VISUAL ORIENTATION IN UNFAMILIAR GRAVITO-INERTIAL ENVIRONMENTS

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INTRODUCTION: The most overt change affecting an astronaut in space flight is the immediate response of the neurovestibular system to changes in gravity level. NASA's Critical Path Roadmap defines spatial disorientation and reduced performance on cognitive and physical tasks as one of the primary biomedical risks of spaceflight. On earth, gravity provides a convenient "down" cue. Large body rotations normally occur only in a horizontal plane. In space, the gravitational down cue is absent. When astronauts roll or pitch upside down, they must recognize where things are around them by a process of mental rotation which involves three dimensions, rather than just one. While working in unfamiliar situations they occasionally misinterpret visual cues and experience striking "visual reorientation illusions", in which the walls, ceiling, and floors of the spacecraft exchange subjective identities. VRIs cause disorientation, reaching errors, trigger attacks of space motion sickness. MIR crewmembers say that 3D relationships between modules - particularly those with different visual verticals - are difficult to visualize. Crew members learn routes, but their apparent lack of survey knowledge is a concern should fire, power loss, or depressurization limit visibility.

CURRENT STATUS OF RESEARCH:
Human visual orientation. We used an 8 foot tumbling room at York to investigate how the perception of self orientation with respect to the vertical is dominated by gravity, the visual frame of reference provided by the room's realistic interior, or by the relative orientation of the subject's body. There is a natural tendency to perceive the feet as "down". It has long been known that moving visual scenes can produce compelling illusions of self motion, but it was not understood that motionless visual scenes could produce large sensations of static tilt under some circumstances. We showed that when gravitationally supine subjects view a furnished room interior that was similarly tilted 90 degrees with respect to gravity, so that it appeared upright with respect to their body, a majority of subjects felt gravitationally upright. We call this a "Levitation Illusion". If subjects extended their limbs above their supine body, their limbs felt weightless. The strength of the illusion has been systematically studied in a large group of subjects with the room and the subject in all the different possible orientations, modulo 90 deg. In certain other relative orientations, subjects experienced VRIs– for example they perceived the floor of the room as a ceiling. Susceptibility to the levitation illusion consistently increased with age. Vestibular function is known to degrade with age, and the association between the orientation of familiar visual objects and gravity (which we refer to as "visual polarity") is probably a learned phenomenon. In a related experiment, we constructed a "mirror bed" device, which allowed us to quantify how "visual polarity". A subject lying gravitationally supine in the bed views the laboratory through a mirror mounted at 45 degrees over his head. When strongly polarized objects are in view, the subject interprets the view as horizontal, and feels subjectively almost upright. When weakly polarized objects are seen, the subject feels nearly supine. Intermediate tilt perceptions can be created by manipulating the polarity (type and arrangement) of objects in the visual scene. Understanding how the relative orientation of gravity, body axis and the visual scene interact is potentially important for astronaut training, and also in entertainment and clinical applications. Strongly polarized objects and pictures may prove useful in reducing the incidence of disorienting VRIs in space station modules. Placing strongly polarized pictures in staircases might help some elderly people be less prone to falling.

Three dimensional spatial memory and learning. What limits human ability to orient and navigate in a 3D weightless environment ? Can spatial abilities in such 3D environments be improved by preflight training ? Most navigation and spatial memory research has addressed only the terrestrial situation. We designed several 3D spatial tasks (Oman, et al, 1999, 2000; Shebilske et al, 2000; Richards, 2000; Richards et al, in preparation) analogous to those confronting astronauts trying to learn the spatial relationships between the six entrance hatches in a space station node module of a space station. Experiments were conducted in both real and virtual environments. After a brief period training, many subjects were able to perform the spatial tasks in any relative orientation to the visual environment. Gravitational body position (erect vs. supine) had little effect. Subjects chose to remember the relationships amongst objects as they would appear with the room in a specific "baseline" orientation, and memorized opposite pairs of objects. Formal training with these concepts helped. Performance also correlated with conventional paper-and-pencil tests of figure rotation ability. Subjects trained in two different environments successively learned faster in the second, suggesting they "learned how to learn". Ability was retained one day, one week, and even one month after initial training. Another experiment showed that learning with randomly chosen rather than grouped (blocked) sets of room orientations enhanced ultimate performance. We are currently extending the paradigm to measure spatial memory across two previously learned modules, one of which is unseen. We want to know if coalignment of the baseline memorized module orientations is critical for performance. Our ultimate objective is to develop a methodology/pedagogy for generic and mission specific ISS preflight visual orientation training. Another application of our paradigms is in the design and evaluation of emergency escape route markings and systems of visual landmarks within modules that help crewmembers keep track of the principal axes of the ISS.

Neural coding of spatial orientation in an animal model. We conducted experiments in a Long-Evans rat model to better understand how the human sense of place and direction may be coded in 3 dimensions. In rats and primates, limbic "head direction" cells appear to code head direction in a gravitational horizontal plane, independent of the animal's location, and roll or pitch of the head up to 90 degrees. The maximum response ("preferred direction") lies in a fixed direction which varies from cell to cell. In 1-G, moving a prominent background visual landmark results in a corresponding re-orientation of the preferred directions of all HD cells by the corresponding angle. Until now, HD cells response has been studied only in a gravitationally horizontal plane. We trained rats to crawl up a wall, across a ceiling and down the opposite wall, in an apparatus that allows us to verify the 3D response characteristics of HD cells in 1-G, and infer whether the response sensitivity remains anchored by gravity or whether the response coordinate frame of the cell re-orients to the animal's locomotion plane. Cells in some animals show robust direction specific firing in the same world-centered reference frame when the animal is walking upside down, and response on the walls depends on the wall and whether the animal was going up or coming down, as expected. In other animals, the cells lose their direction specific firing on the ceiling. and there is a significant increase in background firing, suggesting that the animals may be disoriented. We have also studied HD cell responses in parabolic flight in a test chamber that was visually symmetrical in an up-down direction. All cells HD cells studied maintained their direction specific discharge when the animal was on the floor or the wall of the chamber. However, when placed on the ceiling of the chamber, HD cell directional specificity was frequently lost. In some cases, the preferred direction of HD cell response reversed across the visual axis of symmetry of the cage, as expected if the cell's response coordinate frame had reoriented to the ceiling. When humans roll inverted in parabolic flight and put their feet on the ceiling of the aircraft, they experience a VRI in which the ceiling seems like a "floor", and the left-right axis is reversed. We believe this is the first demonstration of the limbic correlate of a human 0-G spatial orientation illusion. Our experiments provide insights on the role played by gravireceptors in stabilizing the human sense of place and direction not only in astronauts, but also in vestibular and Alzheimer's disease patients.

REFERENCES:
Allison, R., Howard, I.P., and Zacher, J. (1999) The effect of field size, head motion and rotational velocity on roll vection and illusory self-tilt in a tumbling room. Perception, 28, 299-306.
Calton JL, Tullman ML, Taube JS (2000) Head direction cell activity in the anterodorsal thalamus during upside-down locomotion. Soc Neurosci Abstr, Vol 26, Part 1, p. 983
Howard, I and Hu G. (1999) Visually induced reorientation illusions. Submitted to Perception.
Howard, I.P. and Jenkin, H.L. and Hu, G. (2000) Visually induced reorientation illusions as a function of age. Aviation, Space and Environmental Medicine, 71(9), A87-A91.
Oman C, Shebilske W, Richards J, Tubre T, Beall A, Natapoff A. (2000) Three dimensional spatial memory and learning in real and virtual environments. J. Spatial Cog. and Comp. (submitted)
Richards, JT (2000) Three dimensional spatial learning in a virtual space station node. SM Thesis, Dept. of Aeronautics and Astronautics, MIT, Cambridge, MA September, 2000.
Shebilske, WL., Goettl, BP., & Garland, D. (in press). Situation Awareness, Computer-Automation, and Training. In M. R. Endsley & D. Garland (eds.), Situation awareness analysis measurement. Mahwah, NJ: Lawrence Erlbaum.
Shebilske, W. L., Tubre, T., Willis, T., Hanson, A., Oman, C., and Richards, J. (2000). Simulating Spatial Memory Challenges Confronting Astronauts. Proceedings of the Annual Meeting of the Human Factors and Ergonomics Society, July 30, 2000.
Stackman RW, Tullman ML, Taube JS (2000) Maintenance of rat head direction cell firing during locomotion in the vertical plane. Journal of Neurophysiology 83: 393-405.
Taube JS, Stackman RW, Oman CM (1999) Rat head direction cell responses in 0-G. Soc Neurosci Abstr 25: 1383.

Supported by NASA Cooperative Agreement NCC9-58 with the National Space Biomedical Research Institute