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# Resolving Perceptual Conflicts: The Cognitive Mechanism of Spatial Orientation

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**The cognitive mechanisms of spatial orientation were studied in an experiment varying different perceptual cues systematically: the retinal, the visual background, the vestibular, and the somatosensory information. Verbal descriptions of visually presented arrays were required under different head positions (straight/tilt) and under different gravity conditions (1 G/micro G). Results for two subjects clearly show that different coordinate systems are used under the two gravity conditions. Under 1 G it is the gravitational vertical which is chosen for primary reference, whereas under microgravity retinal information is primary. Conflicts between competing pieces of sensory information are solved by weighting the perceptual cues differently. The finding that consistent assignment can be made immediately after first exposure to weightlessness indicates that mental representations of space can be used independently of perceptual input parameters.**

PERCEPTION OF SPACE and communication about space requires computation of different types of information such as visual, vestibular, and somatosensory information. These information types are processed at different levels in the human system. Initial processing of perceptual information involves the physiological level. Interpretation and integration of different perceptual cues, however, takes place at a higher cognitive level, where these cues are weighted and mapped onto some stored knowledge or cognitive representation of space. In order to achieve unambiguous assignment of spatial coordinates of what has been perceived or what has been talked about, the cognitive system has to establish a reference frame with respect to which concepts, like "up" and "down" and "left" and "right," are used. It has been argued that, for the development and the use of cognitive representations of space, the external features of the world are of major importance. In particular, it is held that the Earth's gravitational field is one of the most fundamental constraints for the choice of reference frames (8,9).

When trying to specify the perceptual constraints in dealing with spatial representations, there are at least three types of perceptual cues which are considered to be involved in choosing a reference frame: the retinal coordinates, the intrinsic coordinates of the visually perceived object or background, and the gravitational coordinates defined via vestibular and/or somatosensory input information. It is assumed that possible conflicts between these different types of information are solved by weighting the cues differently (5).

The conflict of gravitational vertical and visual background information has been examined quite extensively. The perception of a vertical line, for example, is influenced by off-vertical visual frames (10), by off-vertical striped visual background information (1), as well as by rotating visual displays (4).

Experiments studying the effect of conflicting gravitational vertical and retinal vertical information varying the perceptual input parameters by the observer's head tilt are not univocal: from a letter identification task, where letter orientation varied at different angles from the retinal vertical, Corballis *et al.* (2) concluded that subjects generally adopted a reference frame which lay between the retinal and the gravitational frame. In a mental rotation study under head tilt, however, it was found that subjects used a frame which exerts a stronger influence of the gravitational than the retinal coordinates (3).

Studies examining the mechanisms of assigning spatial coordinates when gravitational vertical and the body-defined vertical were brought into conflict reported that during

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a target line setting task subjects used the gravitationally-defined vertical as reference when standing upright; when in supine position they used the body-defined vertical (7). When body-defined vertical and retinal defined vertical were brought into conflict during a luminous line setting task, deviations from objective body-defined vertical were greater in supine than in vertical body position when the head was straight (6). This suggests that assignment of the body's vertical can more easily be made when nonconflicting gravitational information is available. When the head was tilted, however, no significant difference was found between vertical and supine position. Although the authors do not draw conclusions from this latter result, it seems to suggest that sensory information of the neck receptors provides a cue that is strong enough to solve induced conflicts between the body-defined vertical and the retinal-defined vertical when additional gravitational cues are not present.

The primary goal of the present study was to determine the impact of these different perceptual factors on spatial orientation and, moreover, on the cognitive representation of space. In order to test the influence of gravitation, in particular, the experiments reported here used weightlessness as the critical variable. The general experimental approach was to vary four different factors systematically: (a) the retinal information, that is, two intrinsic nonoriented objects (two balls) whose connecting axis could be rotated to different angles with respect to the retina's vertical meridians; (b) the visual background information, that is, two intrinsically oriented objects (two linedrawing trees) which could be displayed to the left and to the right of the balls or rotated to some angle; (c) the somatosensory information of the neck receptors was varied by the head's tilt; and (d) gravity information was varied by conducting the task under 1 G and microgravity condition.

## EXPERIMENT I

### Materials and Methods

*Subjects:* The subjects were two male payload specialists (R.F. and W.O.) who were part of the crew of the D1 Mission executed in 1985.

*Stimuli and Apparatus:* The stimuli were visual arrays varying factors (a) and (b). As factor (a), a white ball and a black ball of the same size were displayed under different orientations in the center of the visual field. As Factor (b), two intrinsically oriented objects (two linedrawing trees) were displayed to the left and to the right of the balls (e.g., Fig. 1). The orientation of the (virtual) connecting axis of the two balls varied in 22.5° steps clockwise off-vertical, resulting in 16 different positions ranging from 22.5° to 360°. The trees orientation varied in 45° steps off-vertical, resulting in 8 different positions ranging from 45° to 360°. Ball and tree positions were completely crossed. These stimuli were presented in random order in a specially designed apparatus (VISOS). This hardware consists of a viewing aid mounted on a commercial camera, using an Olympus Camera OM-2 plus Olympus Winder 2 with a remote control, a Pentax Stereo Viewer II, a microcassette recorder (Pearlcorder S801), and a pair of goggles (Schweisser-Schutzbrille, Firma Auer, Berlin). A window is cut in the back of the camera and the Stereo Viewer is placed over this window. The eye pieces of the Stereo Viewer are built into the goggles.

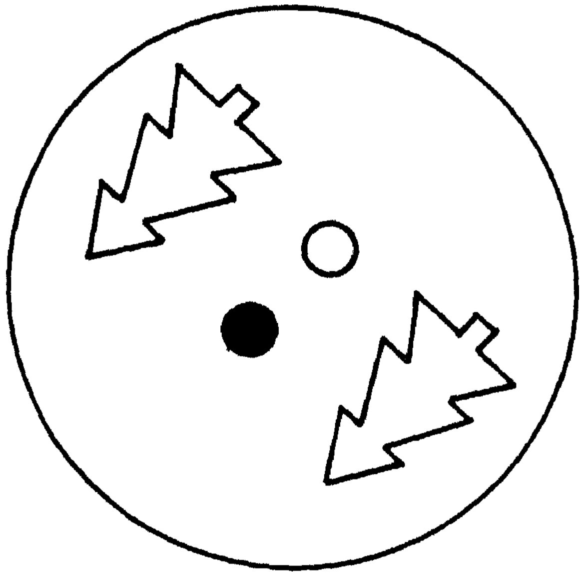


Fig. 1. Example of test item.

For safety reasons, the glass front of the goggles is replaced by a piece of metal. In order to allow incidence of light without any other visual information, a frosted "glass" (polycarbonate) is put over the lens of the camera. A winder which is operated by a remote control transports developed (Agfa FO 71P) film containing the stimulus material. A microcassette recorder (Pearlcorder S801) is attached to the bottom of the winder. The winder as well as the cassette recorder operated on a battery basis. During the experiment the VISOS is attached to the subject's head using an adjustable head band.

*Procedure:* Subjects were required to describe the position of the "white ball" with respect to the "black ball" by using words like "above," "below," "left," "right," and combinations of these. They were asked to respond as accurately and quickly as possible. No further instruction was given, in order to allow an unbiased choice of reference. The exposure duration of each trial, as well as the presentation of the next trial, were controlled by the subject by pressing the remote control button. Subjects' verbal responses were recorded for later analysis. There were three experimental conditions varying factor (c) gravity: preflight, inflight, and postflight tests. During preflight and postflight sessions subjects were standing upright with their heads upright. During the two inflight sessions subjects were free floating. A first session was performed immediately after launch (L+2 hours) in the middeck; a second session was performed on L+1 day in the spacelab. Subjects were required to keep their heads straight, that is, aligned with their body axis.

### Results

Verbal responses were analysed with respect to what type of reference was chosen under the different conditions. The verbal responses clearly indicated that neither subject used the intrinsically oriented objects as a reference frame during any of the flight conditions. *Preflight* both subjects used a reference frame which was indicated by the gravitational, the body-defined and the retinal vertical. Their descriptions with respect to this reference are basically without error (W.O.: 0.8% errors; R.F.: 2.8% errors) (Table I).

TABLE I. EXPERIMENT I—VISUAL AXIS ROTATED IN STEPS OF 22.5° WITH HEAD STRAIGHT: PERCENTAGE OF RESPONSES WHICH WERE INCORRECT WITH RESPECT TO THE PREDOMINANTLY CHOSEN REFERENCE.
(L = Launch, R = Return, h = hours, d = days)

| Time of performance | Preflight | Inflight | | Postflight | |
|---|---|---|---|---|---|
| Subject | L−85d | L+2h* | L+1d | R+18 h* +19 h | R+108 d +104 d |
| R.F. | 0.8 | 14.3 | 18.1 | 11.4 | 3.2 |
| W.O. | 0.8 | 2.6 | 2.9 | 5.7 | 2.3 |

* During these sessions shortened versions of the original stimulus set were used.

*Inflight* both subjects used the coinciding retina-defined and body-defined vertical as reference. R.F., in contrast to W.O., displays a significant increase of descriptions which are incorrect with respect to this chosen reference when preflight and inflight tests are compared (L+2h: $\chi^2 = 6.64$; $p < 0.01$ and L+1d: $\chi^2 = 7.43$; $p < 0.01$). Although these descriptions are also incorrect with respect to the visual background frame when interpreted intrinsically, R.F.'s responses are clearly influenced by this type of information. Most of these inadequate descriptions are adequate when intrinsically oriented objects are interpreted as horizontal (90° and 270°) or as vertical (180° and 360°) coordinates. In the L+2 hour session 100% of the responses, and in the L+1 day session 47.37% of the incorrect responses are correct with respect to these coordinates.

Immediately *postflight* both subjects used the coordinates jointly indicated by gravitational, body-defined, and the retinal vertical. On R+18 hours R.F. demonstrated a significant decrease of inadequate descriptions with respect to this predominantly chosen gravitational reference ($\chi^2 = 6.74$; $p < 0.01$). Most of the descriptions (75%), which are inadequate with respect to the predominantly chosen reference, are adequate when visual context information is interpreted as nonoriented vertical or horizontal coordinates. On R+1 day, performance in this task was back to the preflight level. Subject W.O. showed no significant changes in rate of inadequate descriptions.

### Discussion

The results from the two subjects show, first, that consistent assignment of spatial reference is possible under the absence of gravity information. Second, it is clear that the coordinates provided by the intrinsically oriented contextual frames are not chosen as reference. When different visual cues—such as the retinal orientation and the visual contextual frame information—are in conflict, this conflict seems to be more easily solvable when the retinal vertical coincides with the body-defined and gravitational vertical, as in 1 G, than when the gravitational cues are absent, as in microgravity. Note, however, that the qualitative analysis supports this only for one of the two subjects. It is assumed that a response latency analysis which is currently being carried out, will reveal whether this is also true for W.O.

## EXPERIMENT II

In order to determine whether it is the retinal or the body-defined coordinate system which is used in weightlessness, a second experiment was designed. The critical variation in this experiment was the position of the head. While in 1 G the head tilt condition does not permit separating the body-defined and the gravitational vertical systems when subjects are standing upright; the head tilt condition in micro-G should permit this separation.

### Materials and Methods

*Subjects:* The subjects participating in this experiment were the same as for Experiment I.

*Stimuli and Apparatus:* The apparatus used in this experiment was the same as in Experiment I. The stimulus material differed from that used in the former experiment in that the connecting axis of the two balls altered in two steps of 7° clockwise and counterclockwise from the vertical (360° and 180°), and the horizontal (90° and 270°). Including vertical and horizontal positions, these objects are displayed in 20 different axis orientations. The visual background information provided by two intrinsically oriented objects (trees) are positioned at the vertical (360° and 180°), the horizontal (90° and 270°), and one 7° step clockwise and counterclockwise off-vertical and off-horizontal axis, resulting in 12 different positions. Positions of intrinsically oriented and nonoriented objects were crossed. In addition, nonoriented objects were displayed in all positions without any background information.

*Procedure:* In this experiment, as in Experiment I, verbal descriptions of visually presented arrays were required. The subject's head was straight in preflight, inflight, and postflight conditions. Both subjects performed one preflight session and two inflight sessions—one immediately after launch (L+2h), a second on L+1 day. Subject W.O. performed two postflight tests (R+19 hours and R+104 days). Subject R.F. performed three postflight tests (R+18 hours, R+6 days, and R+108 days). In order to bring into conflict the body-defined and the gravitationally-defined vertical, inflight and postflight tests were also performed with the subject's head tilted to the left and right sides. Both subjects responded to half of the stimulus items when the head was tilted by approximately 30 to 35° to the left, and to half of the stimulus material when the head was tilted to the right. During inflight sessions subjects were free floating, during pre- and postflight sessions subjects were standing upright with their heads tilted to the left or to the right.

### Results

In general, the subjects' response patterns under the head straight condition for the stimulus material with visual axis rotated in steps of 7° replicated the findings from Experiment I, where rotation was done in steps of 22.5°. Preflight and postflight, both subjects used coordinates indicated by the gravitational, the body-defined vertical, and the retinal vertical, which under head straight condition coincide. In weightlessness, both subjects used the retinal vertical as reference, which coincides with the body-defined axis. The visual contextual frame reference provided by the intrinsically oriented objects (trees) was not used in either condition.

As in Experiment I, subject W.O. did not show significant changes in the correctness of verbal descriptions with respect to the chosen reference. Subject R.F. showed significant increase of inadequate descriptions when comparing preflight and inflight tests: for L+2 hours ($\chi^2 = 4.3$; $p < 0.05$) and for L+1 day ($\chi^2 = 7.43$; $p < 0.01$), cf. Table II. There is a difference between correctness of responses in preflight and in first (R+18 h), second (R+6 day), and third (R+108) postflight sessions ($p < 0.01$). In contrast to preflight tests, postflight tests showed a slight influence of visual contextual information in choosing the reference frame.

The results of the head tilt condition clearly show what type of reference is used under the different gravity conditions for this type of task (Table III). The analysis considers the subjects' verbal responses. These could be correct with respect to the intrinsic visual frame, the retinal-defined vertical, or the body-defined vertical, which under 1 G coincides with the gravitational vertical. Responses could be correct with respect to any of the references or to combinations of these. Fig. 2 gives an example. Since visual background information was not chosen as primary reference, it was not considered in this analysis. Results for the two subjects are displayed in Fig. 3a and b. From these data it is evident that references used in weightlessness are distinct from those used when standing upright in 1 G. Both subjects use predominantly the retinal (head) coordinates as reference in weightlessness, whereas in 1 G they use the gravitational and body-defined reference. In particular, the difference of the distribution of chosen references between weightlessness and postflight test on R+1 day is statistically highly significant for W.O. ($\chi^2 = 5.04$; $p < 0.05$), and significant for R.F. ($\chi^2 = 28.2$; $p < 0.001$). Both subjects used the retinal reference significantly more often than the body-defined reference in weightlessness; whereas, in 1 G immediately postflight on R+1 day the gravitational and body-defined reference was used. The findings from the postflight test on R+104 days for W.O. and R+108 days for R.F. indicate that the strong tendency to choose the gravitational and body-defined coordinates as reference in 1 G is not an immediate aftereffect of having experienced weightlessness, but rather their normal behavior. However, R.F. seems to demonstrate a certain aftereffect of weightlessness concerning the strength of this behavior: immediately postflight (R+1 day) gravitational reference is chosen more often than on both other postflight occasions [on R+6 days ($\chi^2 = 24.54$; $p < 0.001$) and on R+108 days ($\chi^2 = 24.54$; $p < 0.001$)].

TABLE II. EXPERIMENT II—VISUAL AXIS ROTATED IN STEPS OF 7° WITH HEAD STRAIGHT: PERCENTAGE OF RESPONSES WHICH WERE INCORRECT WITH RESPECT TO THE PREDOMINANTLY CHOSEN REFERENCE.
(L = Launch, R = Return, h = hours, d = days)

| Subject | Preflight | Inflight | | Postflight | | |
|---|---|---|---|---|---|---|
| | L−85 d | L+2 h | L+1 d | R+18 h | R+6 d | R+108 d +104 d |
| R.F. | 2.8 | 16.7 | 18.8 | 19.4 | 20.8 | 13.9 |
| W.O. | 8.3 | 2.7 | 6.9 | 9.7 | — | 9.7 |

TABLE III. EXPERIMENT II—VISUAL AXIS ROTATED IN STEPS 7° WITH HEAD TILT: PERCENTAGE OF RESPONSES WHICH WERE INCORRECT WITH RESPECT TO THE PREDOMINANTLY CHOSEN REFERENCE.
(L = Launch, R = Return, h = hours, d = days)

| Subject | Inflight | Postflight | | |
|---|---|---|---|---|
| | L+1 d | R+1 d | R+6 d | R+108 d +104 d |
| R.F. | 28.5 | 0 | 23.6 | 23.6 |
| W.O. | 23.6 | 14.1 | — | 9.7 |

## Discussion

The findings from the two subjects tested here substantiate that during weightlessness and 1 G different reference systems for spatial assignment are used. In weightlessness subjects use predominantly the retinal vertical as reference,

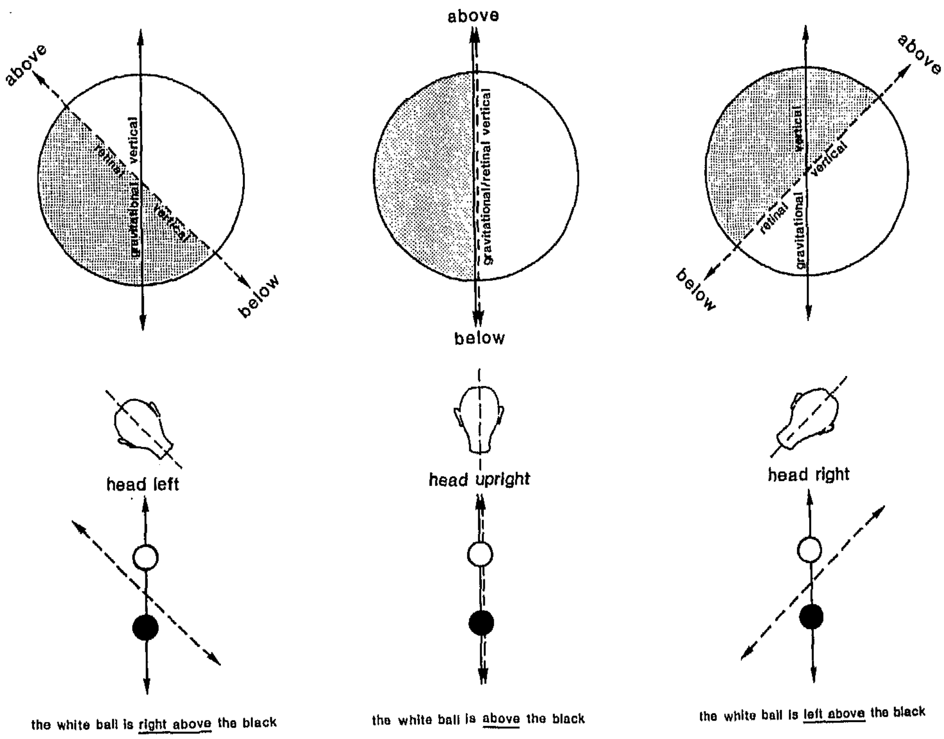
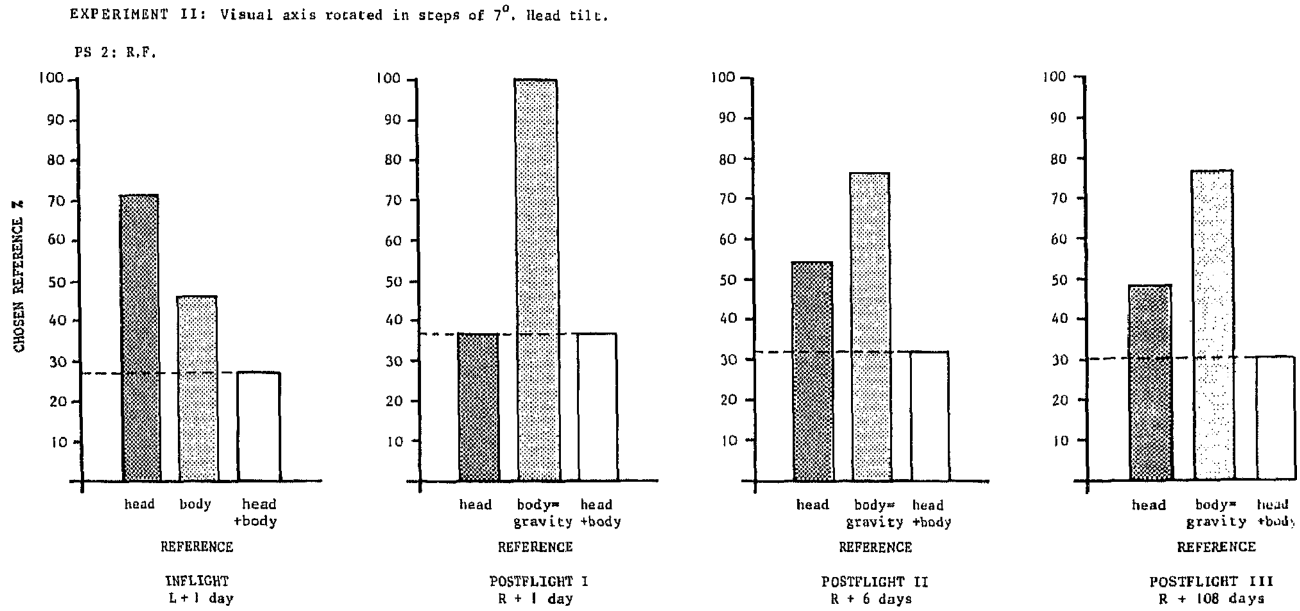



Fig. 2. The upper circles display the retinal and gravitational vertical when the head is upright (middle) and when tilted to the left and to the right side (left and right circle). The lower part of the figure demonstrates how identical visual arrays are described under different head positions when the gravitational vertical is consistently chosen as primary reference.



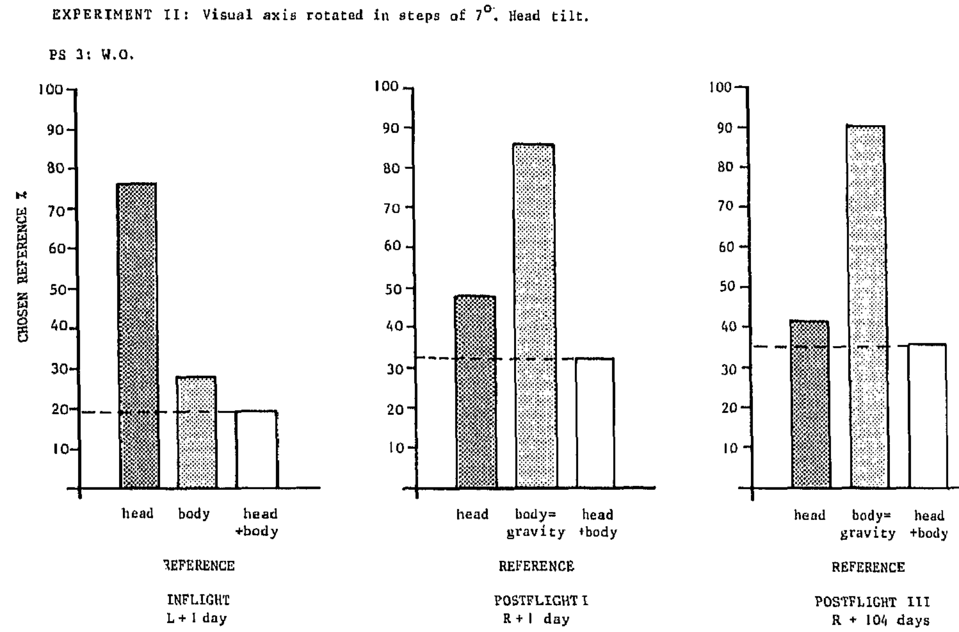




**Fig. 3a and b. Percentage of chosen reference. 3a (upper) is for subject R.F.; 3b (lower) is for subject W.O. *Head* = verbal responses which are correct with respect to the retinal (head) coordinates. *Body* = verbal responses which are correct with respect to the body-defined (in zero G also the gravitational) coordinates. *Head + body* = verbal responses which are correct with respect to both the retinal and the body-defined coordinates, e.g. when connecting axis of the balls is 7° and the head is tilted to the right by approximately 30 to 35°, the correct description with respect to each of the coordinates would be "right above."**

whereas on Earth, when standing upright, they use the gravitationally defined vertical which is the body-defined vertical.

Experiments conducted by the authors with a number of control groups suggest that gravitational reference is dominant whenever unambiguous gravitational cues are available. When sitting upright, subjects always used the gravitational vertical (simultaneously with body-defined and retinal-defined vertical) as reference. When lying on their sides, subjects predominantly used the gravitational vertical which, for this condition, was different from the retinal and the body-defined vertical. These findings show that even when there are two of three cues which suggest the same vertical, this vertical is not necessarily used as reference.

The combined data from the control groups and the two subjects discussed here indicate that, although on-Earth gravity plays a dominant role for the choice of reference frames, mental representations of space can be used adequately, even when gravity is absent. The finding that adequate and consistent spatial assignment is possible immediately after first exposure to microgravity suggests that cognitive representations are not entirely reconstructed on the basis of new perceptual information. Instead, it seems that the cognitive system uses already established representations onto which new input information is mapped. Following this line of reasoning, adaptation may be described as a process of fixing new mapping procedures from given inputs to existing representations. As a precondition for such fast adaptation processes, internal representations have to be highly abstract in order to allow their usage independent of external modality-specific input factors.

## CONCLUSION

The conclusions that can be drawn from this study are twofold. First, the data support the assumption that unambiguous spatial assignment is achieved by a cognitive weighting of the different perceptual cues. Possible conflicts between different types of information are solved by giving dominant weight to one. On Earth, gravity is the dominant cue for spatial assignment. In weightlessness it is the retinal information that plays the dominant role; visual frame information and body-axis orientation are largely ignored. The finding that, in general, adequate spatial assignment can be made in weightlessness indicates that the mental representation of space is highly abstract and can be used independently of different perceptual input parameters.

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