

Development and Implementation of Inflight Neurosensory Training for Adaptation/Readaptation (INSTAR)

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ABSTRACT

Resolution of space motion sickness, and improvements in spatial orientation, posture and motion control, and compensatory eye movements occur as a function of neurosensory and sensorimotor adaptation to microgravity. These adaptive responses, however, are inappropriate for return to Earth. Even following relatively brief space Shuttle missions, significant re-adaptation disturbances related to visual performance, locomotion, and perceived self-motion have been observed. Russian reports suggest that these disturbances increase with mission duration and may be severe following landing after prolonged microgravity exposure such as during a voyage to Mars. Consequently there is a need to enable the astronauts to be prepared for and more quickly re-adapt to a gravitational environment following extended space missions. Several devices to meet this need are proposed including a virtual environment - centrifuge device (VECD). A short-arm centrifuge will provide centripetal acceleration parallel to the astronaut's longitudinal body axis and a restraint system will be configured to permit head movements only in the plane of rotation (to prevent "cross-coupling"). A head-mounted virtual environment system will be used to develop appropriate "calibration" between visual motion/orientation signals and inertial motion/orientation signals generated by the centrifuge. This will permit vestibular, visual and somatosensory signal matches to bias central interpretation of otolith signals toward the "position" responses and to recalibrate the vestibulo-ocular reflex (VOR).

INTRODUCTION

Stable vision, posture and locomotion, and accurate perception of how one is oriented in and moving through space depends on complex physiological integration of signals from virtually every sensory system. Changes in the environment and the way we interact with the new stimuli in that environment will result in a different interpretation by the nervous system of the incoming sensory information. Initially on-orbit, the response outputs from the nervous system that control vision, posture, perception of orientation and motion are inappropriate and result in space motion sickness and disturbances in these functions. Over time, however, people adapt to these changes in appropriate ways. Changes in the sensory stimulus conditions in the environment are referred to as sensory stimulus rearrangements. The environment of orbital flight and return to Earth represent the stimulus rearrangements that are our immediate concern.

Neurosensory adaptation may be defined as a transient or long-term modification of sensory apparatus and perceptual processes which involves forming new associations between stimuli and responses to those stimuli. Adaptation is enhanced by active exploratory behavior in a new environment with resulting feedback and the formation of associations between sensory inputs and response outputs that promote appropriate orientation and movement in that environment (microgravity). *Readaptation* is the process(es) by which the nervous system relearns the associations between sensory inputs and response outputs that promote appropriate orientation and movement on Earth. Russian reports suggest that these disturbances increase with mission duration and may be severe following landing after prolonged microgravity exposure such as during a voyage to Mars or an extended stay on space stations.

On orbit, the absence of an effective gravity vector creates the requirement for adaptive changes in the sensorimotor and perceptual systems that, on Earth, subserve the voluntary and reflexive control of eye, head, and body orientation and motion relative to Earth. The favorable consequences to the astronaut of the adaptive changes to microgravity are improved sensorimotor performance, reduction in spatial orientation and motion perception disturbances (illusions of self and/or surround motion), and abatement of space motion sickness (SMS). The unfavorable consequences for these improvements on-orbit are maladaptive sensorimotor and perceptual reactions during return to Earth and for some time after landing.

Our overall goals are to develop training devices and procedures that will allow astronauts first to develop appropriate responses preflight (on Earth) to the sensory conditions of microgravity and second to maintain appropriate responses (on-orbit) to the sensory conditions of Earth. A brief description of the Preflight Adaptation Training (PAT) program currently underway and a proposed Inflight Neurosensory Training for Adaptation/Readaptation (INSTAR) program will be presented in the next two sections of this paper. The underlying design principles for INSTAR are essentially the inverse of those for PAT. That is, PAT provides an environment where: (1) in the presence of gravity, stimulation to the graviceptors is held constant (graviceptor stabilization) during real and visually induced self-motion in the pitch, roll and yaw planes, and (2) adaptation to rotation without changes in the gravity vector is accomplished within a visual context representative of the interior of the spacecraft. INSTAR, on the other hand, should provide an environment where: (1) in the absence of gravity, the equivalent of a 1g stimulus to the graviceptors is provided during static and dynamic head rotation, and (2) maintenance of adaptation to Earth would be accomplished within visual contexts representative of familiar places on Earth.

PREFLIGHT ADAPTATION TRAINING (PAT)

The general concepts underlying PAT are: (1) that the brain can learn to "recalibrate" the incoming sensory signals in a manner that would be appropriate to microgravity, and (2) because the central nervous system is "plastic," people can learn and store perceptual and sensorimotor responses to different sensory stimulus conditions. That is, they can develop *dual-adapted states* and can learn to switch rapidly between different stimulus conditions. For example, experienced SCUBA divers exhibit altered compensatory eye movement gains immediately upon donning their diving masks. Apparently, they have learned that a higher gain is required to compensate for the magnification of the visual scene due to the air-water interface. Removal of the mask is associated with a nearly immediate return of the normal gain. The primary goals of this effort are to develop trainers that can simulate the stimulus rearrangements of microgravity and develop training scenarios and procedures to facilitate adaptation to microgravity and readaptation to Earth (dual-adaptation), and the ability to switch rapidly between these states.

Our general approach was to develop two part-task trainers to induce the appropriate adaptive responses. The Device for Orientation and Motion Environments Preflight Adaptation Trainer (DOME PAT) incorporates virtual environment technology to: (1) produce the perception of self-motion (vection) without changes in gravity inputs to the vestibular system, and (2) provide an environment where the trainee can "virtually" position themselves in any orientation, and view their visual environment from an infinite number of perspectives without changes in gravity inputs to the vestibular system. A more detailed description of this system is available in this proceedings in a paper titled "Using Virtual Environment Technology for Preadapting Astronauts to the Novel Sensory Conditions of Microgravity."

The tilt-translation device (TTD) couples translational visual motion with body tilt to: (1) produce the perception of translational (linear) self-motion, and (2) facilitate central nervous system reinterpretation of tilt motion as translational motion. Adaptation induced by this device is based on the otolith tilt-translation reinterpretation (OTTR) hypothesis of neurosensory adaptation to microgravity. This hypothesis states that during adaptation to microgravity, the brain learns to process information from the vestibular graviceptors (otoliths) and other graviceptors differently. On Earth, inputs from otolith receptors is interpreted by the brain as linear motion or as head tilt with respect to gravity. Because of the absence of stimulation from gravity during orbital flight, interpretation of otolith responses as tilt is meaningless. Therefore, the brain adapts to sustained microgravity by reinterpreting all otolith receptor output as linear motion. (see Bibliography for additional readings on PAT)

INFLIGHT NEUROSENSORY TRAINING FOR ADAPTATION/READAPTATION (INSTAR)

The overall goals of INSTAR are to enable astronauts to be prepared for and more quickly readapt to Earth's gravitational environment following extended space missions in order to reduce eye movement control, postural/locomotion, and perceptual disturbances associated with return to Earth and the potential impacts of such disturbances on: (1) orbiter control during landing, (2) egress from the orbiter, and (3) physical injuries from falls. Long-duration missions require inflight countermeasures because, as they are more remote in time, preflight countermeasures (PAT) become less effective, that is, there is a limited time period that dual adapted states can be retained.

Our general approach will be to develop a set of training devices, coupled with VET, that can provide astronauts with visual, inertial and somatosensory stimuli analogous to those associated with voluntary activity in normal gravity. The equivalent of an Earth gravitational force could be provided by a centrifuge and by elastic head and limb loading. Figure 1 depicts our initial concepts for a Virtual Environment - Centrifuge Device (VECD). The VECD requires the development of a short-arm centrifuge to provide a gravitational force stimulus to otolith and somatosensory graviceptors, and that is configured to permit head movements only in the plane of rotation to prevent semicircular canal "cross-coupling" effects. A head-mounted virtual environment system is incorporated to support the development of appropriate "calibration" between *visual* motion/orientation signals and the *inertial* motion/orientation signals generated by the centrifuge.

The anticipated benefits of inflight training using the VECD would be the maintenance of the "dual-adapted" state initially developed in the PAT by providing sensory signal matching, similar to the 1-g Earth environment between: (1) otolith (graviceptors) and semicircular canal signals - to bias the otolith response toward the "tilt" interpretation (OTTR hypothesis), (2) visual, otolith and semicircular canal signals to - recalibrate the VOR and (3) visual, vestibular and somatosensory signals.

SUMMARY AND CONCLUSIONS

Changes in the sensory stimulus conditions present in a given environment result in disturbances in eye movement control, posture and locomotion, and perception. People can adapt to altered sensory conditions which would result in the abatement of sensory and sensorimotor disturbances. With appropriate training procedures and schedules, people can develop dual-adapted states and learn to switch rapidly between these states. However, retention time of dual-adapted states is limited without regular exposure to both sets of sensory conditions. Therefore, both PAT and INSTAR will be necessary for extended stays on-orbit, and VET is a critical component of devices being designed to adapt space travelers to microgravity and to maintain adaptation to Earth.

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VIRTUAL ENVIRONMENT CENTRIFUGE DEVICE

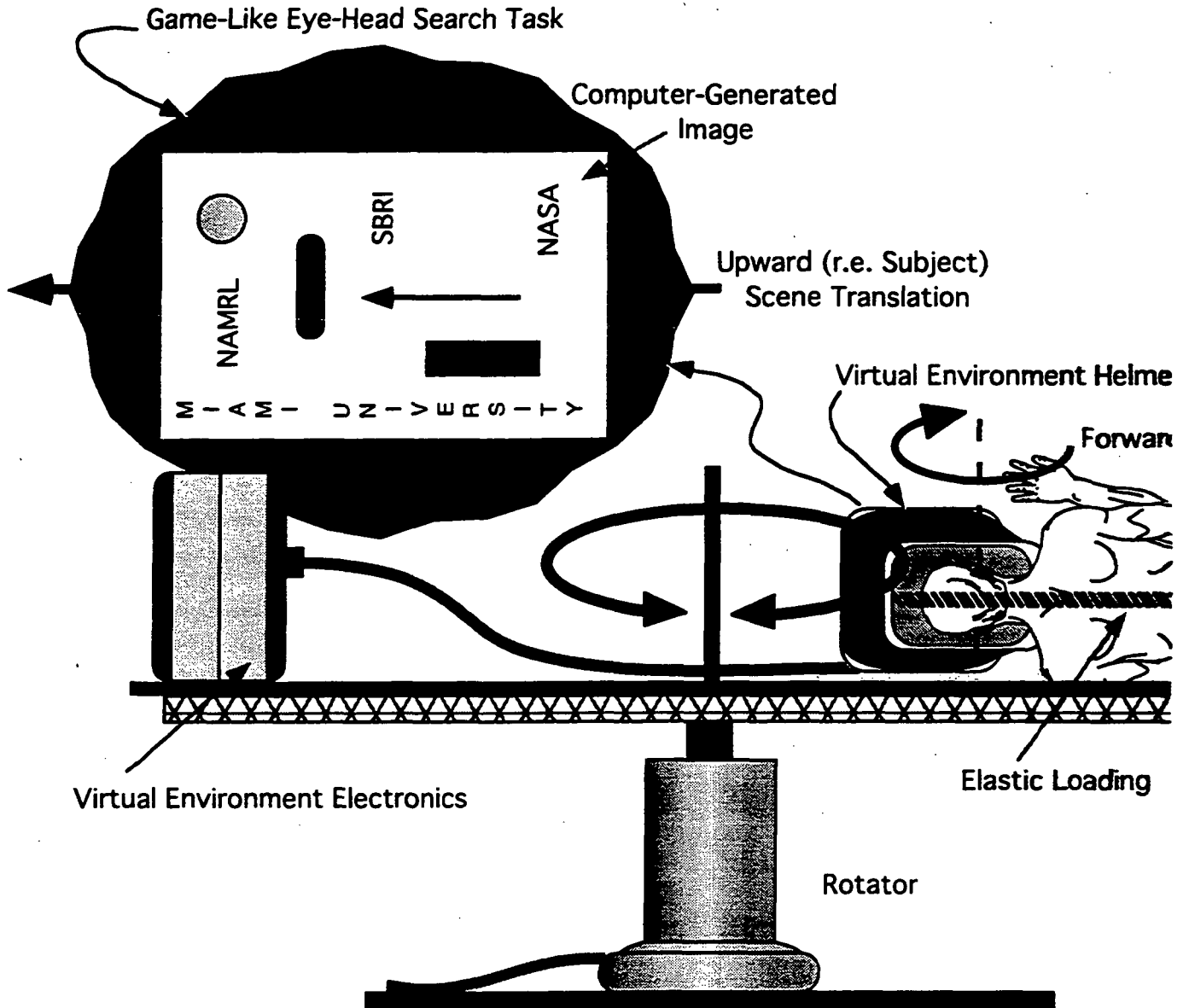


Figure 1. Conceptual Design for INSTAR Device