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Neuroscience Investigations
An Overview of Studies Conducted

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INTRODUCTION

The neural processes that mediate human spatial orientation and adaptive changes occurring in response to the sensory rearrangement encountered during orbital flight are primarily studied through second and third order responses. In the Extended Duration Orbiter Medical Project (EDOMP) neuroscience investigations, the following were measured: (1) eye movements during acquisition of either static or moving visual targets, (2) postural and locomotor responses provoked by unexpected movement of the support surface, changes in the interaction of visual, proprioceptive, and vestibular information, changes in the major postural muscles via descending pathways, or changes in locomotor pathways, and (3) verbal reports of perceived self-orientation and self-motion which enhance and complement conclusions drawn from the analysis of oculomotor, postural, and locomotor responses.

In spaceflight operations, spatial orientation can be defined as situational awareness, where crew member perception of attitude, position, or motion of the spacecraft or other objects in three-dimensional space, including orientation of one's own body, is congruent with actual physical events.

Perception of spatial orientation is determined by integrating information from several sensory modalities (Figure 5-1). This involves higher levels of processing within the central nervous system that control eye movements, locomotion, and stable posture. Spaceflight operational problems occur when responses to the incorrectly perceived spatial orientation are compensatory in nature. Neuroscience investigations were conducted in conjunction with U. S. Space Shuttle flights to evaluate possible changes in the ability of an astronaut to land the Shuttle or effectively perform an emergency post-landing egress following microgravity adaptation during space flights of variable length. While the results of various sensory motor and spatial orientation tests could have an impact on future space flights, our knowledge of sensorimotor adaptation to spaceflight is limited, and the future application of effective countermeasures depends, in large part, on the results from appropriate neuroscience investigations. Therefore, the objective of the neuroscience investigations was to define spaceflight related adaptive changes within a narrowly defined subset of the sensorimotor systems that could have a negative effect on mission success.

The Neuroscience Laboratory, Johnson Space Center (JSC), implemented three integrated Detailed Supplementary Objectives (DSO) designed to investigate spatial orientation and the associated compensatory responses as a part of the EDOMP. The four primary goals were (1) to establish a normative database of vestibular and associated sensory changes in response to spaceflight, (2) to determine the underlying etiology of neurovestibular and sensory motor changes associated with exposure to microgravity and the subsequent return to Earth, (3) to provide immediate feedback to spaceflight crews regarding potential countermeasures that could improve performance and safety during and after flight, and (4) to take under consideration appropriate designs for preflight, in-flight, and postflight countermeasures that could be implemented for future flights.

OPERATIONAL INVESTIGATIONS

Motion Perception Reporting (DSO 604 OI-1)

Preflight, in-flight, and postflight self- and surround-motion perception and motion sickness reports were collected from crew members, using a standardized Sensory Perception Questionnaire [1-2] and Motion Sickness Symptom Checklist. These reports included quantitative estimates of perceived self motion and surround motion associated with (1) voluntary head/body movements in flight, during entry, and immediately postflight, and (2) exposure to motion profiles in a Tilt Translation Device (TTD), and in a Device for Orientation and Movement Environments (DOME) located in the Preflight Adaptation Trainers (PAT) Laboratory at JSC [3]. Verbal descriptions of perceived self motion and surround motion were reported in flight, during entry, and at wheels stop, using a microcassette voice recorder.

This investigation involved four experiment protocols. One protocol using the TTD-PAT device and a second using the DOME-PAT device were performed before

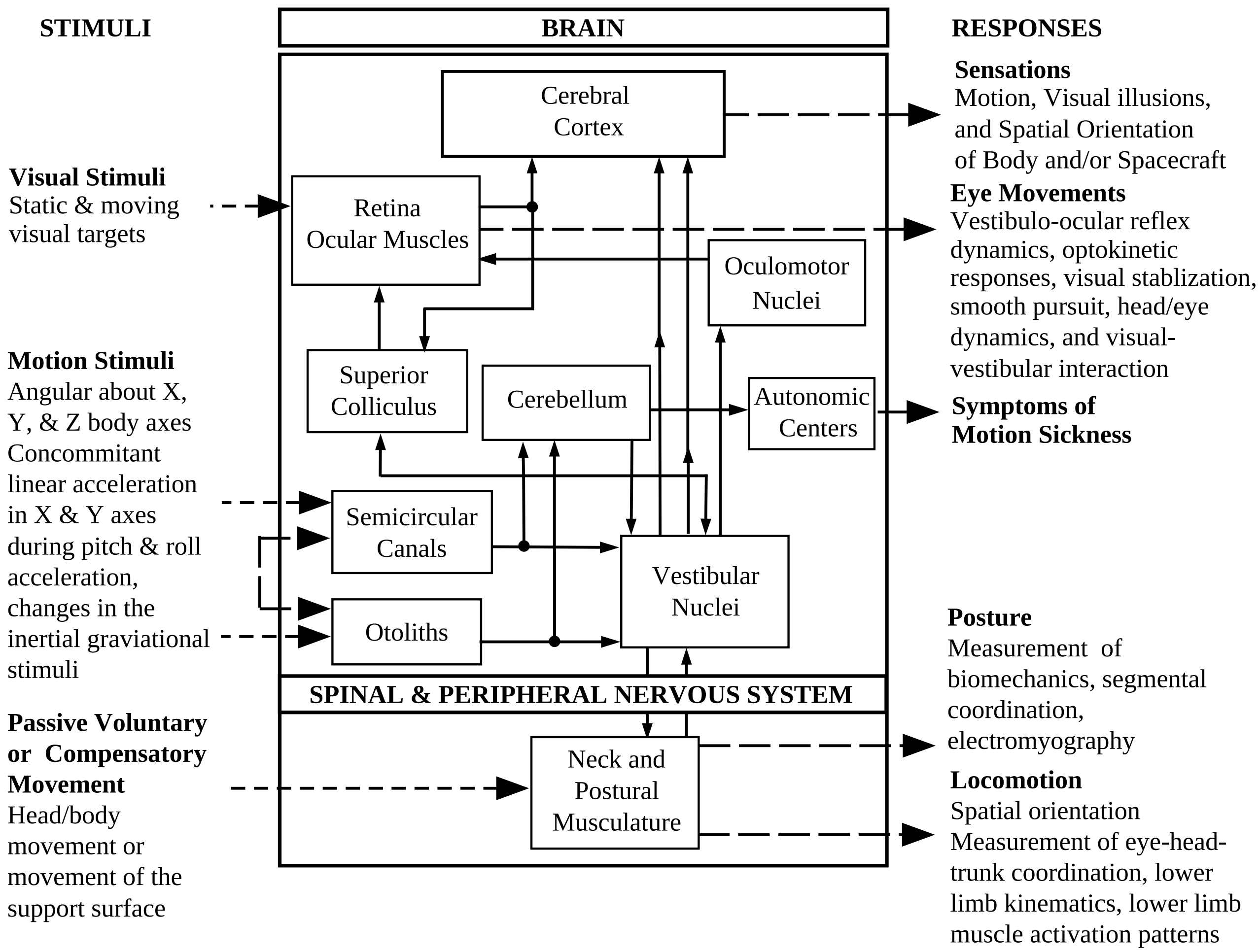

Figure 5.1-1. Stimulus and response make-up of spatial orientation with a schematic of the neural substrate.

flight for training and data collection, and again after flight for data collection. A third protocol, involving voluntary head/torso movements, was performed during flight and immediately after wheels stop at landing. A fourth, head-only movement, protocol was performed during the Shuttle entry phase of the mission.

Self-motion and surround-motion perception and motion sickness reports were collected from crew members, before, during, and after flight, using a standardized Sensory Perception Questionnaire [1-2] and Motion Sickness Symptom Checklist.

Visual-Vestibular Integration (Gaze) (DSO 604 OI-3)

A number of experiment paradigms, classified as voluntary head movements (VHMs), in which the head was unrestrained and free to move in all planes during all phases of the study, were standardized. The investigations included the performance of (1) target acquisition, (2) gaze stabilization, (3) pursuit tracking, and (4) sinusoidal head oscillations. Where possible, each of these four protocols was performed on all subjects during all phases of the spaceflight.

Target acquisition protocols used a cruciform tangent system where targets were permanently fixed at predictable angular distances in both the horizontal and vertical planes. To facilitate differentiation, each target was color coded (±20° green, ±30° red, etc.) corresponding with the degree of angular offset from center. For all target acquisition tasks, the subject was required, using a time optimal strategy, to look from the central fixation point to a specified target indicated by the operator (right red, left green, up blue, etc.) as quickly and accurately as possible, using both the head and eyes to acquire the target. When target acquisition was performed in flight, measurements were obtained using a cruciform target display that attached to the Shuttle middeck lockers. In all cases, surface electrodes were placed appropriately on the face, and eye movements were obtained with both horizontal and vertical electrooculography (EOG). Head movements were detected with a triaxial rate sensor system mounted on goggles that were fixed firmly to the head. Both head movements (using a head-mounted laser) and eye movements were calibrated using the color coded acquisition targets.

The gaze stabilization protocol used transient rotational displacement of the head following occlusion of vision while the subject consciously attempted ocular fixation on a just viewed wall-fixed target. With this simple paradigm, verbal instruction controlled the subject's conscious intent, while the brief stimulus favored constancy of mental set during the testing regime. The short transient stimuli in this protocol had the added merit of simu natural patterns of head movement and minimizing long term adaptive effects.

Pursuit tracking, performed as preflight and postflight trials, used two separate protocols: (1) smooth pursuit and (2) pursuit tracking with the head and eye together. In addition, these protocols were followed using predictable, sinusoidal stimuli and unpredictable stimuli with randomly directed velocity steps. These protocols were selected to study the smooth pursuit eye movement system and to evaluate how this system interacted with the vestibulo-ocular reflex (VOR). The sinusoidal pursuit tracking tasks were performed at moderate (0.333 Hz) and high (1.4 Hz) frequencies to investigate alterations in the strategy used to dictate the relative contributions of eye and head movement in maintaining head-free gaze. The unpredictable pursuit tracking used position ramps that varied in direction, maximal displacement, and velocity. Sinusoidal head oscillations (head shakes) in both the horizontal and vertical plane were made at 0.2, 0.8, and 2.0 Hz with (1) vision intact, in which the subject maintained a fixation point in the primary frontal plane, and (2) vision occluded, where the subject imagined the fixation point available with vision.

Unless indicated otherwise, all 604-OI3 protocols were completed a minimum of three times prior to flight, two times in flight , and up to five times following flight. The last preflight test session was typically within ten days of flight. In-flight measurements were performed within 24 hours following orbital insertion and again within 24 hours of landing. After flight, the first measurement was about 2 hours after wheels stop. Subsequent postflight measurements were obtained 3, 5, 8, and 12 days after landing. The 5, 8, and 12 day postflight tests were completed only when the subjects had not returned to preflight baseline values.

Recovery of Postural Equilibrium Control (DSO 605)

To accomplish DSO 605, two experiment protocols were performed by 40 crew members before, during, and after Shuttle missions of varying duration. The first of these protocols focused primarily on reactive responses by quantifying the reflex (open loop) response to sudden, stability threatening, base of support perturbations. The second protocol focused on sensory integration by quantifying the postural sway during quiet upright stance with normal, reduced, and altered sensory feedback. All participating subjects performed the two protocols on at least three occasions before flight to provide an accurate, stable set of 1-g control data from which postflight changes could be determined. All subjects also performed the two paradigms on up to five occasions after flight to capture the full sensory motor readaptation time course. Postflight tests began on landing day, as soon after Orbiter wheels stop as possible, and were scheduled on an approximately logarithmic time scale over the subsequent eight days.

Of the 40 astronaut subjects studied, 11 were from short duration (4-7 day) missions, 18 from medium duration (8-10 day) missions, and 11 from long duration (11-16 day) missions. Seventeen of the subjects were first time (rookie), and 23 were experienced (veteran) fliers. The effect of spaceflight on neural control of posture was inferred from differences between preflight and postflight performance in all subjects. The effect of mission duration was inferred from statistical comparison between the performance of the short, medium, and long duration mission subjects. The effect of previous spaceflight experience was inferred from statistical comparison between the performance of the rookie and veteran fliers.

Effects of Spaceflight on Locomotor Control (DSO 614)

Five primary protocols were employed to accomplish the goals of DSO 614. The first protocol was designed to determine if exposure to the microgravity environment of spaceflight induced alterations in eye-head-trunk coordination during locomotion. In this protocol, astronaut subjects were asked to walk (6.4 km/h, 20 s trials) on a motorized treadmill while visually fixating on a centrally located earth-fixed target positioned either 2.0 m or 0.30 m from the eyes. In addition, some trials were also performed during periodic visual occlusion. Head and trunk kinematics during locomotion were determined with the aid of a video-based motion analysis system.

Also using a treadmill, the second protocol sought to investigate strategies used for maintaining gaze stability during postflight locomotion by examining the lower limb joint kinematics recorded during preflight and postflight testing and the contribution of the lower limb movement on the head-eye-trunk coordination obtained in the first protocol.

The third protocol was designed to provide a systematic investigation of potential adaptations in neuromuscular activity patterns associated with postflight locomotion. Both before and after flight, the subject was tasked with walking on the treadmill at 6.4 km/h while fixating a visual target 30 cm away from the eyes. Surface electromyography was collected from selected lower limb muscles, and normalized with regard to mean amplitude and temporal relation to heel strike. Protocol 4 investigated changes in spatial orientation ability and walking performance following spaceflight. The subject was asked, before and after flight, to perform a goal-directed locomotion paradigm consisting of walking a triangular path with and without vision. This paradigm involved inputs from different sensory systems and allowed quantification of several critical parameters during a natural walking task. These included orientation performance, walking velocities, and postural stability. The fifth protocol examined the ability of a subject to jump from a height of 18 cm with either eyes open or closed. Three trials in each visual condition were conducted. Body segment measurements were obtained with the aid of a video-based motion analysis system.

DESIGN AND DEFINITION OF PROTOCOLS

The protocols outlined above were established by the Neuroscience Laboratory at JSC, under the guidance of a standing international neuroscience Discipline Implementation Team (DIT), listed in Table 5.1-1. Table 5.1-2 outlines the tests and protocols that were the final product generated through association with the DIT. The DIT participated in semiannual reviews of the science and results of the ongoing neuroscience EDOMP investigations. Where appropriate, the investigations were modified to conform to suggestions and recommendations from DIT members.

Very few subjects on a mission participated in each neuroscience DSO, thus limiting comparisons between investigations (Appendix B). This limitation was partially overcome by the relatively large number of subjects participating in each of the investigations.

SUMMARY

A complete and detailed review of each of the DSOs summarized in this introductory section is presented in the pages that follow. Overall, the results across and within neuroscience investigations show that spaceflight has a profound effect on sensory-motor function. Gaze is disturbed during target acquisition and during locomotion. Dynamic postural responses show clearly a link between duration of flight and prior spaceflight experience, and the magnitude/duration of postural ataxia. Thanks to the EDOMP we have gained valuable knowledge which allows us to obtain a better understanding of the neural substrate controlling sensory-motor function and the effects of spaceflight on that neural substrate. Importantly, the results of the neurosensory investigations have helped define our need for sensory-motor countermeasures. Overall, NASA's commitment to the EDOMP represents perhaps the most advanced set of operational investigations in support of our crew members' health and safety.

Table 5.1-1. Extended Duration Orbiter Medical Project (EDOMP) neuroscience discipline implementation team members

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Table 5.1-2. EDOMP neuroscience investigations

Operational Investigation	*Mission*
DSO 604 OI-1: Mission Perception Reporting (22)	STS-41 (1), STS-39 (1), STS-48 (1), STS-44 (1), STS-45 (2), STS-49 (1), STS-46 (1), STS-52 (1), STS-53 (1), STS-54 (2), STS-57 (3), STS-70 (2), STS-73 (2), STS-74 (2), STS-72 (1)
DSO 604 OI-3: Visual-Vestibular Integration as a Function of Adaptation DSO 604 OI-3A: Preflight, In-flight, Entry, Wheels Stop, Postflight (3) DSO 604 OI-3B: Pre-/Postflight (26) DSO 604 OI-3C: Preflight, Inflight, Postflight (10)	STS-43 (1), STS-44 (1), STS-49 (1), STS-52 (2), STS-53 (1), STS-54 (1), STS-57 (2), STS-51 (1), STS-58 (1),STS-61 (3), STS-62 (4), STS-59 (2),STS-65 (2), STS-68 (2), STS-64 (3), STS-66 (2), STS-67 (3), STS-69 (3), STS-73 (2), STS-72 (2)
DSO 605: Recovery of Postural Equilibrium Control Following Space Flight (40)	STS-28 (1), STS-36 (2), STS-41 (2), STS-35 (3), STS-40 (2), STS-43 (3), STS-44 (2), STS-49 (3), STS-52 (3), STS-53 (1), STS-54 (3), STS-56 (2), STS-51 (1), STS-58 (2), STS-62 (1), STS-65 (2), STS-68 (1), STS-64 (1), STS-67 (2), STS-69 (2), STS-73 (1)
DSO 614: The Effects of Space Flight on Eye, Head, and Trunk Coordination During Locomotion DSO 614A: Head/Gaze Stability (32) DSO 614B: Locomotor Path Integration (9)	STS-43 (2), STS-48 (2), STS-44 (2), STS-45 (4), STS-49 (3), STS-50 (2), STS-46 (4), STS-47 (3), STS-53 (2), STS-57 (3), STS-58 (1), STS-62 (2), STS-65 (2), STS-68 (2), STS-64 (3), STS-66 (2), STS-67 (2)

( ) Denotes number of subjects
*Does not include those subjects for which only partial data were collected.

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