noise devices are starting to come on the commercial market at reasonable prices. These devices make it feasible to provide accurate, yet stable estimates of body tilt which are needed for applications like balance aids.[9] Similarly, microprocessors that are fast enough to provide good signal processing, and also have low power requirements are available. The technology of tactile stimulators, which have previously been developed and FDA approved for sensory substitution devices to aid the hard of hearing is already well developed. Thus, the key elements of devices which can potentially aid those with balance problems are now or will soon be available. The potential applications to provide continuous information or to provide training devices to be used during rehabilitation training are both being actively investigated. While the preliminary results presented herein need larger numbers of subjects and adequate control experiment, there is reason to be hopeful that this kind of device will become clinically useful in the not too distant future.

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