

Chapter 13

Restoring Balance: Replacing the Vestibular Sense with Wearable Vibrotactile Feedback

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ABSTRACT

Bilateral vestibular loss (BVL) is a disorder of the balance sensory organs in the inner ear; it can cause falls which may have grave consequences, particularly among elderly. This chapter presents the iterative user-centered design of a vibrotactile feedback mechanism for substituting the balance sense. Six wearable prototypes were created to compare the suitability of different body parts (foot, ankle, knee, waist, shoulder, upper arm) for perceiving this type of feedback and to compare different encoding mechanisms (number, intensity, and rhythm of vibrations). In a second iteration, two of these wearable devices (for the ankle and the waist), in two feedback encoding mechanisms (directional and non-directional) were improved and evaluated. Based on the combined studies and interviews conducted with patients and specialists, it is argued that vibrotactile non-directional balance feedback should be applied to ankles, and that such devices should be integrated in training systems.

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INTRODUCTION

The human balance system consists of a complex mixture of physical sensation, perception, and motor responses (Huxham, Goldie & Patla, 2001). A condition known as bilateral vestibular loss (BVL) results from damage done to the system of organs in each ear that senses acceleration in different directions, or the neurons leading from this system to the brain. Damage to these sensory organs can affect one's ability to walk or stand while maintaining balance. For people with BVL who are otherwise healthy, if the damaged sense could be replicated in another sensory modality in a manner that can be perceived and acted upon, some of the functionality of the balance system might be substituted.

The substitution of the balance sense through technological means is a possibility that is becoming more realistic thanks to developments in sensors and wearable technologies. For example, Janssen et al. (2005) have developed a device that is specifically intended to help people with BVL replace their damaged sense of balance; it consists of an accelerometer attached to vibration motors that are arranged around the wearer's waist. The accelerometer measures the direction that the wearer is leaning, and informs the wearer of that direction by turning on the corresponding vibromotors.

Crucially, the success of such sensory replacement systems is dependent upon how successfully they present sensory feedback to patients. The scope of possible solutions is quite large, varying with regards to aspects such as location on the body, modality of the feedback, and the encoding of information they use. We present a user-centered exploration of this solution space that examined the suitability of different parts of the body for perceiving vibrotactile feedback and that compared different encodings. Specifically, vibration was applied on the shoulders, arms, waist, knees, ankles and feet. We examined five

different approaches for encoding balance sense information: *intensity* of the vibromotors, *number* of vibromotors on, *rhythm* of vibromotor pulses, a combination of *intensity and number* of vibromotors activated, and the inclusion or exclusion of *directional cues*.

In the remainder of this chapter we outline the iterative design of these devices, the user tests that were done, and the information obtained through interviews with patients and specialists. First, some background information on BVL and related research on technologically supported balance compensation will be presented.

Balance Control and Bilateral Vestibular Loss

Balance control is a systemic function determined by biomechanical and information processing aspects (Huxham, Goldie, & Patla, 2001). Balance control is driven by many independent factors, such as muscular strength and cognitive load. The impact of those factors in balance is influenced by individual differences and lifestyle (Chu, Chi, & Chiu, 2007). Because people are not always aware of the states of these factors and their relationship to balance control, the increased risk of falling may go unnoticed.

Balance disorders occur more frequently among the elderly population, leading to falls during daily activities. Falls among the elderly represent a great risk of mobility loss. Muscle deterioration is increased by lack of mobility, and progressive loss of balance can result (Frank & Patla, 2003). Add to this a potential fear of falling, which, in the elderly population, increases with the individual's history of falls (Hatch, Gill-Body, & Portney, 2003), and a vicious circle of balance deterioration can develop. On the other hand, it is anticipated that individuals who have confidence in their balance walk more, exercise more, and interact more with their community (Hatch, Gill-Body, and Portney, 2003). As a consequence, these

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