A Custom Approach to Vibrotactile Balance Feedback

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INTRODUCTION

The CDC has estimated that one in three adults over the age of 65 fall annually [1]. Of those who fall, at least 20% suffer injuries ranging in severity from lacerations to bone fractures to potentially deadly traumatic brain injuries [1]. These injuries cost the U.S. health care system over $30 billion in 2010 and the associated costs are expected to rise to almost $55 billion by 2020 [1].

Vibrotactile feedback (VTF) is a technique designed to augment sensory information to compensate for deficiencies in normal balance processes [2]. Tactors placed on the torso surface vibrate when the subject is no longer within a defined stable zone. Vibrotactile feedback have proven effective at improving balance in older adults and patients with bilateral vestibular loss [2].

Products currently on the market utilize position-velocity (PV) feedback models which use weighted position and velocity information to determine if the subject is at risk of a fall. These products include the BalanceTek Balance Belt™ [3] and the VestiCure Vertiguard® RT [4]. Both products use four tactors around the hip and a sensor that measures sway in the mediolateral and anterior-posterior axes.

These products have two main problems: they are not customizable to the user and they perform differently depending on sway frequency [2]. Other sensory prostheses, like glasses and hearing aids, are tuned to the specific deficiencies of the wearer. These products are uniform, using the same position-velocity model for all users. Also, while they decrease low-frequency sway well, they tend to increase high-frequency sway (figure 1), which may counteract some of the stabilization produced by the low-frequency reduction [2].

OBJECTIVES

Figure 1: Theoretical sway reduction (compared to no VTF) over perturbation frequencies for PV (red) and uniform (blue) models.

A model which uniformly decreased sway across all frequencies was developed to remove the frequency dependence of the sway reduction (figure 1, blue line) [2]. The model can also be customized to the specific user by changing various parameters.

SUCCESS CRITERIA

The effectiveness of the model is represented by the root-mean-square (RMS) power (equation 1) of the subject’s angular deviation from the vertical.

\[
RMS = \sqrt{\frac{1}{n} \sum_{i=1}^{n} x^2}
\] (1)

The RMS power for the custom model is expected to be significantly lower than that for the PV model for both total and high frequency sway.

METHODS

Ten control subjects were tested using the PV and custom models in this study. Subjects were strapped into a harness to prevent falling. During each of eight trials, the subject stood with eyes closed on a balance platform which moved mediolaterally according to a 2-degree peak-to-peak pseudorandom signal. Angular position, velocity, and acceleration data were collected by a sensor on the small of the patient’s back. No VTF was applied during the first trial. The results of the first trial were used by a Matlab program to fit parameters of the custom model (equation 2) developed.

\[
H_f(s) = \frac{1}{G_T \left( 1 + \frac{1}{c} \right)} \left( \frac{s \left( J s^2 + K_d s + (K_p - mgh) \right)}{K_d s + K_p} \right) ^\frac{1}{2}
\] (2)

where \(G_T\) is a normalization factor, \(c\) is the desired attenuation level, \(J\) is the body moment of inertia, \(K_d\) and \(K_p\) are, respectively,
damping and stiffness coefficients, \(m\) is body mass, \(g\) is gravitational acceleration, \(h\) is center of mass, and \(s\) is the Laplace variable.

The vibrating tactors were then placed on the subject. Six trials, two trials for each of the three VTF models (PV, custom, and a predictive model), were then performed in randomized order to prevent learning. The tactors were then removed and the last trial was performed with no VTF applied to account for learning as a possible source of reduced sway.

A high-pass filter was applied to the angular position to filter out data below 0.5 Hz. The RMS powers of the high-pass and total signals were calculated.

PRELIMINARY RESULTS

Eight of the ten control subjects tested had usable data (the model parameter values fell within nominal range [6]). The RMS values were averaged across all subjects for each condition (figure 2).

As can be seen in figure 2, no significant difference was found between the RMS values for the custom model developed and the established PV model, for total or high-frequency sway.

DISCUSSION

Only control subjects have been examined so far. Control subjects tend to have lower RMS values than those with balance deficiencies. In subjects with larger RMS values, there may be a more measurable difference.

Also, it is assumed that when VTF is applied, the parameters calculated from a trial without VTF remain constant. Subjects seem to tend to stiffen when VTF is applied due to being startled at the tactor activation. Figure 3 shows the actual gain ratio of the model if \(K_p\) and \(K_d\) increase by a factor of 1.2 (blue), compared to the uniform model (red).

This resulting model more closely resembles the PV model, with more reduced sway at lower frequencies and increased sway at higher frequencies. This changed model could account for the similarities in the RMS power values for total and high-frequency sway.

CONCLUSION

This custom vibrotactile feedback model has the potential, if implemented properly, to prevent dangerous falls caused by high-frequency sway. The developed custom model has been shown to work at least as well as the PV model for reducing postural sway in control subjects. Further directions for this study include examination of subjects with bilateral vestibular deficiencies and of amplitude modulation methods of tactor activation. Because of this, bilateral subjects deviate more greatly from vertical due to their balance deficiencies and might show a more marked performance difference between models. Amplitude modulation, where the intensity of the tactors increases with increasing deviation, may remove the startling effects of tactor activation by habituating the subject to the tactor vibration.

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REFERENCES


