Naturwissenschaften

# Cognitive Processes of Spatial Coordinate Assignment

## On Weighting Perceptual Cues

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Perception of space and communication about space requires the computation of different types of information, such as visual, vestibular and somatosensory information. Although initially processed at physiological levels, integration and interpretation of these different perceptual cues take place at a cognitive level. At this level different types of perceptual information are weighted and mapped onto some stored, cognitive representation of space. In order to achieve unambiguous representations 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", "left" and "right" are used. It has been argued that the earth's gravitational field is one of the most fundamental constraints for such a reference choice [5, 6]. There are, however, at least three types of perceptual cues which are to be considered when choosing a referential 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 likely that possible conflicts between coordinate systems suggested by different types of information are resolved by weighting the cues differentially [3]. Gravitational information, for example, is given a different weight depending upon which information types are brought into conflict [1, 2, 4]. The primary goal of this study was to determine the role of gravity for a spatial coordinate assignment and, moreover, for the mental representation of space. The general experimental approach was to vary four different factors systematically: (a) the retinal information, (b) the visual background information, (c) the somatosensory information and (d) the gravity information.

## Experiment I

### *Method*

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.
The stimuli were visual arrays varying factor (a), represented by two intrinsically non-oriented objects (a white ball and black ball) whose (visual) connecting axis could be rotated to different angles with respect to the retinas' vertical meridians, and factor (b), represented by two intrinsically oriented objects, i.e. two line drawings of trees which could be displayed to the left and to the right of the balls or rotated to some angle. The orientation of the axis of the two aligned balls varied in 22.5° steps, clockwise off-vertical, from 22.5° to 360°, the tree orientation varied in 45° steps off-vertical, from 45° to 360°, resulting in 128 different stimulus items. These stimuli were presented in random order in a specially designed apparatus (VISOS). This hardware consisted 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 and a pair of goggles. Developed films, containing the stimulus material, were presented in the goggles. A microcassette recorder (Pearlcoder S801), which served to record the responses, was attached to VISOS. The winder as well as the cassette recorder operated on a battery basis.
Subjects were required to describe the position of the "white ball" with respect to the "black ball" in each of the visual arrays, using words like "above", "below", "left", "right" and combinations of these. They were asked to respond as accurately and as fast as possible. The exposure duration of each trial as well as the presentation of the next trial was controlled by the subject, who pressed a remote control button. The subject's verbal responses were recorded for later analysis.

  

Tests were performed preflight, inflight and postflight. During preflight and postflight sessions, subjects were standing upright with their heads upright. During the two inflight sessions, subjects were free floating and were required to keep their heads straight, that is, aligned with their body axis, i.e. factor (c) was kept constant in this experiment.

## *Results*

Verbal responses were analyzed with respect to what type of reference was chosen under the different conditions. From the analysis it is clear that subjects did not use the visual background information, i.e. the trees, as a reference frame, either in preflight and postflight tests or in weightlessness. *Preflight*: Both subjects used a coordinate system indicated by three information types: the gravitational, the body-defined vertical and the retinal vertical, all of these being aligned. Their descriptions with respect to this reference were basically without error (Table 1). *Inflight*: Both subjects used the retinal, and at the same time body-defined vertical coordinate system as a reference. In contrast to W.O., R.F. displayed a significant increase of inadequate descriptions when comparing inflight tests with the preflight performance (L + 2 h: $x^2 = 6.64$; $p < 0.01$ and L + 1 d: $x^2 = 7.43$; $p < 0.01$). Most of the descriptions which were incorrect with respect to the primary chosen reference, were, however, adequate when intrinsically oriented objects were interpreted as horizontal (90° and 270°) or as vertical (180° and 360°) coordinates, i.e. there was an effect of visual background information. Immediately *postflight* both subjects chose a vertical system, indicated by the gravitational, the body-defined and retinal coordinates as the primary reference. At R + 18 h R.F. demonstrated a higher rate of inadequate descriptions with respect to the predominantly chosen gravitational reference than preflight ($x^2 = 8.05$; $p < 0.01$). On R + 1 d R.F.'s performance in this task was back to the preflight level.

Table 1. Experiment I: Visual axis rotated in steps of 22.5°. Head straight. Percentage of responses which were incorrect with respect to the predominantly chosen reference (L = Launch, R = Return of Space Shuttle, h = hours, d = days)

| Subject | Time of performance | | | | |
|---|---|---|---|---|---|
| | Preflight | Inflight | | Postflight | |
| | L − 85 d | L + 2 h[a] | L + 1 d | R + 18 h[a] R + 19 h | R + 108 d R + 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 |

[a] During these sessions, shortened versions of the original stimulus set were used

## *Discussion*

The results from the two subjects show that a correct spatial coordinate assignment is possible under the absence of gravity information when retinal and body-defined vertical coordinates were kept aligned. The data, furthermore, indicate that conflicts between competing perceptual cues can be more easily resolved as more information types "conspire" to suggest the same coordinate system as in 1 *g*, where gravitational, body-defined and retinal vertical systems coincide when standing upright with the head straight. Note, however, that the qualitative analysis supports this only for one of the two subjects.

# Experiment II

A second experiment was designed in order to determine the predominant reference choice under different gravity conditions when retinal and body-defined reference systems conflict.

## *Method*

The subjects participating in this experiment were the same as for Experiment I.
The apparatus was the same as in Experiment I. The stimulus materials differed from those used in the former experiment in that the axis of the two intrinsically non-oriented objects (balls) as well as the orientation of the two intrinsically oriented objects (trees) were altered in steps of 7° clockwise and counterclockwise from the vertical (360° and 180°), and the horizontal (90° and 270°), resulting in 240 visual arrays. In addition, the non-oriented objects were displayed in all positions without any contextual frame information.
As in Experiment I, verbal descriptions of visually presented arrays were required with the subject's head straight under preflight, inflight and postflight conditions. Inflight and postflight tests were also performed with the subject's head tilt to the left and right side. 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 postflight sessions, subjects were standing upright with their heads tilted to the left or to the right.

## *Results*

The subjects' response pattern under the *head straight* condition basically replicated the findings of Experiment I (Table 2). *Preflight* and *postflight*: Both subjects used the gravitational vertical coordinate system, which at the same time was the retinal and the body-defined vertical as reference. In *weightlessness* both subjects chose a vertical system, which was indicated by the retinal and the body-defined axes. The visual background information was not chosen as a primary reference. Subject R.F. showed a significant increase of inadequate descriptions when comparing preflight and inflight tests $x^2=4.73$; $p<0.05$ and $x^2=7.43$; $p<0.01$), and when comparing preflight with each of the postflight tests (all comparisons were signifi-

Table 2. Experiment II: Visual axis rotated in steps of 7°. Head straight. Percentage of responses which were incorrect with respect to the predominantly chosen reference

| Subject | Time of performance | | | | | |
|---|---|---|---|---|---|---|
| | Preflight | Inflight | | Postflight | | |
| | L−85 d | L+2 h | L+1 d | R+18 h | R+6 d | R+108 d<br>R+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 |

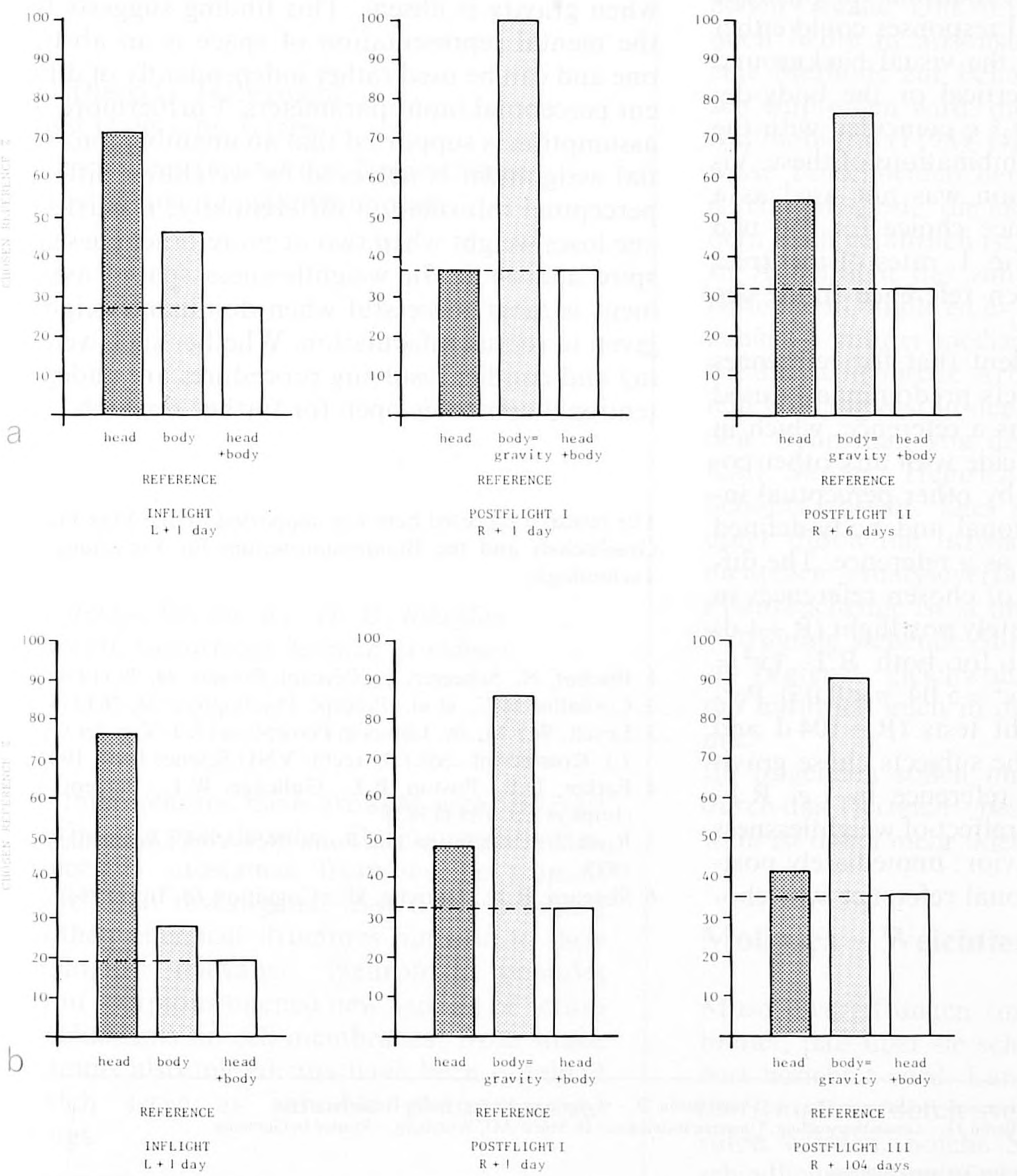


Fig. 1. Experiment II: Visual axis rotated in steps of 7°, head tilt, subjects R.F. (a) and W.O. (b). Percentage of chosen reference. *Head* verbal responses which are correct with respect to the retinal (head) coordinates. *Body* verbal responses which are correct with respect to the body-defined (in 1 *g* also the gravitational) coordinates. *Head + body* verbal responses which are correct with respect to both retinal and body-defined coordinates, e.g. when visual axis of the balls is 7° and the head is tilt to the right by approximately 30° to 35°, the correct description with respect to each of the coordinates would be "right above"

Table 3. Experiment II: Visual axis rotated in steps of 7°. Head tilt. Percentage of responses which were incorrect with respect to the predominantly chosen reference

| Subject | Time of performance | | | |
|---|---|---|---|---|
| | Inflight | Postflight | | |
| | L+1 d | R+1 d | R+6 d | R+108 d<br>R+104 d |
| R.F. | 28.5 | 0 | 23.6 | 23.6 |
| W.O. | 23.6 | 14.1 | – | 9.7 |

cant at $p<0.01$). In contrast to preflight performance, R.F.'s postflight performance showed a slight influence of the visual background information in choosing the reference frame.

The results of the *head tilt* condition unambiguously determined what type of reference was used under the different gravity conditions for this type of task. The subjects verbal responses could either be correct with respect to the visual background information, the retinal vertical or the body-defined vertical, which under 1 *g* coincided with the gravitational vertical, or combinations of these. Visual background information was not used as a primary reference. Reference choice for the two subjects are displayed in Fig. 1, rates of incorrect responses within the chosen reference frame are listed in Table 3.

From these data it is evident that for references in microgravity both subjects predominantly used the retinal (head) vertical as a reference, which in this condition did not coincide with any other coordinate system suggested by other perceptual information. In 1 *g* gravitational and body-defined coordinates were preferred as a reference. The difference of the distribution of chosen references in weightlessness and immediately postflight (R+1 d) was statistically significant for both R.F. ($x^2=28.2$; $p<0.001$) and W.O. ($x^2=5.04$; $p<0.05$). Performance of later postflight tests (R+104 d and R+108 d) indicated that the subjects chose gravitational coordinates as a reference in 1 *g*. R.F. demonstrated a certain aftereffect of weightlessness in the strength of this behavior: immediately postflight (R+1 d), a gravitational reference was chosen more often than on both other postflight occasions (R+6 d: $x^2=24.54$; $p<0.001$ and R+108 d: $x^2=24.54$; $p<0.001$).

## Discussion

The findings from the two subjects tested here, indicate that different reference systems are used for spatial assignment in 1 *g* when standing upright and in microgravity. In weightlessness subjects predominantly use the retinal vertical coordinates as reference, whereas on earth they prefer the gravitationally defined vertical which, when standing upright, coincides with the body-defined vertical.

The combined data show that although gravity normally plays an important role in the reference choice, consistent spatial assignment can be made when gravity is absent. This finding suggests that the mental representation of space is an abstract one and can be used rather independently of different perceptual input parameters. Furthermore, the assumption is supported that an unambiguous spatial assignment is achieved by weighting different perceptual information differentially; a particular cue loses weight when two or more other cues conspire against it. In weightlessness spatial assignment is most successful when dominant weight is given to retinal information. Whether such weighting and conflict resolving procedures are under attentional control is open for further research.

The research reported here was supported by the Max-Planck-Gesellschaft and the Bundesministerium für Forschung und Technologie.


1. Bischof, N., Scheerer, E.: Psychol. Forsch. *34*, 99 (1970)
2. Corballis, M.C., et al.: Percept. Psychophys. *24*, 263 (1978)
3. Levelt, W.J.M., in: Limits in Perception (A.J. Van der Grind, J.J. Koenderink, eds.). Utrecht: VNU Science Press 1984
4. Parker, D.E., Poston, R.L., Gulledge, W.L.: Percept. Psychophys. *33*, 139 (1983)
5. Rock, I.: Orientation and Form. New York: Academic Press 1973
6. Shepard, R.N., Hurwitz, Sh.: Cognition *18*, 161 (1984)


Verantwortlich für den Anzeigenteil: E. Lückermann, Heidelberger Platz 3, D-1000 Berlin 33. – © Springer-Verlag, Berlin-Heidelberg 1986. Springer-Verlag GmbH & Co. KG, D-1000 Berlin 33. – Gesamtherstellung: Universitätsdruckerei H. Stürtz AG, Würzburg. – Printed in Germany.

Das Heft enthält eine Beilage des Gustav Fischer Verlages, Stuttgart