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Effects of electrotactile vestibular substitution on rehabilitation of patients with bilateral vestibular loss

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ABSTRACT

The present study evaluated the effectiveness of electrotactile tongue biofeedback (BrainPort®) as a sensory substitute for the vestibular apparatus in patients with bilateral vestibular loss (BVL) who did not have a good response to conventional vestibular rehabilitation (VR). Seven patients with BVL were trained to use the device. Stimulation on the surface of the tongue was created by a dynamic pattern of electrical pulses and the patient was able to adjust the intensity of stimulation and spatially centralize the stimulus on the electrode array. Patients were directed to continuously adjust head orientation and to maintain the stimulus pattern at the center of the array. Postural tasks that present progressive difficulties were given during the use of the device. Pre- and post-treatment distribution of the sensory organization test (SOT) composite score showed an average value of 38.3 ± 8.7 and 59.9 ± 11.3, respectively, indicating a statistically significant improvement ($p = 0.01$). Electrotactile tongue biofeedback significantly improved the postural control of the study group, even if they had not improved with conventional VR. The electrotactile tongue biofeedback system was able to supply additional information about head position with respect to gravitational vertical orientation in the absence of vestibular input, improving postural control. Patients with BVL can integrate electrotactile information in their postural control in order to improve stability after conventional VR. These results were obtained and verified not only by the subjective questionnaire but also by the SOT composite score. The limitations of the study are the small sample size and short duration of the follow-up. The current findings show that the sensory substitution mediated by electrotactile tongue biofeedback may contribute to the improved balance experienced by these patients compared to VR.

Bilateral vestibular loss (BVL) is a balance disorder caused by failure of the peripheral vestibular apparatus, and results in multiple problems in the control of posture, gait instability and balance difficulties. It is a condition that occurs in approximately 1–2% of all subjects who complete electronystagmography tests [11]. The most common etiologies of BVL are drug toxicity, traumatic brain injuries, meningitis, labyrinthitis, bilateral tumors, otosclerosis and several other factors, including those associated with aging [10]. The main symptoms described by patients with BVL are oscillopsia and disequilibrium. Oscillopsia is the optical illusion that stationary objects are moving back and forth or up and down and occurs because the vestibulo-ocular reflex cannot maintain the target of gaze on the fovea [19]. Maintenance of postural control requires accurate sensing of the environment using vestibular, visual, and proprioceptive cues. Body balance depends on at least two of these three sensory systems working well. So, disequilibrium increases in dark environments and on irregular surfaces. In the absence of a functional vestibular system, the central nervous system (CNS) has difficulty integrating the conflicting information between the visual and proprioceptive systems and in providing the correct motor commands [15].

To date, the treatment of choice for these patients has been vestibular rehabilitation (VR), which is effective in up to 50% of the cases, but is less effective with patients who have BVL compared to patients with other vestibular disorders such as unilateral vestibular loss [14,16]. Once the therapy is performed the final result is limited. Another option has been used over the last few years by the introduction of neuro(bio)feedback procedures. A neurofeedback system applies an additional (auditory, galvanic, vibrotactile) stimulus to the patient while he is performing vestibular exercises [13,21,18].

Regardless of the exclusion of peripheral information, patients with BVL maintain the sensorial integration of central mechanisms for postural stability. Thus, it could be possible to connect an arti-

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ficial movement receptor to the brain structures associated with perception, integration and output of the responses related to body balance, prompting the reorganization of the cortical map and subsequent compensation of the damaged system [3,4].

With this purpose, Tyler et al. [22] developed a vestibular substitution system and showed that postural coordination can be restored using a man–machine interface that offers a unique pattern of electrotactile stimulation on the tongue's surface. The use of the tongue as an optimal sensorial organ is well established and draws heavily on in the characteristics of the organ, i.e., the nervous fibers' high density and sensitivity, in addition to the physical properties that provide reception and maintenance of the electrical contact [5]. Another attribute of the tongue is a large somatosensory cortical representation [20]. The vestibular substitution system provides biofeedback and consists of supplying individuals with additional artificial information regarding body orientation and motion to supplement the natural visual, somatosensory and vestibular sensory cues. This device uses an electrotactile stimulus on the tongue to transmit artificially sensed head orientation with respect to gravitational vertical. Head position data (artificially sensed by a micro-electromechanical system (MEMS) accelerometer) serve as the input signal for the device. The Intraoral Device is made up of an electrotactile array and a MEMS 3-Axis, digital output accelerometer. The MEMS accelerometer senses head position in both the anteroposterior and mediolateral directions and is mounted on the upper surface of the electrode array (away from the tongue). The accelerometer is encapsulated in a silicone material to ensure electrical isolation from the user.

Recent studies have demonstrated the efficacy of alternative mechanisms such as balance devices that translate information (generally provided by the vestibular system) through electrical stimulation of the tongue [5,23]. In order for the brain to correctly interpret the information from a sensory substitution device, it is not required that the information be presented in the same way as the natural sensorial system. What is simply required is that important information be accurately encoded into the action potentials of an alternative information channel. With training, the brain learns to properly interpret the information and use it according to the natural and normal data perception [2].

The aim of this study was to evaluate the effectiveness of electrotactile tongue biofeedback (BrainPort®) as a sensory substitute for the vestibular apparatus in patients with BVL who did not have a good response to conventional VR.

This was a clinical assay approved by the Ethics Committee of the University of Sao Paulo, Brazil. Written informed consent was obtained from all patients prior to their participation. Seven patients with balance disorders due to BVL, who had completed treatment with VR without reaching a satisfactory result, were included in this study. Exclusion criteria were injuries in the oral cavity and to the tongue, tobacco smoking habits, implanted electric devices such as pacemakers, neurodegenerative diseases, and orthopedic injuries of the lower extremities.

Patients included in the study were evaluated according to their clinical history, head and neck exams, cranial nerve exams, balance tests (Romberg and Fukuda stepping test), coordination tests (diadochokinesia with alternate pronation and supination of the forearm, and finger-nose test) electronystagmography, pendular rotatory test (PRT), and the sensory organization test (SOT) component of Computerized Dynamic Posturography (CDP) (Equitest, NeuroCom). All patients were diagnosed with BVL as identified by history, physical examination, evidence of reduced vestibulo-ocular reflex (VOR), bilaterally absent responses to warm (44 °C) and cold (30 °C) water in caloric tests (System 2000; Micromedical Technologies), and no response to stimulation of horizontal canals in rotational pendular testing −0.1 Hz (CGM-4; Contronic).

After clinical evaluation, patients were trained to use the device (BrainPort®). The stimulation on the surface of the tongue was created by a dynamic pattern of electrical pulses and the patient was able to adjust the intensity of stimulation and spatially centralize the stimulus on the electrode array. Before training, the patients were instructed to learn how to use the stimulus perceived on the tongue and to adjust their posture to keep it centered – in the middle of the electrode array – as a response to its postural correction.

Patients were directed to continuously adjust head orientation and to maintain the stimulus pattern at the center of the array. Postural tasks of progressive difficulty were applied during the use of the device (changing position of the feet and switching from a firm to foam surface according to patient capability). Patients completed two 15-min training sessions every other day, separated by 3–4 h. Training was done for 6 days (3 times per week, for 2 weeks), for a total of 12 sessions. Clinical effects of treatment were determined by comparing pre- and post-treatment SOT composite scores and sensory analysis scores. The numbers of falls experienced pre- and post-treatment during conditions 5 and 6 of the SOT were compared. Additionally, a visual analog scale (VAS) was used to characterize patients' symptoms after treatment according to three criteria:

- remission (R): corresponding to 100% relief of symptoms.
- partial recovery (PR): with a 50–90% improvement of symptoms.
- without recovery (WR): with an improvement of symptoms of less than 50%.

For analysis of the SOT, sensory analysis and the composite score (CS) were used.

The significance of the difference between pre-treatment and post-treatment was estimated by the paired-sample *t*-test. Differences were considered significant when $p < 0.05$.

Seven patients with BVL participated in this study (6 males and 1 female; age = 56.9 ± 11.6). In addition, each BVL patient fell without an apparent postural response soon after the start of condition 5 of the SOT (sway-referenced platform with eyes closed) consistent with their BVL. Table 1 summarizes the etiologies, ages and gender of BVL patients.

The pre- and post-treatment distribution of SOT composite scores and the number of falls in conditions 5 and 6 are presented in Table 2, with an average of 38.3 ± 8.7 pre- and 59.9 ± 11.3 post-training. A statistically significant improvement of the SOT composite score was observed ($p = 0.01$).

The results of the clinical response according to the VAS are illustrated in Fig. 1. Clinical improvement occurred in 85.5% of the patients, three of them without symptoms (42.9%) and three with partial recovery (42.9%) on the last day of treatment. Only one patient (14.2%) showed no improvement.

The present results suggest that a specific rehabilitation program improved the postural control of patients with BVL who participated in this study. Bilateral vestibular loss is a rare diagnosis among patients with dizziness and imbalance. Although full compensation for BVL is not expected, VR may be used as a therapeutic method for these patients. The limitations caused by BVL

Table 1
Characteristics of BVL patients.

Patients	Gender	Age	Diagnosis
1	M	57	Ototoxicity
2	M	57	Infection
3	F	74	Ototoxicity
4	M	61	Idiopathic
5	M	54	Traumatic
6	M	60	Idiopathic
7	M	35	Auto-immune