Journal of Vestibular Research 21 (2011) 69–72
DOI 10.3233/VES-2011-0403
IOS Press

Oral Session 2: Spatial Disorientation

2–1 [#3011]

Intuitive displays may help prevent spatial disorientation in degraded visual environments: Lessons from helicopters

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In the absence of visual orientation cues, the inadequacy of the vestibular sense often contributes to orienting illusions [1] during flight. Spatial disorientation (SD) plays a significant role in helicopter accidents [2, 3], often when outside visual references are lost during landings in dusty environments [4]. The lack of ambient visual cues, the close proximity to the ground, and the urgency of the situation (seconds from impact) often cause the helicopter pilot to act on the erroneous perceptions of motion generated by the vestibular system. Historic video clips of Apollo lunar landings show the potential for SD as the astronauts encountered similar situations during which clearly visible landing sites became totally obscured by blowing dust seconds before touchdown. This lack of time and altitude for reorientation and recovery has required the military to seek the development of displays that convey orienting information in more intuitive ways. The similarity between helicopter dust landings and extraterrestrial landings presents an opportunity for those designing future space vehicles and their instrumentation to gain from the lessons learned from military helicopters. Recent developments in visual/sensor (e.g., Brownout Symbology System, 3D Conformal Landing Symbology) and tactile (Tactile Situation Awareness System) technologies promise to provide helicopter pilots critical orienting information in more timely, intuitive representations of the flight and landing environments, thereby compensating for the unreliability of the vestibular system and reducing the possibility of SD due to vestibular illusions. This presentation will contrast current flight instruments with these evolving displays.

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2–2 [#3024]

Modeling and mitigating spatial disorientation in low G environments: A progress report

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The goal of this collaborative industry-university research and technology development project is to extend Alion's spatial disorientation mitigation software – originally developed for aviation – to NASA's space applications. Extensions to Alion's software include adapting and adopting algorithms from the Massachusetts Institute of Technology's spatial orientation models, as well as Frame-of-Reference Transformation (FORT) theory concepts.

The four overall specific aims of the project, and progress on each, are as follows:

1. Extend Alion's Spatial Disorientation Analysis Tool (SDAT) by incorporating an enhanced MIT *Observer* model into SDAT. Validate enhancements with existing and new flight data sets.
   - Progress: A compiled version of Observer was developed for incorporation into SDAT processing. When Observer includes vestibular

ISSN 0957-4271/11/$27.50

thresholds, we intend to fully integrate it into SDAT. In the mean time, we are adapting SDAT algorithms to include a full set of vector math functions.

2. Extend SDAT assessments to include typical space vehicle illusions. Validation will include assessment of Shuttle landing data, and Altair simulator data.
   - Progress: We designed new illusion models for vertical landing vehicles (e.g., helicopters and lunar landers) and obtained actual helicopter flight data sets that include SD events. Shuttle data sets are unusable. Altair simulator data (e.g., from the NASA-Ames vertical motion simulator) are being analyzed. Furthermore, we are distributing an IRB-approved survey to Shuttle commanders and pilots to quantify their experiences with illusory sensations resulting from the transition from 1 g to 0 g and back.
3. Further extend SDAT by examining alternative visual reference frames. FORT is used to predict the cognitive cost of transitioning between reference frames.
   - Progress: The FORT tool has been partially validated; further validation is ongoing. The FORT tool is a stand-alone tool and will not be integrated into SDAT.
4. To further enhance SDAT assessor performance, pilot multi-sensory workload is considered in countermeasure selection.
   - Progress: We have added a representation of the N-SEEV attention model (noticing – salience, effort, expectancy, value) to SDAT to improve countermeasure triggering.

The presentation will emphasize the Shuttle survey and results to date.

2–3 [#3049]

Pseudo-coriolis effect: A 3D angular velocity storage phenomenon described by a left-hand rule

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When stationary, gravitationally upright human subjects undergoing optokinetic stimulation experience yaw circular-vection and then make a pitch or rolling head movement, they describe strong paradoxical tumbling and tilt sensations resembling vestibular Coriolis Effect (CE). Brandt and Dichgans [1,2] referred to this as a "Pseudo- Coriolis Effect [PCE], noting that "a model that would explain the pseudo-Coriolis effects entirely, including the surprising conformity of direction of the illusory tilt in CE (Coriolis Effect) and PCE (Pseudo-Coriolis Effect) cannot yet be proposed." These and several subsequent studies [3,4] compared the nauseogenic properties of PCE as compared to CE, and noted that CE and PCE effects appeared qualitatively similar. We recently applied Merfeld's et al's "Observer" model for vestibular cue integration [5,6] to predict CE when subjects make head movements during prolonged physical rotation in darkness. We confirmed that vestibular CE follows a positive vector cross product ("right hand") rule, e.g. during clockwise rotation, a clockwise head roll produces a pitch *backward* sensation [7]. We then [8,9] extended the Observer model to include optokinetic angular velocity and visual "down" cues, and ran PCE simulations. The extended model incorporates a 3D visual-vestibular angular velocity storage-like mechanism. It predicts that – as proposed by Guedry [10] and Bles [3] – vection perception initially moves with the head, producing tumbling and tilt sensations analogous to "Purkinje" (aka Dumping) vestibular illusions. However, we emphasize that, unlike vestibular CE, optokinetic PCE sensations actually follow a *"left-hand-rule,"* e.g. during clockwise vection, a clockwise roll produces a pitch *forward* illusion. Also, unlike CE and Purkinje illusion, vection continues, but paradoxical PCE tumbling and tilt components disappear as the vection axis gradually realigns with visual and gravitational stimuli. We experimentally confirmed the CE/PCE direction difference in a group of human subjects.

Acknowledgement: Supported by the National Space Biomedical Research Institute through NASA NCC 9–58.

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2–4 [#3010]

Relationships between observer and Kalman filter models for human dynamic spatial orientation

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How does the central nervous system (CNS) combine sensory information from semicircular canal, otolith, and visual systems into perceptions of rotation, translation and tilt? Over the past four decades, a variety of input-output ("black box") mathematical models have been proposed to predict human dynamic spatial orientation perception and eye movements. The models have proved useful in vestibular diagnosis, aircraft accident investigation, and flight simulator design. Experimental refinement continues. We review the history of these models, distinguishing two widely known model families, the linear "Kalman Filter" and the nonlinear "Observer". We derive simple 1-D and 3-D examples of each model for vestibular inputs, and show why – despite apparently different structure and assumptions – the models predictions are dynamically equivalent when model free parameters are adjusted to fit the same empirical data, and perceived head orientation remains near upright. We introduce the idea that the motion disturbance and sensor noise spectra employed in the 1-D Kalman Filter formulation may reflect human perceptual thresholds and prior motion exposure history, and thus justify the interpretation that the CNS cue blending scheme minimizes perceptual errors.

Acknowledgement: Supported by F. Prieur, Integral Design, and by the National Space Biomedical Research Institute through NASA NCC9-58.

2–5 [#3041]

Sensory conflict compared in microgravity, artificial gravity, motion aickness, and vestibular disorders

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Introduction: Perceptual disturbances and motion sickness are often attributed to sensory conflict. Specific measures of sensory conflict, the Stretch and Twist Factors, have been modeled and used to explain and predict perceptual disturbances for head movements in a rotating environment in 0-g, 1-g, on-axis, and in centrifuges [1,2]. Results agreed with known differences between conditions, and predicted that head movements in a rotating environment would cause greater perceptual disturbance with greater gravito-inertial acceleration. For example, they predicted that an artificial gravity environment would be provocative not just in relation to rotation speed but also in relation to the centripetal acceleration.

Methods: The present research applies the Stretch and Twist Factors to head movements in microgravity and other conditions by modeling the sensory conflict between the vestibular and somatosensory systems. Provocative motions are predicted to be those with the greatest Stretch and Twist Factors.

Results: For head movements in microgravity, the Stretch Factor can explain the provocativeness of head movements in the short term, and its reduction over the course of adaptation. For off-vertical-axis rotation (OVAR) in 1-g, the Stretch Factor predicts that the most provocative frequency is higher than that for vertical linear oscillation (heave). For vestibular pathology, this same sensory conflict can be used to explain the perception of "walking on pillows" or "stepping in a hole" reported by vestibular patients.

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2–6 [#3044]

Sensory weighting in space: The Bodies in the Space Environment (BISE) experiment

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On Earth the perceived direction of "up" can be predicted from a weighted sum of visual, gravity and body orientation cues. The relative weightings of these cues vary from person to person and depend on the task, for example when aligning a line with gravity or when identifying the optimal orientation for object recognition. How are the weightings affected when one cue becomes uninformative? During short periods of microgravity (during parabolic flight) the relative weighting of vision decreased (Dyde et al., 2009, Exp. Brain Res., 196: 647). What is the effect of longer term exposure to microgravity?

We measured perceived orientation in seven astronauts before, during and after long-duration space flight. Pre- and post-flight we used the oriented character recognition test (OCHART, Dyde et al., 2006, Exp. Brain Res., 173: 612), shape-from-shading and luminous line probes in upright and right-side-down body orientations. On station, subjects performed OCHART early and late in flight. A parallel study used ground-based controls tested at similar intervals.

A trend for a reduction in visual influence was observed in flight with lower-than-baseline levels maintained throughout six months in orbit. Visual influence was still lower than baseline levels several months after returning to Earth.

We conclude that sensory weightings are altered by long-term exposure to microgravity and do not recover within six months of return to normal gravity. These findings will be discussed in terms of sensory adaptation and in comparison to the ground-based control data.

2–7 [#3026]

LASOIS: Enhancing the spatial orientation capabilities of astronauts on the lunar surface

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The environment experienced by astronauts on the lunar surface can seriously limit the perception of spatial orientation. Lack of atmospheric cues and familiar objects of reference can cause a lunar explorer to miscalculate distance, spatial relationships, and shapes of terrain objects [1,2]. The microgravity environment causes the vestibular system to provide the brain with an incorrect understanding of position and motion. During Apollo 14, astronauts successfully completed a traverse of about 2 KMs, but they suffered from disorientation due to several lunar environmental factors such as influence of reduced gravity, different reflection properties, and lack of familiar references, so that they did not reach the science target of Cone Crater that was very close while resources were running out [3].

To overcome challenges to spatial orientation experienced on the lunar surface, we are developing a Lunar Astronaut Spatial and Orientation Information System (LASOIS) composed of on-suit, foot-mounted, and off-suit sensors [4]. Data from the on-suit stereo cameras and foot-mounted IMU, integrated by an Extended Kalman Filter, continuously track the astronauts and provide spatial information in real time. What to display (and how) of the derived spatial information (on a wrist-mounted device) is determined using a psychological-effectiveness algorithm developed to best represent the perceptions of position, distance, and spatial orientation. LASOIS has been tested successfully in lunar- like environments at Moses Lake, WA and Black Point, AZ, where LASOIS was able to achieve a 2.67% accuracy over a 1700 m traverse.

Acknowledgement: This work is supported by the National Space Biomedical Research Institute through NASA NCC 9-58.

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