EVALUATION OF GALVANIC VESTIBULAR STIMULATION SYSTEM

I.S. Kofman[1], E. Warren[1], R. DeSoto[2], G. Moroney[1], J. Chastain[1], Y.E. De Dios[1], N. Gadd[1], L. Taylor[1], B.T. Peters[1], E. Allen[1], M.F. Reschke[3], J.J. Bloomberg[3], and A.P. Mulavara[1]

[1]KBRwyle, Houston, TX; [2]Leidos, Houston, TX; [3]NASA Johnson Space Center, Houston, TX

Introduction

- Transcutaneous electrical stimulation applied across the vestibular end organs (galvanic vestibular stimulation, GVS) at low levels has been shown to aid with balance and locomotion tasks through the phenomenon of stochastic resonance [Collins et al. 1995] (Figure 1)
  - ✓ Improved balance performance on an unstable surface [Mulavara et al., 2011; Goel et al. 2015]
  - ✓ Improved locomotion performance on an actively moving surface [Mulavara et al., 2015]
- GVS can also be used (at higher stimulation levels) to disrupt vestibular function as a way to simulate vestibular disturbances caused by prolonged exposure to weightlessness [MacDougall et al., 2006] (Figures 2, 3)
- Other potential applications in space (e.g., sensorimotor adaptability training) and on Earth (e.g., improvement of postural and gait instability in Parkinson's Disease patients)

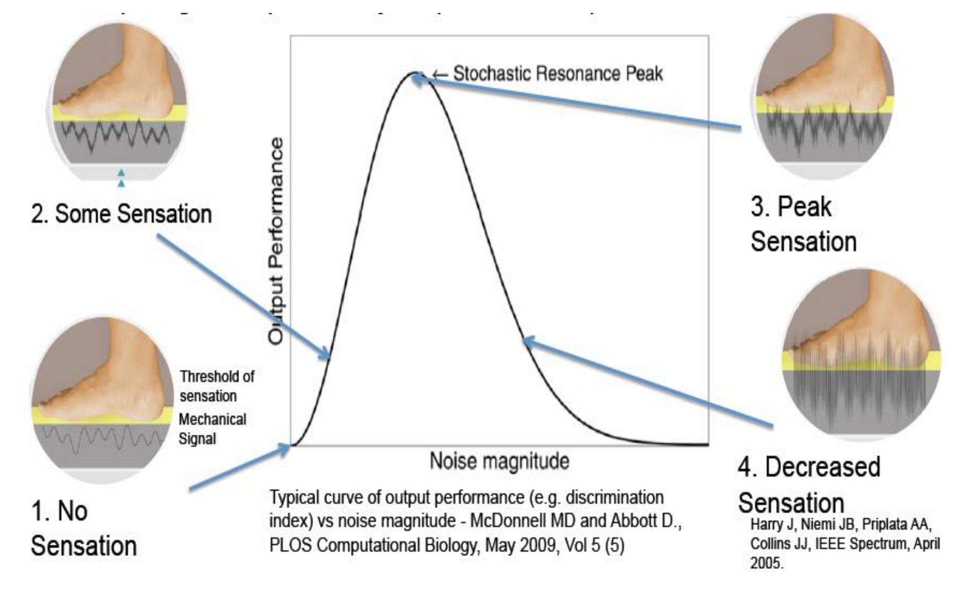

Figure 1. Stochastic resonance: Adding noise enhances performance via increased information transfer.

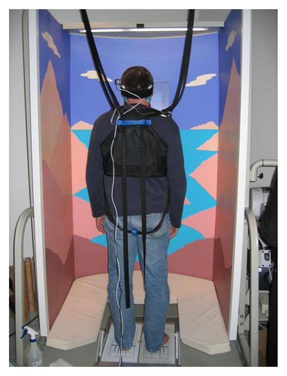

Figure 2. Computerized Dynamic Posturography (CDP).

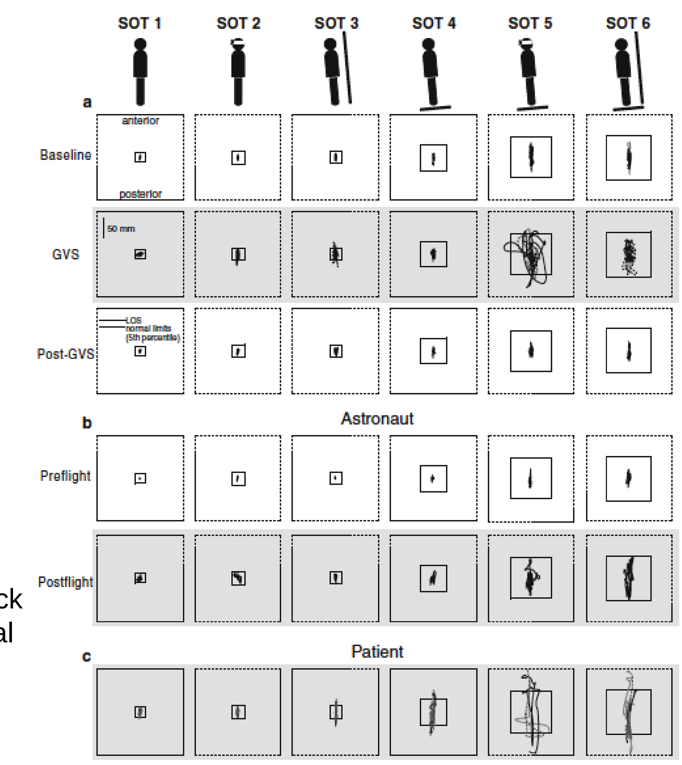

Figure 3. MacDougall H, Moore ST, Curthoys IS, Black FO (2006) Modeling postural instability with Galvanic vestibular stimulation. *Exp Brain Res.172(2) 208-20.*

Objectives

The goal of this project is an engineering human-in-the-loop evaluation of a new GVS device that can degrade performance of balance and locomotion tasks to simulate astronauts' experience during transitions to new gravitational environments.

Specific aims

1. Develop and build a new portable GVS device (Figure 4) capable of delivering constant (time-varying) current stimuli.
2. Evaluate the new device as a simulator of spaceflight-related vestibular disturbances and determine the stimulation levels producing effects most comparable to postflight deconditioning.

Stimulator design requirements

- Isolated output stage
- Output current range: ±5 mA
- Output refresh rate: 100 Hz
- Rechargeable battery
- 2-hr continuous operation
- Light & compact
- On-board data logging
- Variable gain and current limit
- Real-time output current monitoring
- Analog inputs for external instrumentation (e.g., switches, sensors)
- Two modes of operation
  - Standalone – stimulation waveform file is read from a memory card
  - External input – stimulation waveform is provided through an analog input
- Two types of stimulation (Figure 5)
  - Binaural, two electrodes – mediolateral plane (ML) stimulation
  - Double monoaural, three electrodes – anteroposterior plane (AP) stimulation

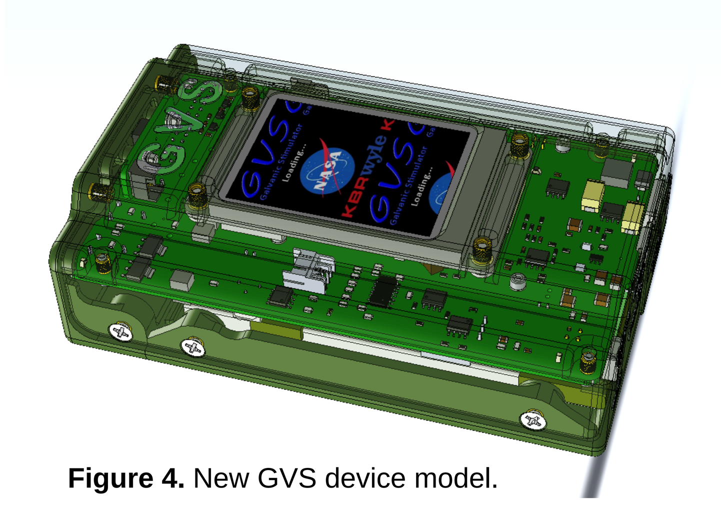

Figure 4. New GVS device model.

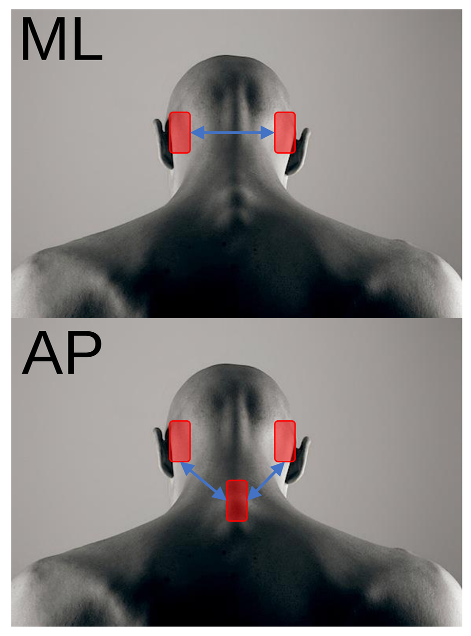

Figure 5. Electrode placement and current flow for two types of stimulation.

Project Status

A portable (5.25" x 3.25" x 1.5") GVS device has been developed and built (Figures 6-8). The stimulator is driven by a Raspberry Pi 3B single board computer. Final testing of the system is underway.

Figure 6. New GVS device.

Features

- 2.4" touchscreen user interface
- microSD card for storage of stimulation profiles and data logging
- USB ports for data transfer
- Rechargeable 3.7V battery
- Redundant safety features
- Output current displayed in bar-graph and numeric formats
- Isolated analog output for current monitoring by external instrumentation
- 7 analog inputs for external instrumentation (e.g., accelerometers)
- 2 digital inputs for triggers or event markers
- Battery level monitoring
- Custom pouch with arm/waist bands (Figure 9)

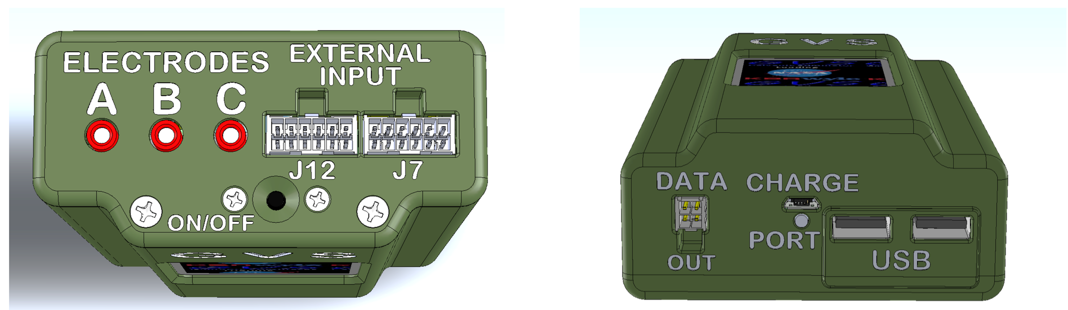

Figure 7. Top and bottom panels with all I/O connectors.

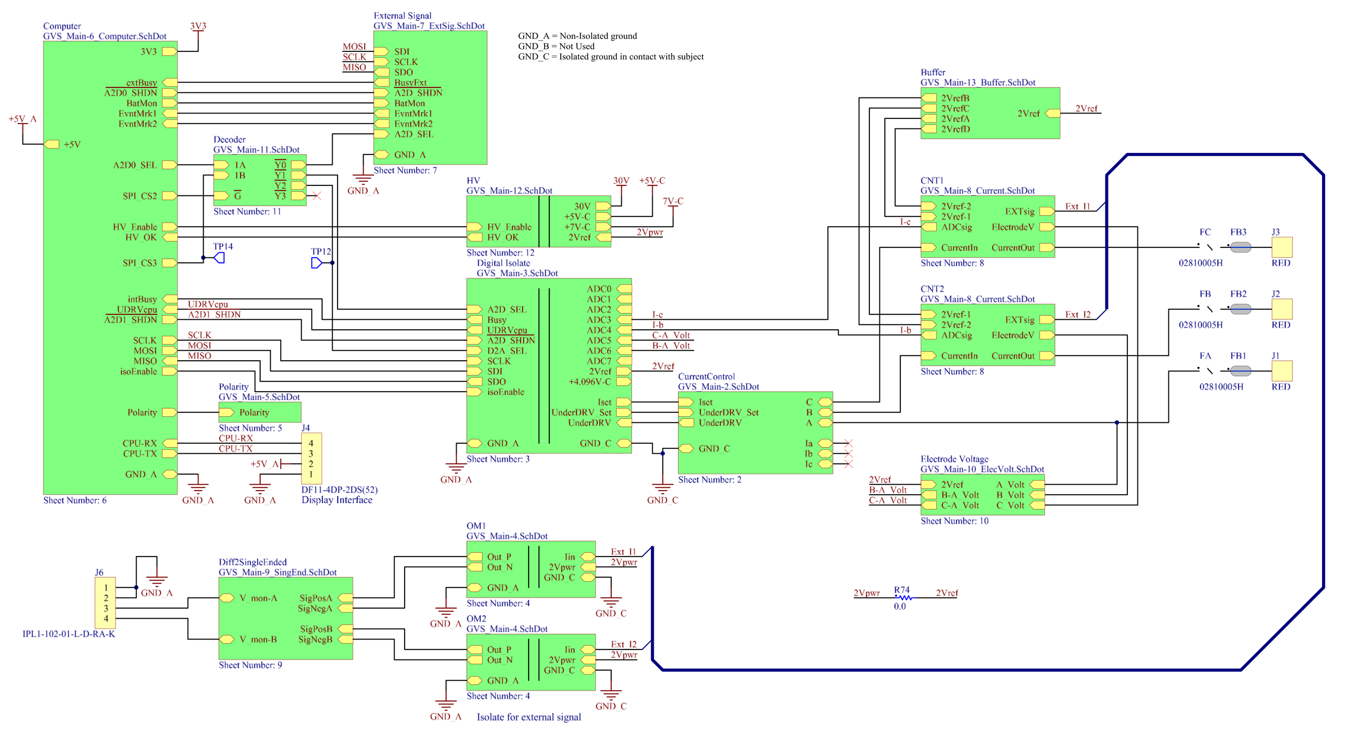

Figure 8. Overall block diagram.

Figure 9. Ready for action!

Forward Work

MPCV Egress with Vestibular Disruption - The goal of this follow-on study is to characterize performance of the critical mission task of egress from the Multi-Purpose Crew Vehicle (MPCV) with the disrupted functionality of the vestibular system by using GVS.

Aim 1: Determine the amplitude and electrode configuration of GVS that produces degradation in performance equivalent to the effects of post-flight sensorimotor dysfunction on two key balance tasks quantified in the Functional Task Test (FTT) study conducted after long-duration spaceflight.

In Experiment 1, we will select the configuration of GVS that produces degradation in performance equivalent to mean change in post flight FTT performance in the CDP (Figure 10) equilibrium score and Tandem Walk (TW) (Figure 11) percent correct steps. In addition, to cover a range of subject responses for the two tests, two stimulation levels that produce ±50% of the actual mean change for both the CDP and the TW tests will also be selected.

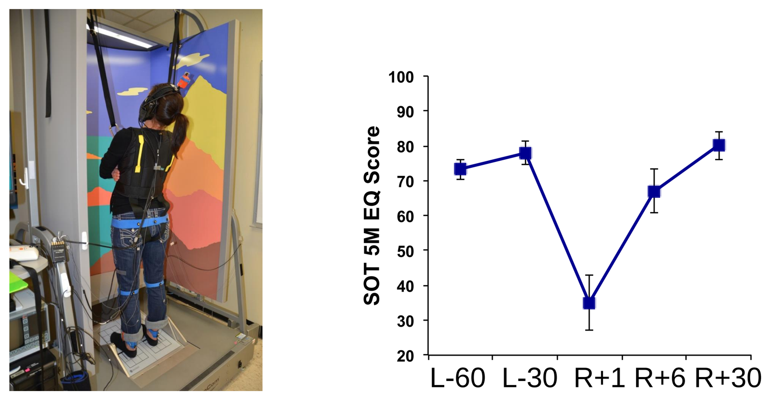

Figure 10. CDP test; FTT flight study data.

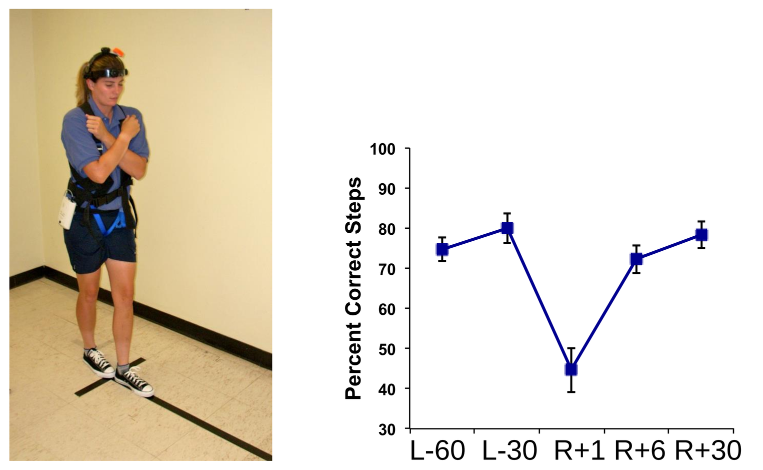

Figure 11. Tandem Walk test; FTT flight study data.

Aim 2: Using the calibration settings identified in Aim 1, characterize the effect of GVS on performance of the Seat Egress and Walk test (Figure 12) that was previously used to test long-duration crewmembers as part of the FTT study.

In Experiment 2, subjects will perform the Seat Egress and Walk test with and without GVS stimulation in configurations and levels as determined in Experiment 1 in a random order. Performance will be measured as the time to complete the test. Data collected in this study will be compared to those from the FTT flight study.

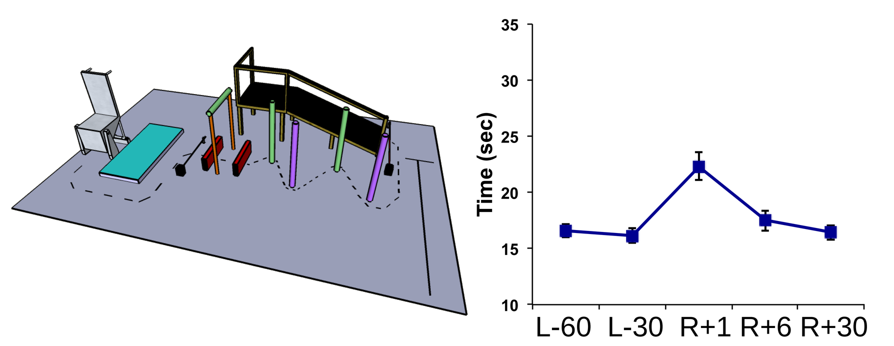

Figure 12. Seat Egress and Walk test setup; FTT flight study data.

Aim 3: Using the calibration settings identified in Aim 1, characterize the effect of GVS on egress from the MPCV.

In Experiment 3, subjects will perform the MPCV Egress Test - a simulated egress from a stationary MPCV mockup (Figure 13) with and without GVS stimulation in configurations and levels as determined in Experiment 1 in a random order. Performance will be measured as the time to complete the test.

Figure 13. MPCV mockup.

This work is funded by NASA Human Research Program.