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Perception of longitudinal body axis in microgravity during parabolic flight

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Abstract

It has been proposed that an internal representation of body vertical has a prominent role in spatial orientation. This investigation investigated the ability of human subjects to accurately locate their longitudinal body axis (an imaginary straight body midline running from head to toes) while free-floating in microgravity. Subjects were tested in-flight, as well as on ground in normal gravity in both the upright and supine orientations to provide baseline measurements. The subjects wore a goggle device and were in total darkness. They used knobs to rotate two luminous lines until they were parallel to the subjective direction of their longitudinal body axis, in the roll (right/left) and the pitch (forward/backward) planes. Results showed that the error between the perceived and the objective direction of the longitudinal body axis was significantly larger in microgravity than in normal gravity. This error in this egocentric frame of reference is presumably due to the absence of somatosensory cues when free-floating. Mechanical pressure on the chest using an airbag reduced the error in perception of the longitudinal body axis in microgravity, thus improving spatial orientation.

Keywords: Gravity; Spatial orientation; Reference frames

Under terrestrial conditions, the force of gravity provides a constant reference for orientation, determining unequivocally the direction of up and down [15]. As a result, under 1-g conditions the gravitational vertical is chosen as a primary reference for the self-estimate of body and object orientation relative to the environment. When subjects are in free-fall, such as during the weightless conditions of orbital or parabolic flight, there are no gravity-determined tactile cues related to body orientation and no gravity-determined otolith cues about head orientation. This can give rise to spatial disorientation and space motion sickness [22].

Personal reports by astronauts and cosmonauts suggest that there are two categories of individuals: those who come to rely on the visual verticals of the spacecraft to gauge their body orientation and those who rely on their body longitudinal axis for the direction of up and down [14,25]. The former feel upright when they are aligned with the architectural verticals of the spacecraft with their head toward the “ceiling”. The latter feel upright regardless of their actual orientation relative to the spacecraft, i.e., they always perceive the surface below their feet as “floor”, and the surface above their head as “ceiling”. This observation indicates that the longitudinal body axis provides a strong subjective reference for vertical in these subjects. According to Mittelstaedt [23], an internal representation of the longitudinal body axis (z-axis), i.e., a virtual line running from the head to the feet, would be used as a reference frame for the perception of body orientation. In the absence of graviceptive (i.e., vestibular, cutaneous, and visceral) and visual cues, such as during free-fall in darkness, the egocentric body vertical is the default frame of reference [11].

Several studies demonstrated that blindfolded subjects in the microgravity phase of parabolic or orbital flight had difficulty in estimating their position relative to their surroundings [7,21,19]. When asked to point to landmarks in the spacecraft, after a couple of angular displacements, they are completely guessing [31,12]. Lackner and Graybiel [20] have shown, however, that although their sense of spatial position is lost, a sense of relative body configuration is preserved. As soon as tactile

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cues are present on the body surface, a sense of orientation is restored. Reports from spaceflight experiments indicate similar experiences in orbital flight [5,31].

We hypothesized that misperception of the orientation of the longitudinal body axis (LBA) could occur in subjects placed in microgravity and that mechanical pressure applied to the torso might reduce this misperception. Accordingly, 14 healthy subjects (7 women, 7 men, aged 25–49) were tested during free-floating in parabolic flight and in normal gravity in an upright position. Ground-based tests were also performed in a supine position, when otolith cues and other graviceptive cues are minimized [29].

The experiments was carried out during two campaigns of parabolic flights of the European Space Agency onboard the Airbus A300 Zero-G. This aircraft is capable of flying parabolic trajectories during which the entire cabin is in microgravity (less than $10^{-2}g$) for about 20 s. Subjects had given their informed consent to participate in this study in accordance with the guidelines of the local ethics committee, and had passed the equivalent of an Air Force Class III medical examination.

The measurement device, developed and constructed by student researchers, consisted of an opaque plastic 'salad bowl' mated with a diving mask. Inside the bowl, two luminous lines produced by linear LEDs could be alternately presented in an otherwise dark field. Each line could be rotated about its center, one about the roll axis and one about the pitch axis, by means of a knob mounted to the device. A digital display that indicated the line positions was mounted on the outside of the goggle. The readout was adjusted so that the instrument zero corresponded to both lines in the vertical direction. Spatial resolution of the measurement was 0.1°. The lines subtended a viewing angle of about 12°, and were seen at a distance of about 30 cm. The "roll" line was presented in front of the subject in the eyes-front direction. The "pitch" line was presented at about 30° to the right of eyes-front, so that subjects could use perspective and parallax distance cues for its adjustment in pitch.

The mask was adjusted on the subject's face so that a vertical rod attached on the outside of the mask was perpendicular and midpoint to a line joining both shoulders. The subjects were tested in free-floating to eliminate orientation-related graviceptive cues (Fig. 1). While free-floating, the operator offset the line and the subjects' task was to set it parallel to "an imaginary straight line running through the vertical center of the body going from head to feet". When satisfied with the setting, they closed their eyes and removed their hand from the knob. This served as a signal to the observer to record the setting and offset the target. Each subject was tested for a total of 10 parabolas. Tactile pressure was applied to the subject's chest during the first or the second series of five parabolas, randomly distributed across subjects. During these parabolas, subjects wore a light (230 g) life jacket containing an inflated airbag (dimensions 30 cm × 30 cm × 15 cm), which delivered a force of about 60 N and a pressure of about 2700 Pa on the chest. The life jacket was fixed to the chest with thin fabric ties fastened on each side of the chest and over the shoulders using slip knots in the back. During the ground-based testing, the life jacket was only used in the upright posture condition, since the knots would have altered the pressure on the back of the torso in the supine position. About eight measurements of the LBA perception were taken during each test conditions. Still photographs of subjects' posture were also taken. Measurements were discarded from the analysis when it was determined that the subject's head was not kept in alignment with the trunk, especially during the free-floating condition.

Fig. 1. Artist's drawing illustrating the goggle device and its use within the aircraft. Note the knob and the readout on the goggle device. The tethers between the subjects' waist and the aircraft floor were used as a safety precaution to prevent them from drifting away from the operator, who was firmly anchored to the aircraft floor. Drawing Philippe Tauzin, SCOM, Toulouse (France).

The flight participants tested had little to no previous experience of parabolic flights. However, none of the subjects showed symptoms of motion sickness during the flight. Most of them had taken prophylactic medication (a combination of scopolamine and caffeine) before boarding the plane. Subjects who took the medication were also tested in normal gravity on board the plane when it was flying straight and level, and the results were not different from those obtained earlier on the ground. Accordingly, it is unlikely that the medication influenced the measurements obtained in microgravity.

None of the subjects expressed any difficulties in carrying out the experimental task either under gravitational or weightless conditions. The settings were made at the same speed in both conditions. All subjects stated that they had no clue about their orientation relative to the aircraft when making the settings while free-floating.

In Fig. 2 are shown the values representing the errors between the objective LBA and the subject's settings across all subjects