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HUMAN ORIENTATION IN PROLONGED WEIGHTLESSNESS (ISS HRF-E085)

Andrew Liu*, Charles M. Oman*, Andrew C. Beall#, Ian P. Howard+, Theodore Smith*, Laurence R. Young*, Laurence Harris+, and Michael Jenkin+

*Man Vehicle Laboratory, Massachusetts Institute of Technology, Cambridge, MA, USA

#Research Center for Virtual Environments, University of California, Santa Barbara, CA, USA

+Center for Vision Research, York University, Toronto, Canada

ABSTRACT

This Human Research Facility (HRF) experiment focuses on how human spatial orientation mechanisms adapt during prolonged (3-6 month) exposure to weightlessness, and the time course of readaptation after return to earth. It will utilize the HRF Rack 2 Workstation as a "science kiosk" for the crew to study the role of visual, vestibular, and haptic cues on spatial orientation. The removal of gravity alters the sensory integration process, as evidenced by the orientation illusions and motion sickness that have been reported in weightlessness, and the profound disorientation and malaise seen in some individuals after prolonged spaceflight. The five test procedures in the E085 experiment are designed to investigate the following questions: (1) How does the perception of orientation rely on static and dynamic visual cues, (2) Does the illusory self-motion change in microgravity due to changes in graviceptor stimulation, and (3) Does the spatial frame of reference used by the astronaut influence their ability to interpret ambiguous objects? In this paper, we will describe the design and development of the flight hardware, software and experiment protocols. Some relevant scientific background is also provided.

INTRODUCTION

The objective of this investigation is to determine how human spatial orientation mechanisms adapt during prolonged (3-6 month) exposure to weightlessness, and the time course of readaptation after return to earth. Perception of self-orientation and object orientation are interdependent: perceived self-orientation influences how we recognize objects and perceive their orientation, and conversely, how we perceive the objects around us influences our perception of our own orientation in space. This process is dependent on visual cues from nearby objects and the surrounding environment, and input from the otolith organs of the vestibular system, as well as gravireceptors in skin, muscle, and arguably even the viscera and cardiovascular system. The removal of gravity alters the sensory integration process, as evidenced by the inversion, visual reorientation, and proprioceptive illusions and motion sickness that have been reported in weightlessness, and the profound disorientation and malaise seen in some individuals after prolonged spaceflight.

The inversion illusion refers to the paradoxical sensation of feeling continuously upside down, regardless of the body's orientation with respect to the environment. It is not exclusively a visual phenomenon since it persists even when eyes are closed. Instead, it is caused primarily by the unweighting of the otolith organs in 0-G but likely enhanced by the fluid shift and elevation of the viscera that result from 0-G exposure. Fortunately, susceptibility lasts only for day or so and then subsides. The visual reorientation illusions (VRI), however, are caused by visual stimuli. They tend to occur when the astronauts are working "upside-down" relative to the cabin or when they see inverted crewmembers when they are upright. The result is that the ceiling spontaneously changes its subjective identity and now seems like the floor. The sudden change in perceived orientation can often trigger attacks of space motion sickness. Mir astronauts report that susceptibility can often persist for months and impede their sense of direction aboard station.

In the NASA program, the incidence of postflight ataxia, disorientation, and earth sickness was relatively low when missions were limited to 1-2 weeks. Many people concluded that sensory-motor adaptation to space was largely complete in 3-5 days. However, the higher incidence of relatively severe "downhill" neurovestibular problems described by astronauts and flight surgeons after 2 week EDO missions and 1-14 month Mir flights implies that many aspects of the process are likely prolonged. There is now more concern about re-entry disorientation and pilot induced oscillations during landing, week-long cases of earth sickness and disorientation, oscillopsia and ataxia lasting several months. Clearly there is still a great deal of importance to be learned about long term adaptation to 0-G.

A set of experiments was flown the 1998 Neurolab space shuttle mission , to investigate the role of visual cues on spatial orientation in microgravity. the experiments proposed here flew on the. However, most of the data from those experiments was collected early in the mission (FD3/4). The Space Station flight opportunity provides a way to confirm or refute our Neurolab findings and to study adaptation to space and readaptation to earth over a much longer term, and extend the number of subjects and observations.

In the remainder of the paper, we will describe the hardware and software to be used in the experiment, including both NASA-provided equipment and experiment unique equipment. The last section will provide some scientific background, an overview of the experimental protocols, and a brief discussion of the Neurolab results.

HARDWARE

The proposed experiments utilize the Human Research Facility's high performance computer workstation, the Rack 2 Workstation. In conjunction with a wide field helmet mounted display, head/hand tracker, and subject restraint system, the system provides a powerful virtual reality platform, allowing experimenters to control visual, tactile, and auditory stimuli, and measure both subjective and motor responses. The equipment will be supporting both the E085 experiments described here, but also the E507 experiments being conducted by Drs. Alain Berthoz and Joe McIntyre of the College de France. Together the two experiments form the VOILA ("Visuomotor and Orientation Investigations in Long-duration Astronauts") investigation. Equipment is easily deployed by a single crewmember. The multimedia capability of workstation supports onboard refresher procedures training and troubleshooting, as well as automated data archiving. The hardware development and fabrication is being led by an engineering team at the Center for Space Research at MIT.

HRF Rack 2 Workstation

The E085 experiments will utilize various capabilities of the HRF Rack 2 Workstation (R2WS) that is currently scheduled for delivery to the ISS on Shuttle Flight ULF-1 in mid-2002. The R2WS is a dual Pentium3 processor workstation running the Windows 2000 operating system that has been designed to support many types of science activities for the HRF.

The visual stimuli for our experiments will utilize the hardware OpenGL acceleration of the two 3dLabs Oxygen GVX1-PCI 3D graphics cards. The dual cards allow us to accelerate a display for each eye in the Head-mounted Display (HMD) described in a later section. Our 3-D scenes have only a few hundred polygons and rely on the advanced texture capabilities of the cards, so we easily achieve a 60Hz frame rate.

We will be attaching a number of peripherals to the workstation for tracking the subject's movements, monitoring the progress of the experiment, allowing them to interact with the environment, and recording voice comments. These will be attached to the available USB connections. We also require serial connections which are not directly available but will be implemented through the USB port. The voice comments will be recorded through the Soundblaster Platinum sound card.

Further technical information and documentation for the Rack 2 Workstation can be found on the Internet (http://hrf.jsc.nasa.gov/r2ws.html).

Experiment Unique Equipment (EUE)

The EUE is being designed and will be fabricated at the Center for Space Research (CSR) at the Massachusetts Institute for Technology (MIT). The HMD and Subject Restraint System (SRS) are Neurolab flight hardware that will be refurbished by the manufacturer or MIT to improve their performance. The remaining equipment is being developed from COTS hardware by the MIT engineering team.

HMD. The HMD is a Kaiser Electro-Optics ProView-80 HMD. It provides a 65° (H) x 48º (V) field-of-view in each eye with 100% binocular overlap. Each LCD in the eye pieces has true VGA resolution (640 x 480 pixels). The contrast of the unit flown on Neurolab was barely sufficient to properly display some of the experimental stimuli. Therefore, the LCD panels will be upgraded to lower power LED units that have better brightness and contrast performance. Figure 1 shows the Neurolab unit in use. When performing the experiment, the user also deploys a plastic shroud to mask the ambient light to enhance a sense of presence in the virtual environment. For ISS, the crewmembers will not wear a headset underneath the HMD as shown in the figure. Instead, the HMD will be fitted with a microphone and earphone headset. The microphone will be wired to the Line In input of the R2WS soundcard to capture voice comments during the experiment to disk. Ambient sound is captured by a microphone mounted off the subject. It is replayed binaurally to suppress any directional sound cues that may arise while allowing the crewmember to be easily alerted with minimal impact to the experiment.

Figure 1.In-flight photograph of the HMD in operation aboard Neurolab. The communication headset worn underneath the HMD will be replaced with an integrated microphone and earphones. The shroud covering the HMD is in the crewmember's right hand.

VOILA Tracking System. The VOILA Tracking system is a new hybrid inertial-optical system that combines the Charnwood Dynamics Ltd. CODA mpx30 active LED optical tracking system (http://www.charndyn.com) with the Intersense IS-300Pro inertial tracker (http://www.isense.com). The optical system tracks active infrared LED markers that are placed on the subject in a known configuration. The inertial system uses small angular rate sensors to detect changes in orientation. The optical and inertial information is fused to generate the position and orientation of the head, body, and hand of the subject. While not essential to the E085 experimental protocol, the ability to change the scene with respect to head motions should enhance the "presence" felt in the virtual environments. Development of the fusion algorithms is being led by one of the VOILA co-PIs, Dr. Joe McIntyre of the College de France, with support from CNES. In the flight configuration, two CODA camera bars will be mounted facing each other on the module seat track rails and cover a working volume between the units of approximately 2 m per side. This will allow the subject to freely move in certain experimental protocols while maintaining tracking of the head, body, and hand. The camera bars will also contain a small USB webcam taking slow-scan imagery of the subject during the course of the experiment This provides a visual check in case of a problem with any of the equipment or subject positioning.

SRS. The Subject Restraint System is used to restrain the subjects in a variety of body postures or orientations during the experiment. In some protocols, it is configured to generate a downward force on the subject that approximates the proprioceptive sensations at the feet in a gravity environment. In other protocols, the subjects may be sitting or supine and restrained from floating. The SRS is composed of four major pieces: (1) a platform that supports the subjects while in a standing/sitting/lying position, (2) a set of spring coils that impart the force on the subjects, (3) a vest/harness system that is worn by the subjects which has attachment points for the coils, and (4) a quasi-free-floating restraint.

Since all four sides of any of the modules where our experiments may take place are likely to contain equipment, we have designed an SRS platform on which subjects will be positioned (Figure 2). The aluminum platform will stretch across and just above the equipment rack and be mounted in the seat track. When stowed, the seat back and footrest will be folded under the main plate to minimize volume. There will be various restraints to help the subjects maintain their posture and padding to provide some comfort. In the seated and supine positions, the long body axis is parallel to the module's long axis. A set of active LED markers will be mounted on the platform to provide a common frame of reference for the tracking system during the experiments.

Figure 2. An early prototype of the SRS platform in the seated configuration.

The SRS spring coils are mounted on the platform when required by a particular experimental protocol. The ISS design will use the same pair of coils flown on the Neurolab mission with a few modifications to improve the process of attaching the coils. In the anticipated operating range, each spring coil will generate approximately 34 ± 2 lbs of force. (Figure 3)

The crewmembers will wear a vest during the experiment that will have attachment points for the SRS spring coils. The vest will be designed to place most of the load from the springs on the hips, much as a backpack's waist belt.. The shoulders will also receive some of the load to minimize any discomfort. In addition, the vest will also have an integrated electronic connection box that will provide some signal processing for the video and voice signals. It provides handy connections for the peripherals used by the subjects and helps minimize the number of cables leading to the R2WS. A set of active LED markers and inertial sensor for the tracking system will also be mounted on the vest to provide information about the position and orientation of the subject.

For experiment protocols requiring a quasi-free floating posture, we are designing a pole that will attach to the platform or SEAT track and have a lockable rotating mechanism at the top. The crewmember will attach him/herself to this mechanism with a mating device integrated onto the vest. The pole also provides a handhold for crewmembers to pull themselves up to a standing position after attaching themselves to the spring coils.

Figure 3. The Neurolab SRS in operation. The springs are mounted to the floor and generate ~34 lbs force each. The harness is worn low on the hips to distribute the forces generated by the coils.

Subject Input Device. The subjects will use the SID to respond to queries during the experimental protocols. It will be based on some type of commercial off-the-shelf (COTS) USB gamepad as they provide an array of buttons and joysticks that can be monitored through the standard game controller drivers provided through the Windows 2000 OS. The final design of the SID has not yet been determined as the experimental protocols have not been finalized.

Experiment Software. On Space Station, the style of conducting experiments will be quite different from the shuttle operations. Initially many hours of the crew's day will be devoted to other activities and exercise, and their schedules will be subject to last minute change. It is not practical to make the Investigator team available to support experiment operations for the duration of the mission. Many other important resource constraints are not yet defined. Thus, we are designing the in-flight test procedures to be easily completed by a single crewmember and to provide flexibility in scheduling. All test procedures are non-invasive, and each test protocol requires only 12-30 minutes.

Our experimental software will launched from the HRF Common Software (CSW) running on the R2WS. The software will allow the crew members to use the R2WS as a "science kiosk" which will present a prioritized list of experiment protocols that the crewmember can perform at that time. The experiment software is being developed in the Python scripting language. Python is a cross-platform interpreted programming language that enables easy prototyping of the interface and experimental protocols with fast turnaround time. It is also freely available for download from the Internet (http://www.python.org) and is easily extensible through its application programming interface (API). The VRUT Python module, developed by one of the authors in C/C++, is one such extension. The VRUT module provides the OpenGL graphics calls used in generating the 3D visual stimuli. In our experience, it has been very fast and easy for novices to learn 3D graphics programming and create sophisticated virtual environments for experiments with VRUT. The VRUT installer and accompanying documentation is freely available from the University of California, Santa Barbara, Internet site (http://www.psych.ucsb.edu/research/recveb/vrut/index.html).

The software load consists of two major types of Python scripts: (1) a "Session Manager" and (2) an "Experiment Manager". The Session Manager is the main interface for the crew members to initiate experiments, record notes between experiments, perform diagnostic or calibration procedures, and find help information. It will be used by both the E085 and E507 experiments in the VOILA suite. It automatically performs various file administration tasks such as backing up data files or selecting those files ready for downlink through the Common Software. It maintains a database of the current Expedition crew(s) and the time periods during the Expedition crew mission that the various experiment protocols should be performed. When the crewmember checks in with the Session Manager, it presents a prioritized list of experiment protocols that need to be performed. Since it is still unspecified how much time the crew will have in a given session, the Session Manager also indicates the estimated time needed to complete a given protocol. It also maintains the list of protocols that have been completed by each of the crewmembers. All the preceding information is kept in a set of ASCII text configuration files, which allows the investigators to update the files by uplinking new configuration files.

The Experiment Managers are the Python scripts that perform the experiment protocols by generating the virtual environments, collecting and analyzing data. There is a separate script for each experiment protocol. They all import the VRUT module in order generate the 3D graphics. The objects in our virtual environments are VRML97 format objects developed from 3DSMax models. The Experiment Managers get data from the tracking system through a VRUT plug-in, or driver, which is being developed by the experiment team. VRUT has built in capabilities for obtaining data from standard game controllers like our SID.

EXPERIMENTAL PROCEDURES

General Procedures

The experiments are scheduled throughout the crew's mission and return in order to investigate the changes in adaptation and perception of orientation. The pre-flight tests, at approximately 120, 90, and 60 days prior to launch, will provide a baseline with which to compare the in-flight and post-flight data. In-flight tests are slated to begin in the first week of flight and continue throughout the mission at 3-4 week intervals. Post-flight we will monitor the readaptation to Earth's gravity with four sessions during the first 2 weeks upon return and a late test at R+30 or later.

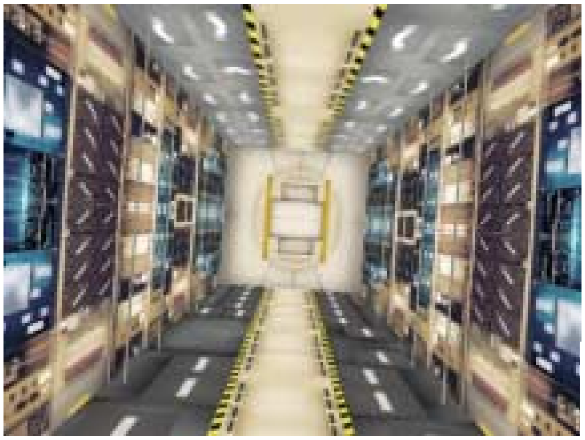
The same visual stimuli will be used for both the ground and in-flight experiment protocols although the postural/orientation configurations will differ. In each test session, the subject will be tested under multiple conditions. Inflight, the subject will be tested quasi-free floating upright in the virtual visual environment, and also (depending on the experiment) either floating left shoulder down relative to the visual environment, or "standing" in the SRS restraint harness described earlier. Pre- and post-flight tests will be conducted in either the erect or supine conditions. The SRS is not used for the ground experiments. In the following sections, we will describe the scientific background for each of the flight experiments as well as an overview of the visual stimuli and procedures.

Virtual Tilting Room

The virtual tilting room test follows up on astronaut subjects' descriptions of visual reorientation and inversion illusions[1]. What causes these VRIs? Laboratory experiments conducted on Earth in specially built tumbling rooms[2] have shown that tilting the room away from the normally upright position shifts the direction a subject will set a "down" pointer toward the principal visual axes of symmetry of the environment. If the room is furnished with familiar "gravitationally polarized" objects with a clearly recognizable "top" and "bottom", and both the room and the subject are tilted 90 degrees, many people report they still feel upright, even though they are gravitationally supine. If a room with a few polarized objects is slowly tumbled around the subject, most people initially feel tilted opposite to the direction of room rotation. Eventually, as a wall or ceiling rotates into a position beneath their feet, that surface suddenly seems like a floor. The subject instantly feels tilted in the opposite direction. This illusion corresponds to the VRIs described by astronauts. Rotating a strongly polarized room typically produces a sensation of full head-over-heels tumbling, with no VRIs.

The hypothesis which emerged from these and other experiments (reviewed by [3]) is that the subjective vertical (SV) direction – and the identity of surrounding surfaces - is determined by the interaction between signals from the body's gravireceptors and visual cues to the vertical. Gravireceptor cues come not only from the otolith organs, but also from mechanoreceptors in the kidneys and the cardiovascular system, and individual subjects show a small but consistent headward or footward bias[4]. Visual cues include the principal directions defined by the major architectural surfaces and symmetries of the surrounding environment, with the up/down axis of the visual environment identified based on two factors: 1) the gravitational polarity of familiar objects and 2) an "idiotropic" tendency to perceive the visual vertical as oriented along the body axis in a footward direction [5]. When there are minor directional differences between the gravireceptor and visual cues to the vertical, the SV points in an intermediate direction. The remaining component of gravity is then perceived as a mysterious force, pulling the body to one side. For large differences, one sensory modality or the other typically captures the SV. Tilting the head away from the gravitationally erect position enhances the effect of visual cues. There seem to be consistent differences between individuals in the relative weighting assigned to visual vs. gravireceptor cues. Older individuals appear more susceptible to visually induced tilt. Scene motion enhances visually induced tilt for most subjects.

In weightlessness, the body's gravireceptors are unweighted, but the individual subject's headward or footward bias presumably remains. The bias may increase in a headward direction, because of 0-G fluid shift, though this effect may only last a few days. The resultant is expected to determine whether a person experiences inversion illusion with eyes closed, and for how long. We hypothesized that with eyes open, the SV should align with the body axis if the crewmember has a strong idiotropic tendency. In a more visually dependent individual, the SV should align with one of the principal environmental axes of symmetry,



(a)

(b)

Figure 4. The Neurolab stimuli for the virtual tilting room test. (a) A weakly polarized scene. (b) A strongly polarized stimulus.

depending on which way the person's feet are pointing (idiotropic effect) and on the orientation of polarized objects in the visual scene. Other crewmember's bodies are strongly gravitationally polarized, since they have a readily recognizable top and bottom, and are consistently encountered gravitationally upright in normal life. Hence VRIs should not occur in a visually familiar environment if everyone onboard remains upright with respect to the deck . However, if the viewer floats sideways or upside down, or another crewmember does so, the viewer may experience a sudden change in the direction of the SV. If unanticipated changes in the relative direction of the SV contribute to space sickness, one could speculate that idiotropic crewmembers should be less prone to space sickness, since they "carry down around with them". There is preliminary evidence suggesting that subjects with large gravireceptor bias and small idiotropic vectors more readily experience 0-G inversion illusion[6, 7].

The tilted room experiments expose the subjects to gravitationally polarized scenes of a familiar but virtual environment (similar to those shown in Figures 4 which were taken from the Neurolab mission stimuli) and attempt to quantify the direction of each subject's SV. Previous experiments with a virtual recreation of the tumbling room experiments indicate that the same orientation effects can be generated with the HMD and virtual environment [8, 9]. The scenes are presented various static orientations covering ±180° in random order and alternating between strongly and weakly polarized scenes. The subjects will be asked to indicate the direction of the subjective vertical with a virtual indicator (e.g., the green balls in Figure4(b)) as well as indicate which surface seems most like the "floor." The experiments are also performed separately in free floating conditions and while using the SRS to provide haptic cues.

Overall, the Neurolab results confirmed that crewmembers show consistent differences of their dependence on static visual cues to their subjective vertical. The effects of spaceflight on visual dependence varied between crewmembers. At least one of the four subjects showed the hypothesized increase in dependence to static visual cues. Postflight carry over of this effect suggests that the inflight visual dependence was not the instantaneous result of the absence of gravireceptor and fluid shift effects. When using the SRS, the subject all became visually independent. None of the four subjects exhibited increased visual independence inflight.

Virtual Tumbling Room

Young and colleagues[10, 11] had crewmembers insert their heads into a polka-dotted drum which rolled about the visual axis, and report the amount of illusory angular self-motion (circular-vection) they experienced. On Earth, upright subjects reported a paradoxical rolling/tilting sensation. In orbit, most astronauts felt continuous rotation. Wearing a bungee cord harness that pulled the subject to the deck inhibited the strength of circular-vection in some subjects. Young concluded that astronauts become more visually dependent in weightlessness since they generally experience stronger sensations of angular speed in response to visual scene rotation.

The virtual tumbling room experiments are a dynamic version of the static tilt tests that also extend the studies by Young et al. We will use the same visual stimuli as in the tilting room experiment as well as a virtual recreation of the dome experiment stimulus (Figure 5). By inducing a constant angular velocity roll about the visual axis, we would expect the subjects to experience circular vection in all scenes. However, we would only expect VRIs in the polarized scenes. Subjects will be asked to report any VRIs they experience during the roll motion exposure. Afterwards, the subjects will use a virtual scale to mark the magnitude of circular vection that they experienced. Other questions will probe the nature of their vection (e.g., continuous, alternating tilt, etc.). Again, the experiments are performed both in the free-floating and SRS restrained postures.

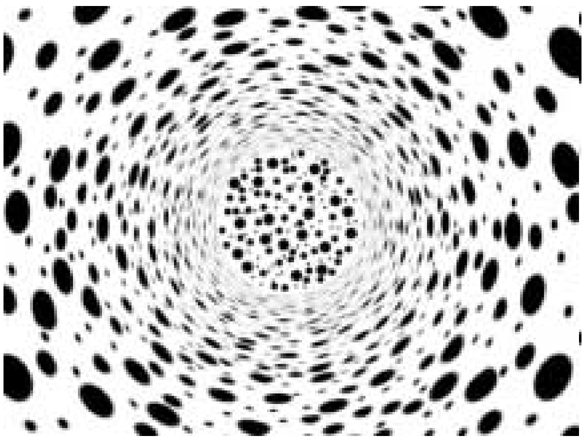


Figure 5. A dotted cylinder scene that replicates the dome experiments [10].

The results from the Neurolab experiments show an increased reliance on rotating visual cues and a strong effect of proprioceptive cues inflight in three of the four subjects. The magnitudes of circular vection were significantly greater inflight than pre- or post-flight in the free-floating condition. Vection magnitude was also significantly greater for the free-floating condition compared to the restrained conditions. Vection magnitudes for the dotted cylinder were greater than for the room scenes. Data from the VRI responses yielded mixed results. The modal phase of the onset of the VRIs showed that 90º (quad) modal tendencies were significantly greater in flight than pre-flight or late post-flight. However, the frequency of VRI response did not show any consistent patterns. This is a good example where the additional subjects from the ISS flight experiments will hopefully provide a clearer evidence of any effects.

Linear Vection

"Linear vection" is the illusion of self-motion induced when the surrounding visual scene translates towards the viewer. Research on the characteristics of moving scenes that influence motion perception suggest that several factors contribute to the magnitude of vection. These include edge rate, and global optical flow rate scaled to the eye level of the observer [12, 13].

Orientation with respect to gravity is known to influence vection. Muller and colleagues [14, 15] have studied vertical linear vection in 10 cosmonauts as part of the long duration AustroMir missions. Results indicated smaller phase shifts in some subjects, but greater ones in others. Pitch as well as vertical vection was reported. Unfortunately, methodological issues have complicated interpretation of the phase data, and subjects did not concurrently report their subjective orientation or their magnitude of vection.

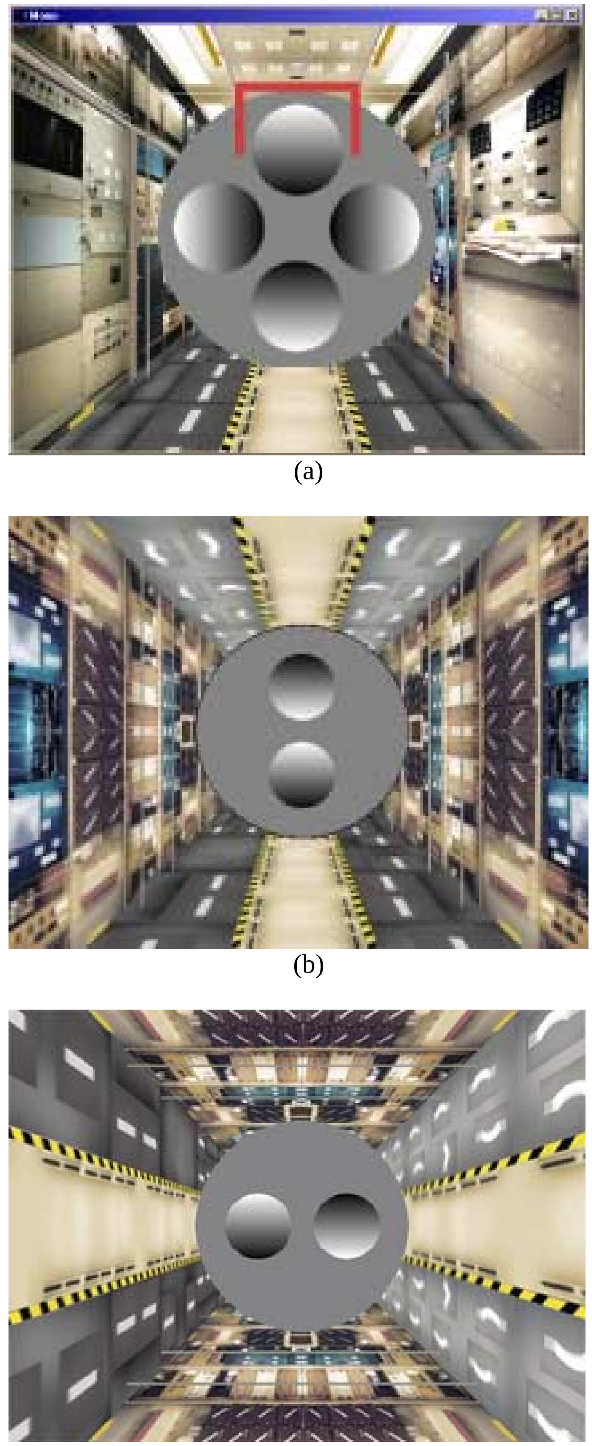
Adaptation to prolonged weightlessness has been hypothesized to involve changes in the relative weighting of visual and otolithic cues. If so, the dynamics of onset of linear vection are expected to be affected. No comprehensive study of x-axis ("looming") linear vection onset responses using magnitude estimation techniques has yet been conducted in orbit. This is the purpose of the proposed experiment.

Figure 6. Neurolab version of the linear vection stimulus. Background scene moved toward subject. Black frame in foreground was stationary relative to the subject.

In our experiments, crewmembers will see a long corridor textured with equipment racks similar to the ISS modules (e.g., Figure 6). Traditional self-motion research has often used simple abstract displays (e.g., clouds of moving dots or peripheral optokinetic moving stripes) that are easily quantified in terms of physical measures. However, the absolute value of the linear vection produced with such stimuli is ambiguous, and depends on the assumed scale of the objects and perceived eye-height above the floor. Use of a checkerboard corridor or ground plane scene[16] partly alleviates the concern about scale ambiguity, because an additional eye height perspective cue is available. However, we have concerns about the validity of the eye height assumption in 0-G, given that our subjects will be living in weightlessness for several months, and moving about at many different distances from the floor. There is also a concern that VRIs may have an impact on the perception of eye-height.

At this time, we have not yet finalized the experimental protocols, although they will involve exposure to stimuli moving at different speeds and some measurement of the onset and magnitude of vection. Subjects may also become accustomed to constant velocity motion without physical effort in 0-G. If increased weight was given to visual cues in weightlessness, the vection sensation should seem more compelling. Subjects will again perform the vection experiments in both a free-floating and restrained posture. We expected that providing a strong body axis force cue indicating that the subject is firmly anchored to the deck would strongly inhibit vection because such cues are entirely absent in weightlessness.

In the Neurolab experiments, the subjects viewed scene motion at 5 different speeds for 10 seconds each. The instantaneous start of the motion causes a momentary visual/otolith cue conflict leading to a latency in the onset of vection. Subjects were instructed to deflect the joystick in proportion to their perceived speed on self-motion. The results show the anticipated effect that inflight free-floating latency was shorter than pre-flight. Latencies to the onset of vection decreased with increased scene speed. In-flight free-floating normalized vection magnitude was generally greater than restrained vection magnitude.



(a)

(b)

(c)

Figure 7. (a) An example of the proposed stimulus for the ISS experiments using four shaded circles. The red reticle is used to select the perceptually convex circle. (b) Stimulus used in the Neurolab experiments. (c) A different stimulus seen in the left-shoulder down orientation. Notice the new position of the “floor” surface.

Convex/Concave Shaded Figures

On Earth, the process of shading interpretation and object recognition depends on the gravitational orientation of the objects seen. For example, Howard and colleagues[17] showed that the illusory concavity or convexity people normally perceive when interpreting shading on a truly flat surface depends on a “light comes from above” assumption, where “above” depends on the relative orientation of the dark-to-light shading gradient to head orientation, and to gravity. If the shading gradient is vertically aligned with the head, dark-over-light, the disk will appear concave, and conversely. If the shading gradient is the “neutral” head and environment horizontal orientation, (light-left, dark-right, or the reverse), the disk will seem flat. We predict that if a subject experienced a VRI in weightlessness, it would not only change the subjective identity of surrounding surfaces, but should also influence the perceived convexity of gradient shaded circles. Many crewmembers claim they can cognitively initiate a VRI in weightlessness (“whichever way I decide is down, becomes down”), so we shall test the hypothesis that shading gradient and figure recognition could even be changed just by cognitively altering the SV, without any physical movement or change in the visual scene content.

For the shaded figure recognition tests the subjects will see arrays of four shading gradient disks appear on a flat virtual surface at an apparent distance of 3 m, within a virtual Space Station-like ambient visual environment. The shading gradient of each of the four disks is oriented in a different principal direction with respect to the environment, but the disks are randomly arranged (Figure 7(a)). The disks are similar to those described by [17]. This arrangement is slightly different from the Neuroloab experiments which used only two disks per scene (Figure 7(b)). A set of four gradient shaded disks are successively presented for 5 sec each, and the subject must identify which disks appear which convex ("out") in each set. Our hypothesis is that preflight, and at least early in the mission, the subject will use a "light from above" assumption.

First, the subjects will see the set while in a free-floating upright posture. Next, the subject rolls 90 deg. CCW, to a left shoulder down (LSD) position, and the same twenty sets of disks are represented, in a different random order. The disks have the same orientation with respect to the environment as in the previous trials (Figure 7(c)). Because the subject has rotated 90º, disks that were formerly in the neutral orientation now have their gradients aligned with the head vertical axis, and conversely. We hypothesize that in this orientation, the interpretation of the disks with shading gradient neutrally oriented with respect to the head will now be determined by their orientation with respect to the surrounding virtual environment. Gradients which neutrally oriented with respect to the head (i.e., perpendicular to the head vertical axis) but which have the dark-over-light relative to the environment will appear concave, and conversely. For those oriented vertically with respect to the subject's head, retinal factors will dominate the interpretation.

In the final phase of this experiment, the subject cognitively initiates a visual reorientation illusion (VRI), imagining that the virtual Space Station scene "floor" on the left side of their body as a "wall", and the surface beneath their feet as a "floor", so that they once again seem in a subjectively upright position. We expect that the results for the neutrally oriented disks will now be approximately equal, at least early in the mission. Results from the second and third parts of this test, taken together, will show that the "gravitational" effect in the shape from shading literature depends on the orientation of the subject's exocentric reference frame, rather than the direction of gravity. We are particularly interested to see whether responses to this experiment change during long duration flight on Space Station, as subjects become more experienced at interpreting shape from shading in a wide variety of body attitudes within the spacecraft. We also expect that after months in space, there may be a long lasting carry over effect postflight.

As stated earlier, the Neurolab experiments used only two disks per scene arranged in one of the following pairs: (1) shading gradients for the disk pairs were both parallel to the body axis, (2) gradients were perpendicular to the body axis, the "neutral" direction, and (3) mixed gradient direction. For the gradients in the parallel direction, subjects reliably chose the "light from above" interpretation. For the perpendicular gradients, the percentage of light left responses for the group of four subjects increased in both the LSD and VRI (imaginary LSD while supine) both preflight, inflight, and postflight confirming that cognitive reference frame, rather than gravity itself, contributes to the illusion of convexity when the shading gradient is perpendicular to the body (head) axis. For the mixed gradient cases, they reliably chose the neutral (light-left) stimulus over convex (light-bottom) in all conditions.

<u>Random Figures</u>

As with the shading interpretation, the process of object recognition is known to depend on the gravitational orientation of the objects seen. For example, Rock[18] found that people more easily recognize nonsensical doodles if they are shown in the same gravitational orientation as when previously seen.

Figure 8. A prototype of the stimulus for the Random Figures test. One of the four choices is in the same head-up orientation that the subject learned the figure.

The random figures test will also use the same virtual Space Station mock-up used in the previous experiment except for the objects shown in the central circle. The subject is shown sets of three training figures in forward and reverse order, and then told to initially fixate a central target on the screen and keep head and body stationary. Next, a circular array of four figures briefly appears before being masked by four dark dots. The array contains four versions of one of the training figures at a different orientation (Figure z2). The subject is instructed to examine the figures and quickly identify the figure in the array which on first impression seems most like one of three training figures shown previously. This is then repeated, using other test arrays.

The procedure is repeated in the left-shoulder down position and in the cognitively-initiated VRI condition as with the shaded circles experiment. A new set of figures is presented for each body position We expect that even though gravity is absent, upright (with respect to the virtual environment) (unrotated) figure rather than the retinally upright (CCW rotated) figure will be recognized more readily, as demonstrable using a chi-square contingency table analysis. For the VRI condition, our hypothesis is that even though the subject has not moved, simply due to the 90º reorientation of the subject's egocentric frame of reference, when the test is repeated, the "upright" orientation (CCW rotated) figure is more frequently recognized. This procedure will be performed several times with stimuli based on different sets of training figures. Multiple sets are used in preflight training and testing, so that subjects do not become too familiar with any of them.

We are particularly interested to see if responses to this experiment change during and after long duration flight on Space Station. If subjects progressively utilize a more head centered reference frame, or learn to code visual information and recognize objects in a more orientation independent way, this experiment would be expected to show it.

Again, for the Neurolab experiments, the stimuli consisted of only two random figures per scene instead of four. The results from the Neurolab experiments are inconclusive. Only one subject 's data truly followed the hypothesized pattern of a preference for the body axis presentations. The other subjects did not show any effect of the manipulations of the SV but this may be due to the fact that two subjects could not recognize the figures in the head-upright position.

SUMMARY

In this paper, we have described the hardware and experiments currently under development for ISS HRF Experiment E085. The experiment objective is to determine how human spatial orientation mechanisms adapt during prolonged (3-6 month) exposure to weightlessness, and the time course of readaptation after return to earth. We have presented some results from similar experiments performed on the Neurolab space shuttle mission to illustrate the expected results.

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