Review

THE RELATIVE ROLES OF THE OTOLITH ORGANS AND SEMICIRCULAR CANALS IN PRODUCING SPACE MOTION SICKNESS

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Abstract — Inflight and post-landing “immunity” to the “coriolis sickness susceptibility test”, observed during the Skylab M131 experiment, suggests that the otolith organs play a major role in space motion sickness (SMS). This view is supported by the report that ocular counter-torsion asymmetries correlate with SMS incidence and severity. Further data indicate that sensory–motor adaptation to microgravity includes a process whereby central interpretation of otolith signals is biased from “tilt” toward translation. However, unexpected responses to linear acceleration suggest the importance of graviceptors distributed throughout the body in addition to the vestibular otolith organs. Research is needed to assess distributed graviceptor effects. © 1998 Elsevier Science Inc.

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Orbital Flight Reduced Motion Sickness Elicited by Coriolis Sickness Susceptibility Index Testing

The Coriolis Sickness Susceptibility Index (CSSI) motion sickness test developed at the Pensacola Naval Aeromedical Laboratory during the 1960s requires subjects to move their heads in pitch and roll while seated upright on a chair rotating around an earth-vertical axis. This procedure produces “cross-coupled” stimulation to the canals, which was thought to cause the motion sickness produced by the CSSI test. The Skylab M131 experiment (1) was undertaken to examine the effects of prolonged microgravity on motion sickness produced by this procedure.

The surprising finding from this experiment was that astronauts who reported motion sickness during CSSI testing preflight on earth were nearly “immune” in orbit. Further, this immunity persisted for up to 18 days postflight before preflight susceptibility returned.

The main importance of these findings was to focus attention on the otolith receptors. There was no reason to expect that, in contrast to the otolith organs, canal stimuli or function would be radically altered by microgravity. This suggests that a canal–otolith conflict, absent or much reduced in microgravity, is the main contributor to the motion sickness elicited by CSSI testing on earth. The M131 results also suggested revision of the view that orbital flight produced “physiological deafferentation of the otoliths.”

It should be noted that CSSI testing was not begun until 5 days in orbit had elapsed; consequently any dynamic phase of immunity development was not observed. Further, postflight CSSI test immunity was not observed during informal observations following the 6-day STS-8 Space Shuttle mission.

Ocular Counter-Torsion Predicts Space Motion Sickness

Diamond and Markham (2) developed procedures to assess precisely ocular counter-torsion
elicited by both static and dynamic roll-axis stimulation. To examine differences in otolith responses to altered gravity, they recorded torsional eye movements during parabolic flight on NASA's KC-135 aircraft. Subjects were placed in a rotatable chair upright, left-ear down or right-ear down (with respect to the gravito-inertial force vector). Torsional eye movements were determined during the hypogravity (approximately 0 G) and hypergravity (about 1.8 G) segments of the parabolas. Differences in the magnitude of torsional disconjugacy between the hypogravity and hypergravity conditions correlated with SMS severity and duration reported by the 8 astronauts during orbital flight. No correlation between SMS and torsional disconjugacy evoked by roll on earth was noted.

These findings support the hypothesis that SMS is partly due to otolith asymmetry. von Baumgarten (3) suggested that the left and right otolith receptors would ordinarily differ in mass and other response properties, and that these asymmetries would normally be compensated by central processes. Alteration of ambient gravito-inertial force may disturb this compensation and result in SMS.

Sensory–Motor Adaptation to Weightlessness Includes Reinterpretation of Graviceptor Signals

To assess possible changes in linear-motion-detection thresholds following orbital flight, subjects were exposed to translational oscillations, roll oscillations, and combinations of both. In addition to motion detection, subjects reported self-motion path (trajectory). The unexpected finding from this experiment was that pure roll stimulation elicited a complex perceived self-motion path that included a strong translation component immediately post-landing but not preflight (4). The basic finding of translational scene or self-motion evoked by roll head motion has repeatedly been confirmed by observations performed in the Space Shuttle middeck during entry and immediately after landing.

Signals from graviceptors, including the otoliths, are fundamentally ambiguous: a signal may indicate accelerated translation or tilt with respect to gravity. In microgravity, central interpretation of graviceptor signals as indicating tilt would lead to inappropriate compensatory responses. Consequently, sensory–motor adaptation to microgravity appears to include a reinterpretation of graviceptor signals such that all are taken to indicate translational motion (4,5). This has become known as the “tilt–translation reinterpretation hypothesis” of sensory–motor adaptation to microgravity.

Responses to Linear Acceleration In-flight and Post-flight Do Not Confirm Predictions

As part of the Microgravity Vestibular Investigations (MVI), astronauts reported perceived self-orientation and self-motion during and after exposure to sustained constant angular velocity stimulation produced by a rotator. Due to space constraints, the subjects were placed on the rotator eccentrically with their heads about 0.5 m from the axis of rotation; this resulted in a maximum linear acceleration at the otoliths of 2.2 m/s² aligned with the longitudinal (Z) head/body axis. Based on the stimuli at the otoliths, self-inversion was predicted. A major finding from MVI was the lack of reported self-inversion inflight during “pitch” and “roll” ramp stimulus profiles (6).

Failure to report self-inversion may have resulted from the non-uniform force gradient produced by the eccentric placement of the astronauts on the rotator. In microgravity, the vector directions at the head and feet were in opposition. This resulted in incongruent cues at vestibular, visual, and visceral receptors. Failure to report self-inversion may have resulted from the non-uniform force gradient produced by the eccentric placement of the astronauts on the rotator. In microgravity, the vector directions at the head and feet were in opposition. This resulted in incongruent cues at vestibular, visual, and visceral receptors.

Conclusion

As reported elsewhere in this issue, vestibular receptors affect autonomic function as well as eye movements, posture, and locomotion, and
perceived self-orientation and self-motion. Development of "countermeasures" for the many disturbances experienced during transitions between different gravito-inertial force environments requires more complete understanding than is currently available of linear acceleration effects in microgravity as well as on earth. This understanding should also inform research and intervention strategies for falling and other age-related disturbances. Future research should focus on graviceptors distributed throughout the body as well as those in the vestibule.

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REFERENCES


