SENSORIMOTOR ADAPTATION FOLLOWING EXPOSURE TO AMBIGUOUS INERTIAL MOTION CUES

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INTRODUCTION

The central nervous system must resolve the ambiguity of inertial motion sensory cues in order to derive accurate spatial orientation awareness. Adaptive changes in how inertial cues from the otolith system are integrated with other sensory information lead to perceptual and postural disturbances upon return to Earth's gravity. The primary goals of this ground-based research investigation are to explore physiological mechanisms and operational implications of tilt-translation disturbances during and following re-entry, and to evaluate a tactile prosthesis as a countermeasure for improving control of whole-body orientation during tilt and translation motion.

METHODS

Tactile Situation Awareness System (TSAS): Two studies were conducted to examine the influence of vibrotactile feedback on balance and manual control tasks. For these studies a simple 4 tactor system was implemented to provide feedback when projected sway/tilt position exceeded predetermined levels from upright. Instantaneous measures of position and velocity were used to derive feed-forward projections of orientation at 0, 500 and 1000 msec. During the first study, postural equilibrium was measured with a computerized hydraulic platform in 14 subjects (7M, 7F). Trials (100 s duration with eyes closed) were conducted with the support surface sway-referenced, during sum-of-sines perturbations (0.01 - 0.6 Hz) or during a combination of the sway-referencing and sum-of-sines perturbations. During the second study, a hydraulic tilt chair was utilized to provide transient (≤45°) or pseudorandom (0.01-0.6 Hz) roll-tilt motion disturbances in complete darkness about the naso-occipital axis. Fourteen subjects (7M, 7F) were instructed to align a bar with perceived earth-horizontal during some trials, and use this same bar on other trials to null out tilt motion and maintain upright orientation.
Tilt-Translation Device (TTD): During a third study, we examined adaptive changes using a 'vision aligned' paradigm with JSC's Preflight Adaptation Training laboratory's TTD. This device was designed to recreate post-flight orientation disturbances by exposing subjects to matching tilt self motion with conflicting visual surround translation. Twelve subjects (6M, 6F) were tested during 3 sessions separated by at least one week. During each of the three sessions (out-of-phase asymmetrical, in-phase asymmetrical, in-phase symmetrical), subjects were exposed to visual surround translation synchronized with pitch tilt at 0.1 Hz for a total of 30 min. Tilt and translation motion perception was obtained from verbal reports and a joystick mounted on a linear stage. Horizontal vergence and vertical eye movements were obtained with a binocular video system. Responses were also obtained during darkness before and following 15 min and 30 min of visual surround translation.

RESULTS

TSAS: Peak-to-peak and RMS sway during either sway-referencing or sum-of-sines perturbations were significantly lower with vibrotactile feedback. Postural stability was greater with feed-forward projections of sway at 500 msec compared with 0 msec (no velocity used) or 1000 msec projections. RMS error during the roll-tilt nulling trials was also significantly lower ($p<0.05$) when vibrotactile feedback was provided based on feed-forward projections of tilt orientation ≤500 msec. TTD: Each of the three TTD conditions involving visual surround translation elicited a significantly reduced sense of perceived tilt and strong linear vection (perceived translation) compared to pre-exposure tilt stimuli in darkness. These changes were also present in darkness following 15 and 30 min exposures, provided the tilt stimuli were not interrupted.

DISCUSSION

The TSAS results suggest that incorporating sway or tilt velocity will optimize the effectiveness of vibrotactile feedback for balance prosthesis and manual control applications. These results are promising in that a fairly simple device with as few as 4 tactors may prove useful to significantly improve control performance of acceleration platforms when attempting to maintain orientation within a limited tilt range. The TTD results are consistent with the hypothesis that the central nervous system resolves the ambiguity of inertial motion sensory cues by integrating inputs from visual, vestibular, and somatosensory systems.

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