# Self-Attitude Awareness Training: An Aid To Effective Performance In Microgravity and Virtual Environments?'

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## ABSTRACT

This paper describes ongoing development of training procedures to enhance self-attitude awareness in astronaut trainees. The procedures are based on observations regarding self-attitude (perceived self-orientation and self-motion) reported by astronauts. Self-attitude awareness training is implemented on a personal computer system and consists of lesson stacks programmed using Hypertalk with Macromind Director movie imports. Training evaluation will be accomplished by an active search task using the virtual Spacelab environment produced by the Device for Orientation and Motion Environments Preflight Adaptation Trainer (DOME-PAT) as well as by assessment of astronauts' performance and sense of well-being during orbital flight. The general purpose of self-attitude awareness training is to use as efficiently as possible the limited DOME-PAT training time available to astronauts prior to a space mission. We suggest that similar training procedures may enhance the performance of virtual environment operators.

## INTRODUCTION

The self-attitude awareness training project described in this paper is designed to support the Preflight Adaptation Training (PAT) Project currently being pursued at NASA's Johnson Space Center. The overall goal of the PAT Project is to reduce hazards and discomfort associated with space motion sickness and to mitigate entry and post-landing self-orientation and locomotion disturbances. The specific goal of self-attitude awareness training is to enhance astronauts' ability to manipulate spatial mental representations and to perform mental simulations of movement through the unusual environment of microgravity. We hypothesize that these training procedures will enhance astronauts' abilities to determine their own orientation, motion and location. Successful training should facilitate adaptation to microgravity and transitions between microgravity and normal gravity on earth.

Training procedures are based on reports regarding self-attitude from astronauts in microgravity and in the Device for Orientation and Motion Environments Preflight Adaptation Trainer (DOME-PAT). Sensory information about spatial relationships in and movement through microgravity and virtual environments differs from that which is ordinarily detected in a normal terrestrial environment. Objects that ordinarily exhibit a constant visual polarity on earth, such as computer monitors and people, may be seen in unusual orientations. Relationships between visual scene polarity and the observer's internal body axes may differ from those ordinarily experienced. Changes in scene orientation and motion as a consequence of real or virtual locomotion may conflict with orientation and motion changes, or the absence thereof, detected by the astronaut's inertial receptors, including the vestibular and somatosensory receptors. Perceived self-orientation and self-motion with respect to the environment, a phenomenon analogous to what pilots call "attitude awareness," may be disturbed by discordant spatial information. These disturbances are likely to have negative effects on the performance and comfort of astronauts.

### Astronauts' reports

During space Shuttle missions, astronauts enjoy looking though a window on the flight deck at the earth as it passes "under" the spacecraft. This is possible because the orbiter is usually oriented so that it flies "upside-

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down;" that is, the roof of the orbiter's cabin is oriented toward the earth. Astronauts often "lie" on the cabin ceiling when they look though the window. After a few minutes, they report feeling as though they are lying prone with the earth "down." However, when they look back into the spacecraft, the cabin seems to be "upside down." Early in the mission, this is disturbing. After a few days in orbit, however, most astronauts readily shift between earth-referenced down and cabin-referenced down. This and several related observations suggests that for most astronauts self-attitude awareness improves as the mission progresses.

Recent observations suggest that astronauts develop enhanced ability to perform mental rotations during orbital space flight. Berthoz (1992) reported a study of mental rotation while subjects were exposed to the stimulus rearrangement of microgravity during a Russian space mission. Cosmonauts were trained to asymptotic mental rotation performance using a procedure described by Shepard and Metzler (1971) prior to flight. These cosmonauts exhibited significantly improved mental rotation performance during the mission relative to that observed preflight.

Prior to a recent mission an astronaut who had flown once eight years previously participated in a series of DOME-PAT training sessions. In this apparatus, graviceptor output is held constant by keeping the trainee stationary or permitting movement around an axis orthogonal to gravity. A visual scene produced by a computer-generated imagery (CGI) system and representing a complex enclosed space is presented to her/him via projectors and a dome/screen. Scene movement depends on attempted head movements by the trainee and/or inputs to hand controllers. However, gravity information transduced by the otolith and somatosensory receptors does not change, thereby achieving graviceptor stabilization. (Details regarding the rationale for and implementation of the PAT apparatus can be found in Parker, 1991, and Harm and Parker, in press.)

During training the astronaut practiced using the hand controller to move virtually through a simulated Spacelab. He practiced moving along the walls and ceiling, attempting to view those features as a floor. He practiced moving into the dark tunnel, which connects the Spacelab to the middeck, then turning around, re-emerging into the Spacelab, and identifying his orientation after re-emergence. Following the space mission, he returned to the DOME-PAT and attempted to perform the same activities.

This astronaut's performance in the simulator apparently was affected by his experience in microgravity. Preflight, he reported some orientation and motion difficulties in the virtual Spacelab environment. He found it difficult to view the Spacelab walls as a floor and he reported that the hand controller was difficult to use. One day after the mission, he remarked that it was easy to perceive the ceiling or walls as a floor and that "locomotion" through the virtual Spacelab using the hand controller was "intuitive." A week after landing, he reported greater difficulty in mentally rotating the virtual Spacelab; also, using the hand controller to move about in the Spacelab became less intuitive than it had been immediately post flight.

## METHOD

### Stacks

Self-attitude awareness training is being implemented using on a personal computer (Macintosh Quadra 700 4/230 with 20 MB RAM) and a color monitor (NEC 5FG). "Lessons" are being programmed using Hypercard stacks with Macromind Director movie imports. Four set of stacks are currently being developed: (1) overview — purpose and general procedures, (2) object orientation and motion, (3) self- (eye-point) orientation and motion, and (4) eye-point recognition

### General procedure

"Clicking on" a TITLE CARD results in presentation of a randomly selected animation or scene (stimulus) from a subset of possible stimuli. The stimulus is followed by presentation of a RESPONSE CARD displaying four written descriptions of possible stimuli, only one of which is correct. The trainee selects his/her best guess regarding the correct stimulus description with a key stroke. Response accuracy (correct or incorrect) and reaction time are recorded. When a preset number of trials (stimuli) have been completed, a RESULTS CARD

summarizing response accuracy and latency is presented and the trainee may repeat the current lesson, proceed to the next lesson or quit.

**Object orientation and motion**

The purpose of these stacks is to familiarize the trainee with a 3-D coordinate system for describing orientation and motion. Stimuli consist of animations of a mannequin (nutcracker doll). The animations illustrate rotations (yaw, pitch, roll) and translations (X, Y, Z) from an initial "upright and facing forward" cardinal orientation. Yaw rotations (left or right), pitch rotations (forward or rearward) and roll rotations (left or right) are of $90^0$, $180^0$ or $270^0$ magnitudes. Translations include X-axis (forward or rearward), Y-axis (left or right) and Z-axis (headward or footward).

Four lessons are included in the object orientation and motion stacks:
lesson 1– object orientation and motion from a cardinal position; stimuli consist of rotations and translations from an initial "upright and facing forward" cardinal orientation;
lesson 2 – object orientation and motion from a non-cardinal position; stimulus initial orientations are $90^0$, $180^0$, or $270^0$ rotated in pitch, roll and yaw from the cardinal orientation;
lesson 3 – object orientation and motion, complex motion; stimuli include combinations of rotations and translations starting from the cardinal orientation;
lesson 4 – object orientation and motion, complex motion starting from non-cardinal positions; stimuli include combinations of rotations and translations starting from non-cardinal orientations.

**Eye-point orientation and motion**

The purpose of these stacks is to familiarize the trainee with a 3-D coordinate system for describing eye-point orientation and motion. Stimuli consist of scene animations representing movement of the trainee's eye-point in the Spacelab. Animations include yaw scene rotations (left or right), pitch scene rotations (forward or rearward) and roll scene rotations (left or right) of $90^0$, $180^0$ or $270^0$ magnitudes starting from a cardinal orientation (facing the tunnel entrance). X-axis scene translations (forward or rearward), Y-axis scene translations (left or right) and Z-axis scene translations (headward or footward) are of two magnitudes, 50 cm or 90 cm.

Four lessons are included in the eye-point orientation and motion stacks:
lesson 5 – eye-point orientation and motion from a cardinal position; stimuli include scene rotations and translations starting from a cardinal orientation (facing the tunnel entrance);
lesson 6 – eye-point orientation and motion from a non-cardinal position; stimuli include scene animations starting from non-cardinal orientations.
lesson 7 – complex eye-point orientation and motion; stimuli include combinations of rotations and translations starting from the cardinal orientation.
lesson 8 – complex eye-point orientation and motion from a non-cardinal position; stimuli include combinations of rotations and translations starting from non-cardinal orientations.

**Eye-point recognition**

The trainee will be presented with an object animation from the Object Orientation and Motion Lessons followed by four still images of the Spacelab interior. The trainee's task is to select the Spacelab image that corresponds to the object's current eye point.

**Training evaluation**

Training efficacy will be evaluated using a performance task in the DOME-PAT and by evaluating astronaut performance and sense of well-being during orbital flight. Specifications for the DOME-PAT evaluation task are incomplete but will include the following. The trainee will enter the virtual Spacelab from the tunnel in a randomly determined orientation (facing aft, facing forward, rolled left, and so on. The trainee's task is to move virtually, using the hand controller, through the Spacelab to a specified location and to report the status of a

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display at that location. Evaluation during orbital flight will employ a variation of a currently approved Detailed Supplementary Objective (DSO 468).

## EXPECTED RESULTS

We anticipate the following results: lesson performance, as assessed by percent correct response and response latency, will depend on (a) rotation complexity -- single axis rotation easier than multiple axis rotation, (b) relationship between axis of rotation and everyday activity -- yaw easier than pitch easier than roll, (c) rotation direction -- pitch back easier than pitch forward, and so on; subject's trained with the procedures described above will exhibit improved performance relative to untrained subjects in a DOME-PAT evaluation task; astronauts trained with the above procedures prior to flight will report more rapid development of self-attitude awareness inflight than will untrained astronauts, as assessed by the modified DSO 468 procedure noted previously.

## DISCUSSION

Self-attitude awareness may be based on the activity of a perceptual system that receives inputs from visual, somatosensory and vestibular receptors (Gibson, 1966; Parker, 1991). Activity in this perceptual system permits the subject to answer the questions "where am I" (within an enclosed space) and "how am I moving?" Perception (P) of self-orientation and self-motion with respect to the environment may be dependent on the ability to detect and integrate information regarding three vectors: gravity/linear acceleration - G, visual scene polarity - VS, and internal vectors aligned with the trainee's head or trunk Z axis - IZ. A fourth determinant of perception is the observers' expectations - E - based on his/her own actions. As a first approximation, self-orientation perception may be considered as the weighted sum of these vectors:

$$\text{Equation 1. } P = W_1{}^*G + W_2{}^*VS + W_3{}^*IZ + W_4{}^*E$$

The major value of self-attitude awareness training may be to "loosen" the normal (1 G) congruence between these vectors and/or to alter vector weightings.

### Mechanisms of self-attitude awareness

Research on self-attitude awareness training may elucidate processes and mechanisms examined in cognitive and perceptual psychology including mental rotation, cognitive maps, shape perception learning and affordance-effectivity.

*Mental rotation.* The face of a well-known person is not so easily recognized when his or her photograph is presented upside-down. This observation suggests the following question: How do people recognize familiar shapes when those shapes are in unfamiliar orientations? This and related questions have been reviewed by Howard (1982, Chap. 14) and by Fink and Shepard (1986).

One line of research suggests that in order to recognize shapes that are presented in unusual orientations people must perform mental rotations. Shepard and Metzler (1971) undertook a study in which observers were presented with pairs of figures representing three-dimensional objects. Some pairs represented the same object in different orientations while other pairs represented different objects. The observer's task was to determine whether the figures represented the same or different objects. As suggested by Howard and Templeton (1966), performance of this task may require observers to perform some internal operation equivalent to rotating the memory image of one figure in order to align it with the other figure.

As noted previously, Berthoz (1992) recently reported that cosmonauts exhibit enhanced mental rotation ability during orbital flight. We suggest that the following may be important for understanding Berthoz's finding. In microgravity, cosmonauts can be in orientations and move in ways that are ordinarily not possible on earth. Mental rotation is important for efficient goal-directed locomotion. In microgravity, as on earth, one must orient in order to locomote efficiently. The Shepard and Metzler procedure may be viewed as "passive;" (i.e., beyond pressing a response key whose location is known, no action on the part of the subject is required). It seems unlikely that this passive procedure would invoke the same neural operations as would active locomotion. Learning complex procedures often seems to elicit improved performance on the simpler, component procedures.

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For example, learning calculus greatly improves the ability to perform algebraic operations. Similarly, learning to perform the complex mental rotations associated with locomotion starting from unusual initial orientations may facilitate performance on a passive mental rotation task. Regardless of the specific mechanisms underlying improvement in mental rotation ability during exposure to microgravity, it is likely that such enhanced ability would lead to increased self-attitude awareness.

*Cognitive maps.* The pioneering work of Tolman (1932) led to the recognition that animals and people are able to form "cognitive maps" — internal representations of the spatial layout of an environment. Ordinarily cognitive maps are illustrated from a plan view, for example, a floor plan as seen from above. However, one has only to imagine a familiar building to recognize that a plan view "picture" may not describe adequately retrieval of information from the spatial representations in one's head. Rather, as one imagines the spatial relationships between landmarks, the process seems more like locomotion, like moving one's eye-point though the imagined environment, than like looking at a map or a picture.

The suggestion that internal map processing includes a mental simulation of locomotion/action is consistent with Boer's (1991) report that the time required to reorient with respect to locations on a memorized geographical map increases with the angular displacement of the required reorientation up to angles of $135^{\circ}$. Similarly, Kosslyn (1983) reported that the time required for a subject to scan points on a memorized map increases as a function of the physical distance between the locations specified by the experimenter.

Consider the internal map problem confronting an astronaut in microgravity. The spacecraft middeck floor plan includes an airlock, a stairway and stowage lockers. For an "upright" astronaut looking toward the airlock from the lockers, a leftward yaw movement is necessary to "climb" the stairs to the flight deck. For an "inverted" astronaut in the same location, a rightward yaw movement is required to move toward the stairs. Due to their extensive experience during mission simulations prior to flight, astronauts acquire internal maps representing the shuttle middeck and flight deck and the processing of those internal maps may include a mental simulation of normal locomotion (walking). Locomotion modes and initial orientations prior to locomotion differ greatly in microgravity. Astronauts push and float rather than walk; locomotion may be initiated from an "inverted" orientation near a ceiling rather than "upright" on the floor. Consequently, new internal maps and mental simulations of locomotion may be required for rapid, accurate real locomotion in microgravity, and these may lead to improved self-attitude awareness.

*Shape perception.* Self-orientation depends on visual scene information including visual polarity, linear perspective, perspective transformations as a consequence of eye-point changes, shading, texture gradient and occlusion.

The accuracy and latency of self-attitude awareness responses may depend on the subject's ability to learn to detect "generic" surfaces (shapes). Nakayama and Shimojo (1992) note that visual shape stimuli are fundamentally ambiguous; i.e., a given physical shape may generate an infinite set of image shapes on the retina depending on the subject's eye-point with respect to the physical object. They suggest that shape recognition is determined by the "principle of generic image sampling." Some image shapes are generic: they have a high probability of occurring during normal locomotion as the subject changes his/her eye-point with respect to physical objects. Other images are labeled "accidental" because they have a lower probability of occurring.

Nakayama and Shimojo suggest further that shape recognition/perception is determined by generic images through a Bayesian-like conditional probability perceptual learning processes. They propose specifically that people learn conditional probabilities of the form p (Sn ∣ Im), where Im is the generic image associated with a particular shape - Sn) and that perception is determined by learning which shape image that is most frequently associated with a particular physical shape, that shape's most generic image.

Nakayama and Shimojo's analysis assumes that locomotion normally takes place in a gravitational environment and ignores the fact that many objects are visually polarized (i.e., have a "normal" orientation with respect to gravity). The set of eye-points from which an subject ordinarily views objects as well as the orientation of the objects themselves is restricted. For a freely floating subject, a new set of "generic" images may be produced as a consequence of the fact that eye-points are no longer restricted by gravity. For example, a tree generates a generic

image on earth that may be labeled "lateral" (i.e., the image a child produces when asked to draw a tree). In microgravity, that same tree generates two generic images, one "lateral upright" and the other "lateral inverted."

The basic issue considered here differs from that addressed by Nakayama and Shimojo. They are concerned with object perception, whereas this paper is concerned with self-attitude awareness or what might be called eye-point perception. However, both classes of perception may be determined by an subject's learning of conditional probabilities for generic images. Following Nakayama and Shimojo's model, the goal of self-attitude awareness training may be described as enhancement of the ability to detect and respond appropriately to generic images produced by polarized shapes in environments where the subject's locomotion is not restricted by gravity.

*Direct perception and affordance-effectivity.* Based on the seminal work of Gibson (1966), ecological psychologists have proposed two new basic concepts: direct perception and affordance-effectivity. Direct perception theory (see Wertheim, 1990) implies that the visual world consists of a structured pattern of light, an *optic array* that includes fundamental structural features called *invariants*. According to this approach, motion perception is understood as the process of *picking up* invariants from the optic array. As suggested above, direct perception theory can readily be extended to self-orientation and self-motion detection by inertial receptors.

Affordance-effectivity has been described as the properties of the environment that support goal-directed activities such as sitting, walking, and so on (Shaw et al., 1990). We consider affordance-effectivity as a subclass of mental simulations which are among our most common conscious experiences. For example, we simulate social interactions with our children and colleagues in the form "if I say X, she is likely to reply Y, then I might suggest Z, etc." Mental simulations regarding action, including locomotion, are examples of affordance-effectivity. For example, on earth the Spacelab ceiling has no important affordance for action; however, in microgravity that same ceiling affords "pushing off" to float across the environment. Alterations of self-attitude awareness in microgravity may include development of new action/environment mental simulations (affordances) that are unique to that environment.

We are currently developing evaluation procedures designed to examine alternative predictions the foregoing mechanisms of self-attitude awareness.

## ACKNOWLEDGMENTS

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