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Vibration-enhanced posture stabilization achieved by tactile supplementation: May blind individuals get extra benefits?

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ABSTRACT

Diminished balance ability poses a serious health risk due to the increased likelihood of falling, and impaired postural stability is significantly associated with blindness and poor vision. Noise stimulation (by improving the detection of sub-threshold somatosensory information) and tactile supplementation (i.e. additional haptic information provided by an external contact surface) have been shown to improve the performance of the postural control system. Moreover, vibratory noise added to the source of tactile supplementation (e.g. applied to a surface that the fingertip touches) has been shown to enhance balance stability more effectively than tactile supplementation alone. In view of the above findings, in addition to the well established consensus that blind subjects show superior abilities in the use of tactile information, we hypothesized that blind subjects may take extra benefits from the vibratory noise added to the tactile supplementation and hence show greater improvements in postural stability than those observed for sighted subjects. If confirmed, this hypothesis may lay the foundation for the development of noise-based assistive devices (e.g. canes, walking sticks) for improving somatosensation and hence prevent falls in blind individuals.

Introduction

The control of human postural sway, gait and other motor activities depends upon the integration of visual, vestibular and somatosensory information. More specifically, it is well known that visual cues, when available, play a paramount role in the accurate control of human posture, balance and locomotion [1–6]. The major contribution of vision in controlling body sway is easily demonstrated when people stand with their eyes closed: postural stability is decreased during quiet stance [3,7–9] as well as during dynamic postural tasks [10–12]. On the other hand, falls are a major public health concern in terms of morbidity, mortality and the cost to health and social services [13] and excessive postural sway (i.e. a poor postural stability) has been associated with increased risk of falls in different populations [14–16]. Moreover, many studies have included measures of visual impairment (i.e. blindness and poor vision) as an important risk factor for falls [17–20].

Therefore, great efforts have been made in order to develop therapeutic interventions designed to improve postural control and consequently prevent falls in the population with sensory-motor impairment. For instance, a promising intervention using low-level noise (electrical or mechanical) has been shown to improve the sensitivity of the human somatosensory system thereby improving balance control [21–24]. The premise is that certain levels of noise can enhance the detection and transmission of somatosensory signals, by a mechanism known as stochastic resonance.

Additionally, it has been widely demonstrated that light touch of a fingertip on an external stable surface (even at contact forces inadequate for mechanical support of the body) provides sensory cues about the direction of body sway and hence greatly improves the postural stability of standing subjects [25–27]. This has brought the notion that, besides providing physical support, assistive devices such as canes, crutches, walking sticks, etc. may much of the time serve as supplementary sources of sensory information, thereby diminishing the probability of loss of balance and consequently prevent falls [28,29].

More recently, we have shown that a low-level vibratory noise applied to a stable surface being touched by the fingertip can improve postural stability beyond that achieved by lightly touching the same stationary surface without the noise [30], suggesting that the addition of vibratory noise to assistive devices may be used as an aid to further improve posture stabilization of individuals with balance impairments.

Given that blind individuals show superior abilities in the use of tactile information [31,32], the hypothesis of this paper is that blind subjects may take extra benefits from the vibration-enhanced representation of haptic supplementation and hence show greater improvements in postural stability than sighted subjects. If proven correct, this hypothesis may lead to useful implications for the design of mobility aids such as canes and walking

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sticks, suggesting that the addition of an appropriate level of noise to these assistive devices may potentially improve postural control and hence prevent falls in blind individuals.

The text ahead explores in detail each point involved in the formulation of the hypothesis. Additionally, directions for future research and possible clinical implications are discussed.

Effect of haptic supplementation on postural stabilization

The combination of cutaneous and kinesthetic inputs from mechanoreceptors located in the skin, muscles, tendons and joints of the hand and arm, named haptic sense, is critical for complex sensory-motor skills, such as object recognition through exploration [33], handling [34] and grasping [35]. Recently, additional haptic information from lightly touching a stationary surface with the fingertip (even at non-mechanically supportive force levels) has been shown to improve postural stability in healthy [27,36,37] and sensory-impaired subjects [38–42]. Jeka and colleagues [27,37,43] have suggested that fingertip contact to a surface provides somatosensory cues about arm position and movement of the body, leading to an anticipatory muscle activity related to postural control and, consequently, body sway reduction. In other words, slight changes in contact force at the fingertip could provide sensory cues about the direction of body sway, allowing attenuation of sway.

Therefore, additional haptic information enhances postural performance by taking advantage of an external reference to improve the control of upright stance. This provides useful implications for the use and design of mobility aids such as canes, crutches and walking sticks commonly used for rehabilitation from musculoskeletal or neuromuscular injuries and balance impairments [28]. As previously suggested [28], these assistive devices may provide sensory cues from somatosensory stimulation of the hand and arm through contact of the cane with the ground or a rigid object.

Thus, the use of additional haptic information to improve postural control has provided new insights to the development of new rehabilitation strategies to improve balance in individuals with impaired sensory-motor functions.

The benefits of noise on postural control

The stochastic resonance phenomenon, which has been described in very different settings, is associated with an improvement in performance of a given system in response to an appropriate level of noise [44–46]. In this case, noise, which is usually viewed as detrimental to signal detection, can be used as a suitable pedestal for enhancing the detection of an input stimulus [22]. For example, a low-level mechanical noise may cause small receptor potential fluctuations, bringing the neuron closer to threshold and hence making normally sub-threshold stimuli (e.g. mechanical tactile input) to be detectable [21].

In this regard, previous work in the literature has shown examples of stochastic resonance as an aid to reduce postural sway. Electrical or mechanical noise stimulation applied to a subject's leg or feet have been found to improve postural stability in different populations, such as healthy young and older subjects [22,23], or patients with impaired sensory-motor function [24,47]. The authors have suggested that the improved detection of somatosensory signals by target receptors involved in muscle and joint sense or foot soles mechanoreceptors leads to these balance control improvements, by providing enhanced information about body movement and position.

More recently, we have shown improved postural stability achieved by adding vibratory noise to the surface that the fingertip touches [30]. This work has brought the knowledge that a further increase in postural steadiness (compared to that observed when subjects touched a stationary surface) may be achieved by adding noise to the source of haptic information. The probable mechanism is that the vibratory noise added to the fingertip's contact surface is able to activate additional or more specialized mechanoreceptors (by a stochastic resonance mechanism), improving the representation of the input signals that reach the central nervous system. This discovery has led to the suggestion that the addition of vibratory noise to canes, walking sticks, handrails, etc., may be used as an aid to improve stabilization in individuals with balance impairments [30].

Cross modal processing of remaining senses in blind subjects

A growing body of evidence suggests that blind subjects, compared to the sighted population, develop higher abilities in the use of their remaining senses, particularly in tasks involving the processing of tactile [31,48] and auditory sensory inputs [49–51]. Numerous studies have demonstrated that, in blind subjects, brain areas normally reserved for visual processing (e.g. occipital cortex) become engaged in cross modal processing of non-visual information, which may account for the blind's superior capacities in performing tasks with the help of haptic and auditory cues [32,52–55].

For example, blind individuals showed activation of the primary and secondary visual cortical areas during tactile tasks, whereas sighted control subjects showed deactivation [32], which confirms that cortical areas commonly associated with vision may be activated by haptic stimulation. Moreover, transcranial magnetic stimulation of the occipital cortex disrupted the tactile discrimination abilities of blind subjects, but had no effect on tactile performance in normal-sighted subjects [55]. This confirmed the functional relevance of this cross modal plasticity in blind humans, by showing that the visual cortex can indeed process somatosensory information in a functionally relevant way.

Hypothesis: may blind subjects show enhanced balance stabilization in response to vibratory noise added to haptic supplementation?

As briefly reviewed in the previous sections, beneficial effects of haptic cues and noise stimulation on posture stabilization have been extensively reported. More specifically, the combination of vibratory noise and haptic supplementation has shown to be more effective than haptic supplementation alone [30]. Additionally, given that blind people develop capacities of their remaining senses that exceed those of normal subjects (particularly their ability to process tactile information), the hypothesis addressed here is that blind subjects may thus take greater advantage of vibratory noise added to haptic supplementation than sighted subjects. More specifically, we hypothesize that blind subjects may take advantage of their larger cortical representation of tactile inputs and hence take extra benefits from the noise-enhanced balance control associated with haptic supplementation, thanks to a cross-modality plasticity process.

The protocol to test the above hypothesis involves experimental and clinical studies in order to explore the improvement in measurements of postural stability achieved by applying noise-based sources of haptic supplementation in blind individuals, as well as to compare such improvements with those achieved by sighted subjects. Although this hypothesis has not been tested directly, the effect of additional sensory cues on posture stabilization of blind individuals has been previously investigated: no superior abilities with respect to sighted subjects with eyes closed were observed when postural control was tested providing blind subjects with additional haptic [26] or auditory cues [56]. In these experiments, however, no noise was added to the source of additional sensory information, and additionally, both blind and sighted subjects were näive to the task, which could have precluded the blind individuals to develop superior postural abilities, since activation of the new functional connections of blind subjects is strongly task-related and training-induced [57–59]. Therefore, investigations involving long-term adaptation (i.e. allowing training) may also be necessary to elucidate the potential abilities of blind subjects to take extra benefits from the noise-based haptic supplementation. Moreover, we highlight that the addition of vibratory noise to the haptic supplementation may be of great importance because it may potentially improve the representation of haptic cues, an effect that has never been tested in blind individuals.

From a clinical standpoint (if the hypothesis is proven corrected), noise-based assistive devices could be designed for blind individuals so as to enhance somatosensation and hence improve their postural control. It may be possible, for example, to build walking sticks that apply vibratory noise to the site of contact with the hand and fingers. This could potentially reduce the risk of falls associated with blindness, which would lead to significant health and economic benefits.

Conflict of interest statement

The authors disclose no conflict of interest.

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