Integration of multi-sensory inputs to detect tilts relative to gravity is critical for sensorimotor control of upright orientation. Displaying body orientation using electrotactile feedback to the tongue has been developed by Bach-y-Rita and colleagues as a sensory aid to maintain upright stance with impaired vestibular feedback. This investigation has explored the effects of Tongue Electrotactile Feedback (TEF) for control of posture and movement as a sensorimotor countermeasure, specifically addressing the optimal location of movement sensors. TEF of pitch and roll orientation was derived from a two-axis linear accelerometer and displayed on a 144-point electrotactile array held against the anterior dorsal tongue (BrainPort, Wicab, Inc., Middleton, WI).

The purpose of Specific Aim 1 (SA1) was to compare postural performance when providing orientation cues via TEF using sensors attached either to a head band or torso belt. Postural equilibrium was measured with a computerized hydraulic platform in 12 healthy adults (7M, 5F). Trials (100 s duration with eyes closed) were conducted with the
support surface fixed, sway-referenced, during sum-of-sines perturbations or during a combination of sway-referencing and sum-of-sines perturbations. Sway-referencing was performed with the platform rotating equal to anterior-posterior (AP) sway angle, by translating the support surface proportional to AP sway, or by rotating and translating the support surface. Subjects were required to keep the intraoral display in their mouths on all trials, including those that did not provide tactile feedback. Postural performance was assessed using deviations from upright and convergence toward stability limits. As expected, there were improvements in postural performance, based on peak-to-peak AP sway, when using the TEF. The largest changes in postural performance occurred with the platform in the translate sway-referenced mode with or without support surface rotation. In this case, the peak-to-peak sway was significantly reduced with the accelerometers (sensors) mounted on the torso. MacDougall et al. (2006) recently demonstrated that unpredictably varying Galvanic vestibular stimulation (GVS) significantly increased anterior-posterior (AP) sway during rotational sway referencing with eyes closed. The purpose of Specific Aim 2 was to assess the influence of TEF on postural control performance with pseudorandom binaural bipolar GVS. Postural equilibrium was measured with a computerized hydraulic platform in 10 healthy adults (6M, 4F) with the linear accelerometers mounted on the torso belt. Subjects performed 24 randomized trials (20 s duration with eyes closed) including four support surface conditions (fixed, rotational sway-referenced, translating the support surface proportional to AP sway, and combined rotational- translational sway-referencing), each repeated twice with and without GVS, and with combined GVS and TEF. Postural stability was impaired with GVS in all platform conditions, with larger decrements in performance during trials with rotation sway-referencing. TEF improved performance with GVS toward non-GVS levels, again with the greatest improvement during trials with rotation sway-referencing. These results demonstrate the effectiveness of tongue electrotactile feedback in providing sensory substitution to maintain postural stability with distorted vestibular input. The purpose of Specific Aim 3 was to evaluate the efficacy of TEF to improve gaze stabilization during walking. Dynamic Visual Acuity (DVA) performance was measured in 10 healthy adults (6M, 4F) during treadmill walking (3mph) using sensors attached either to the head band or torso belt as with SA1. Similar to the posturography results from SA1, there was a trend for improved dynamic visual acuity during treadmill walking to be improved with TEF with the sensor mounted on the trunk.

We conclude that locating sensors on the torso may be advantageous for sensory supplementation type countermeasures in conditions that naturally involve head-on-trunk motion, such as counter-rotation of the head during fore-aft translational movements or locomotion. These results suggest that the effectiveness of tactile sensory supplementation for balance prosthesis and vestibular rehabilitation applications may be optimized by accounting for the body segment orientation needed for specific task performance.

Our results demonstrate the effectiveness of tongue electrotactile feedback in providing sensory substitution to maintain postural stability with distorted vestibular input. Our results further suggest that the effectiveness of tactile sensory supplementation for balance prosthesis and vestibular rehabilitation applications may be optimized by accounting for the body segment orientation needed for specific task performance. For example, locating sensors on the torso may be advantageous for sensory supplementation type countermeasures in conditions that naturally involve head-on-trunk motion, such as counter-rotation of the head during fore-aft translational movements or locomotion. Electrotactile feedback has also been effective in stabilizing balance in chronic vestibular loss patients and retention effects following TEF training appear promising. Our research confirms the utility of Galvanic Vestibular Stimulation (GVS) as a model for functional impairment of vestibular origin. Others had demonstrated that GVS induced postural instability that is similar to profound bilateral loss, especially during conditions where visual and proprioceptive feedback is altered. Our study demonstrates how GVS can be utilized to evaluate sensory supplementation aids for balance prostheses and vestibular rehabilitation applications. Our study also introduced a novel method of sway-referencing involving translations of the support surface in response to sway from upright. We propose that changing the gain of the translation sway-referencing, or even the polarity of the displacements, will provide additional insight into the use of somatosensory feedback for posture control.

The second and final year of our project was utilized to complete Specific Aims 2 and 3. For Specific Aim 2, postural equilibrium was measured with a computerized hydraulic platform in 10 healthy adults (6M, 4F) with Tongue Electrotactile Feedback (TEF) derived from linear accelerometers mounted on the torso. Subjects performed 24 randomized trials (20 s duration with eyes closed) including four support surface conditions (fixed, rotational sway-referenced, translating the support surface proportional to AP sway, and combined rotational-translational sway-referencing), each repeated twice with and without Galvanic Vestibular Stimulation (GVS), and with combined GVS and TEF. Postural stability was impaired with GVS in all platform conditions, with larger decrements in performance during trials with rotation sway-referencing. TEF improved performance with GVS toward non-GVS levels, again with the greatest improvement during trials with rotation sway-referencing. These results demonstrate the effectiveness of tongue electrotactile feedback in providing sensory substitution to maintain postural stability with distorted vestibular input. This data was recently accepted for publication (Wood et al., Ann NY Acad Sci, 2008). The purpose of Specific Aim 3 was to evaluate the efficacy of TEF to improve gaze stabilization during walking. Dynamic Visual Acuity (DVA) performance was measured in 10 healthy adults (6M, 4F) during treadmill walking (3mph) using sensors attached either to the head band or torso belt as with SA1. Similar to the posturography results from SA1, there was a trend for improved dynamic visual acuity during treadmill walking to be improved with TEF with the sensor mounted on the trunk. We conclude that locating sensors on the torso may be advantageous for sensory supplementation type countermeasures in conditions that naturally involve head-on-trunk motion, such as counter-rotation of the head during fore-aft translational movements or locomotion. These results suggest that the effectiveness of tactile sensory supplementation for balance prosthesis and vestibular rehabilitation applications may be optimized by accounting for the body segment orientation needed for specific task performance.

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