Appendix A

Detailed Testing Protocol

ROTARY CHAIR TESTS:

Participants were tested in a Neuro Kinetics Inc. I-Portal® Neuro Otologic Test Center system (NOTC) by an experienced trained examiner. The I-Portal® NOTC is a chair attached to a high-torque motor driven by a computer and contained inside a light-proof enclosure. The testing protocol took approximately 30 minutes. Participants sat in the NOTC, were secured for safety, and the head was restrained. A binocular infrared video camera system with a frame rate of 100 Hz measured eye movements and a headset enabled communication with the tester at all times. The tester precisely followed a written set of instructions and performed the tests in the same order each time. Participants sat in complete darkness for all tests in the rotary chair, with the exclusion of the "target," if present. The “target” was a small red laser light, driven by fast mirror galvanometers that appeared as a dot on the wall. The “straight line” was generated by the same laser used for the “target” by having the mirrors rapidly oscillating back and forth. The optokinetic starred pattern was projected on the enclosure walls by a planetarium. If a participant was unable to complete any sub-test, that sub-test was not considered in the analysis. The software tracked and measured eye movements or detected the pushing of hand-held buttons. If the participant had concussion, we obtained a baseline dizziness (DZ) and headache (HA) score (0-10) before the tests. Following each group of subtests, we asked again for the DZ and HA scores. If they went up more than three points without rapidly returning to baseline, we stopped the test.
The subtests described in this manuscript include two tests of the peripheral vestibular system, specifically of the horizontal semicircular canals and associated brainstem and cerebellar circuitry: 1) SINUSOIDAL HARMONIC ACCELERATION (SHA): The participant, in complete darkness, looked straight ahead as the chair was oscillated sinusoidally at 0.02, 0.04, 0.08, 0.32, 0.64 Hz, with a peak velocity of 60°/s. Data of interest were the gain and phase of the VOR at each frequency. 2) STEP TEST: The chair rotated to the right at 100°/s for 60 s, was stopped for 60 s, rotated to the left for 60 s, then was stopped for 60 s. The parameter of interest was the time constant, i.e., the number of seconds for the nystagmus to decrease to 37% of peak velocity, averaged over the four conditions. Two subtests examined the interaction between visual and vestibular oculomotor systems: 1) VISUAL ENHANCEMENT: The chair was oscillated right and left at 0.64 Hz in the presence of the stationary optokinetic pattern, simulating an earth-fixed environment, and 2) VOR CANCELLATION: The chair was oscillated right and left at 0.64 Hz as the participant looked at the red target that was being rotated in phase with the chair. The SUBJECTIVE VISUAL VERTICAL AND HORIZONTAL subtests examined the participant's perception of vertical and horizontal in the absence of other visual cues, perception thought to be mediated by the utricle and central utricular pathways. A straight line stimulus appeared tilted off with respect to the vertical or horizontal meridian, up to 30° displacement clockwise (CW) or counterclockwise (CCW). The participant pressed buttons located on the chair armrests to tilt the line to perceived vertical or horizontal for 3 trials CW and 3 trials CCW. The parameters of interest for SVV/SVH were the average degrees off straight alignment and the variance among trials.
CERVICAL VESTIBULAR EVOKED MYOGENIC POTENTIAL:

To further assess the peripheral vestibular system, specifically the saccule, participants were tested using the cervical Vestibular Evoked Myogenic Potential (c-VEMP). Tympanometry preceded the test to ensure integrity of the middle ear. C-VEMP profiles were obtained by averaging the acoustically evoked EMG of the sternocleidomastoid (SCM) muscle on each side (100 evoked potentials per test, 2 tests per side). Recording electrodes were placed symmetrically on the upper half or the SCM and a reference electrode was placed on the forehead. Participants were placed in a reclining position and were asked to lift and turn their head to contract the SCM enough to generate an EMG signal between 50-250 µV. Tone burst stimuli (500 Hz; 107 dB nHL) were presented via monaural insert earphones at a rate of 3.1 per second to the ear ipsilateral to the sternocleidomastoid muscle being monitored. To assure constant tonic activation of the SCM muscle, the SCM EMG activity was monitored by video feedback. The positive (P1) and negative (N1) waveforms were marked. The data of interest were the latency and amplitudes for each ear and the asymmetry ratio, corrected for baseline EMG activity.

SENSORY ORGANIZATION TEST:

Static postural balance was tested with the EquiTest (Natus Medical Inc., San Carlos, CA) Sensory Organization Test (SOT). The SOT includes six conditions: 1) stable floor and visual surround, eyes open; 2) stable floor, eyes close; 3) stable floor and sway referenced visual surround, eyes open; 4) sway referenced floor, stable visual surround, eyes open; 5) sway referenced surface, eyes close; 6) sway referenced surface and visual surround, eyes open. Two 20 second trials of each condition were
completed if the athlete scored above age-matched norms, and three trials if one of the
trials had a score that was below age-matched norms. The sway score for each
condition was averaged. The data of interest were sway scores of each condition and
the composite sway score (0=fall to 100=no sway) as well as the effectiveness ratios, or
the sway score of the condition of interest divided by the sway score of condition 1 or
baseline sway: visual (4/1), somatosensory (2/1) and vestibular (5/1).