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ANGULAR RELATION OF AXES IN PERCEPTUAL SPACE

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ABSTRACT

The geometry of perceptual space needs to be known to model spatial orientation constancy or to create virtual environments. To examine one main aspect of this geometry we measured the angular relation between the three spatial axes.

We performed experiments consisting of a perceptual task in which subjects were asked to set independently their apparent vertical and horizontal plane. The visual background provided no other stimuli to serve as optical direction cues. The task was performed in a number of different body-tilt positions with pitches and rolls varied in steps of 30°.

The results clearly show the distortion of orthogonality of the perceptual space for non-upright body positions. Large interindividual differences were found. Deviations from orthogonality up to 25° were detected in the pitch as well as in the roll direction.

Implications of this non-orthogonality on further investigations of spatial perception and on the construction of virtual environments for human interaction will also be discussed.

INTRODUCTION

Space constancy, achieved by space transformations continually performed in the CNS, is an amazingly reliable ability providing appropriate interactions with the environment. Three different sources of information are used to determine the transforming operation: 1) visual direction cues, 2) somaesthetical direction cues and 3) vestibular direction cues. To model spatial orientation constancy and to create a virtual environment, we have to analyze each of these cues separately and learn about their interaction. Doing this, we find out that it is not always as accurate as one might expect. In the present study, we tried to perform experiments in which visual direction cues were eliminated, to vary mainly the vestibular stimulation while reducing somaesthetical direction cues as much as possible. While there is abundant data on the perception of the vertical, there are relatively little data on the whole perceptual space and the angular relationships of its axes (Bischof, 1974; Bucher, 1988). The reason for this lack of data might be the assumption that the internal representation of space is orthogonal and, therefore, that measuring the perceived vertical also provides data for the perceived horizontal.

This paper provides evidence to suggest that this assumption may be invalid.

METHODS

Apparatus.

Our apparatus allowed us to tilt human subjects into every desired body position respective to gravity (see fig. 1). The cockpit (diameter 110 cm; width 62 cm) in which the subjects were placed could be turned forward and backward in order to vary the pitch dimension. By turning the whole frame in which the cockpit is suspended, we were able to tilt the subject sideways thus varying the roll dimension. Both possible movements could be performed independently as well as in combination. The actual position of the cockpit and the frame was measured electronically with a accuracy of 0.1°.
To reduce extra-otolith postural influence on space perception the subject was placed in a seat of inflatable pillows. This ensured that the subject remained in a fixed position and afforded a more constant and equal distribution of the pressure that he/she experienced. Stabilized by an easily removable bite-board, the subject looked through binoculars. To ask subjects about their perceived vertical/horizontal an adjustable luminous line/ring was presented. By using a UV light-source and a black background the stimulus seemed to be free floating in space. The device had two degrees of freedom, which could be manipulated by the subject with two control knobs mediating the two step motors. An onboard camera, equipped with a macro optical lens and connected to a video system, was used to independently monitor each eye in order to determine the ocular counter-rolling (procedure described detailed in Bucher, Heitger, Mast & Bischof (1990)).
The entire apparatus was remote controlled by a PDP 11/73. Each experimental session could be prepared off-line for a subsequent fully automatized performance of the experiment.

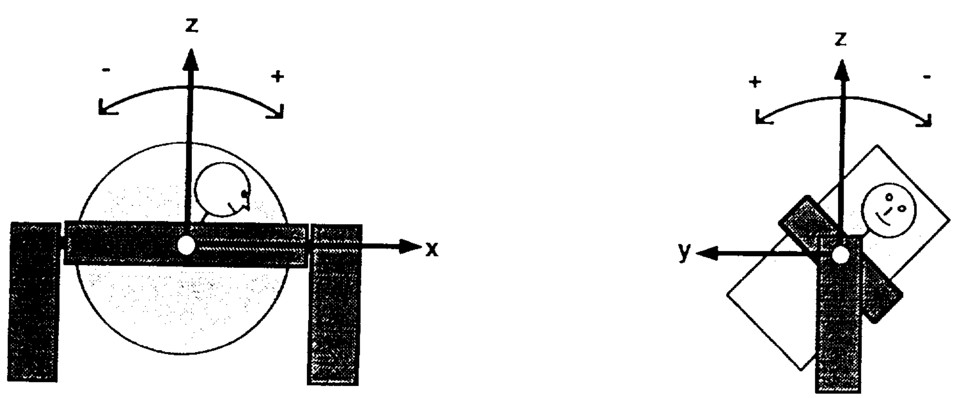


Figure 1a : Pitch

Figure 1b : Roll

Figure 1
Apparatus used to stabilze subjects at various pitch and roll body tilts.
It shows the orientation of the pitch dimension (turning the cockpit, fig. 1a) and the roll dimension (turning the frame, fig. 1b)

Experimental setting.

During each session the subjects were tilted in total darkness to 7 different consecutive body positions from 0° down to 180° in steps of 30°; 2 sessions for roll variation (right or left ear down) and 2 sessions for pitch variation (tilting forward or backward).

In every body position they had to perform the following set of tasks: a) place the luminous line according to the apparent vertical (the line was randomly preset in darkness with a deviation of about 20° in pitch and roll from the objective vertical), b) verify this initial placement twice and, if necessary, adjust this line position (after disappearing and reappearing), c) repeat steps a) and b) with a luminous ring to place according to a horizontal plane. This set of tasks was performed 3 times.

Each session took 55 to 75 minutes from boarding the cockpit. (For a more detailed description see Bucher (1988)). Four subjects took part in the experiments: two females and two males , between 25 and 40 years. Their state of health was checked by standard medical testing.

RESULTS

Roll condition

Due to large *inter*individual differences, as they can be observed often in perceptual experiments, the results will be presented for each subject separately.

Figure 2 displays roll deviations of these settings for the two roll conditions (+180 right ear down, -180° left ear down). For every body position two means were calculated: One for the apparent vertical, which was given by the settings of the luminous line, and one for the apparent horizontal, for which the normal on the plane, described by the settings of the luminous ring, was taken. The solid line represents the values of the vertical, the dashed of the horizontal. The functional characteristics of both curves are about the same whereas they differ clearly in amplitude. More striking, this fact is demonstrated in figure 3, which shows the absolute angular differences between the apparent vertical and the normal on the horizontal in the same conditions (solid line). If the perceptual space strictly would underlie the concept of orthogonality this angular difference would be zero and consequently the solid line identical with the x-axis. Since the standard deviation increases considerably at body tilts larger than 90° it was included in the graph as a reference curve (dotted line); it represents the double standard deviation as a statistical criteria. In general it can be shown that the right angle between the apparent horizontal plane and the apparent vertical is maintained no longer as soon the body is tilted away from its upright position. Although mostly below 10°, deviations as large as 25° are found in body tilts over 90°.

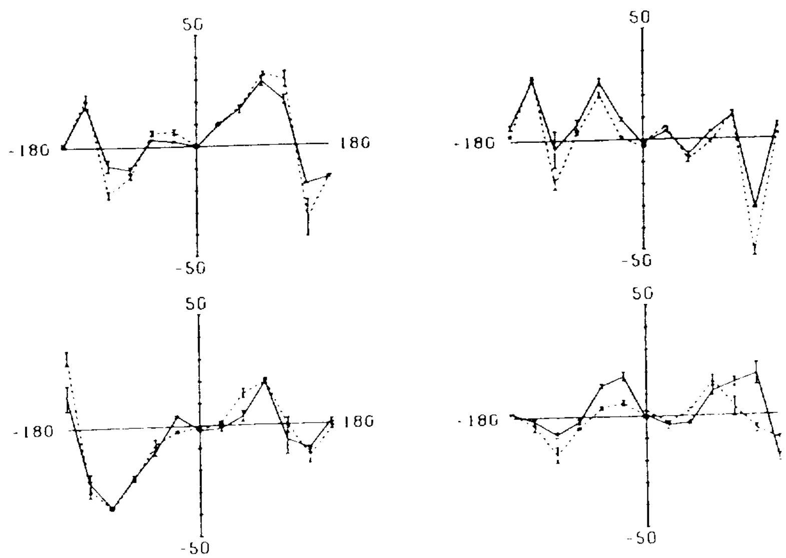


Figure 2
Deviations in the roll dimension under roll conditions:
The settings of the apparent vertical (solid line) and the normal on the apparent horizontal (dotted line).Each crosshair presents data of two independet experiments: roll right ear down (0° to 180°) and roll left ear down (0° to -180°).

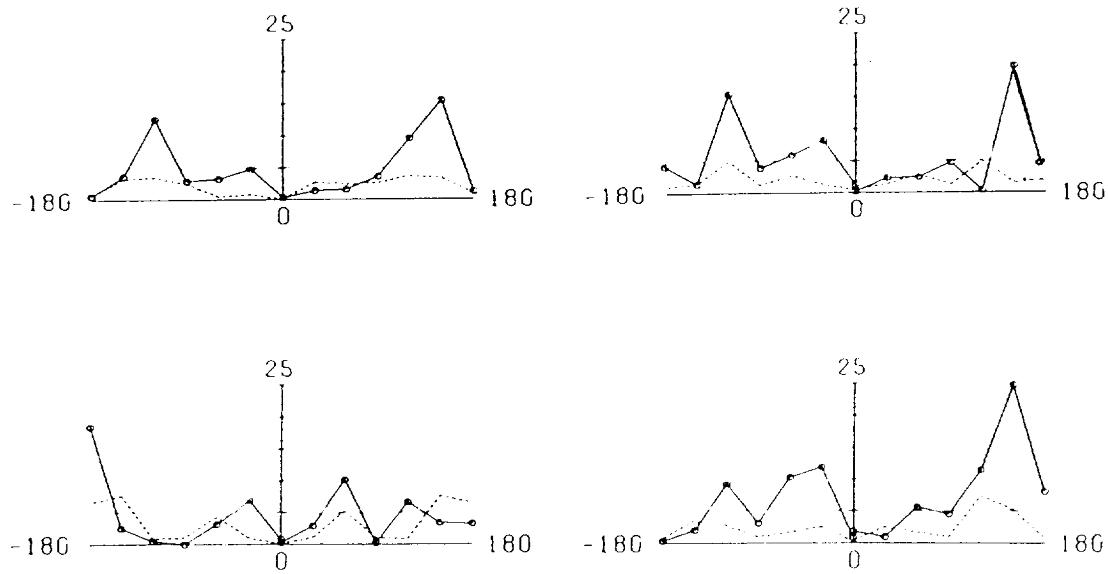
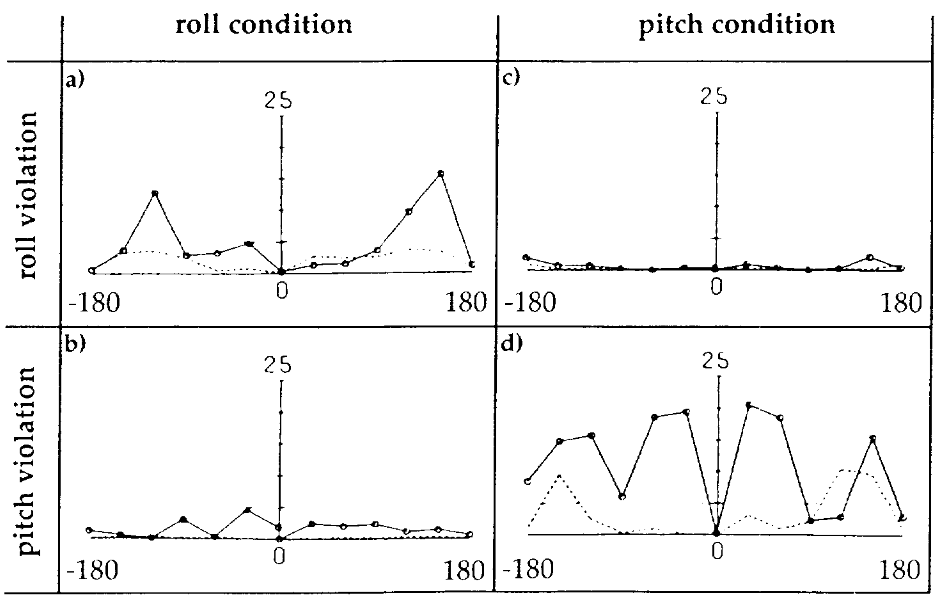


Figure 3
Deviations from the right angle between the apparent vertical and horizontal in the roll dimension under roll conditions from 0° to 180° (right ear down) and from 0° to -180° (left ear down). Subjects 1 to 4.



Figures 4a-d
Subject 1 in pitch and roll conditions:
Pitch and roll violations of orthogonality

Pitch condition

When tilting the body in pure pitch direction similar general characteristics can be observed. The spatial distortions can be broken up in two relevant violations of orthogonality: roll-violation component and a pitch-violation component (see figure 5). There are almost no roll-violations found in pure pitch conditions; the non-varied roll dimension never exceeded 2.5°. This fact stands in contrast to the pure roll conditions, where pitch-violations occurred up to 10° (distortions in the non-varied pitch dimension!). As an example, for 1 subject, figure 4 displays the roll- and pitch-violations in the roll (a and b) and pitch (c and d) tilting conditions; compare fig. 4b with 4c!

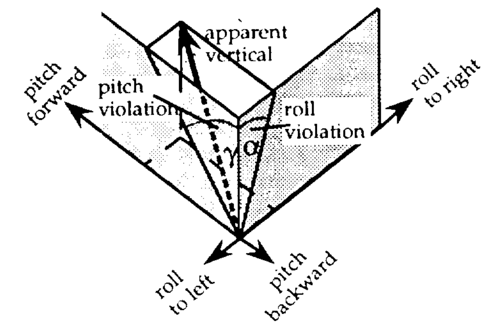


Figure 5
Two components of spatial distorsions:
The pitch violation and the roll violation of orthogonality (solid line).

DISCUSSION AND CONCLUSIONS

As shown before, the largest deviations from the objective vertical and horizontal are found in body tilts over 90° which are of coarse quite unusual in everyday life. This fact fits nice to results published by Ellis, Kim, Tyler, McGreevy & Stark (1985) and Ellis, Tyler, Kim & Stark (1991), who show in three dimensional tracking experiments that the worst performance is found at 125° misalignment between display and control axes. As discussed there, this might be caused by the mental rotation of space.

The present paper focuses on the *angular distortion* of the perceptual space, regardless of the *extent* or the *quality* to which the perceptual system performs space transformations. Although large interindividual differences were found, the apparent space of all our subjects cannot be considered to be orthogonal. One might conceive that the two slightly different tasks, setting a ring horizontal versus setting a line vertical, could be responsible for the distortions, but, in fact none of the tasks was solved systematically better.

Other explanations could be found like e.g. the anatomy of the vestibular organ or, as proposed by Pellionisz & Llinás (1980) and Pellionisz (1987), the non-orthogonal representation of the 3D space in our brain. "Neurobiological evidence shows, ... that the simplest approach (Cartesian coordinate systems erecting spaces with Euclidean geometries) is untenable for natural systems such as the brain" (Pellionisz, 1991). This would imply that, under conditions of unusual body positions, our perceptual system is not able to reconstruct stored spatial data properly. Another set of experiments with a slightly different setting and body tilts with *combined* pitch and roll angles (Bucher, Mast & Bischof, 1991) confirmed these results.

Certainly, the results are partly due to the artificial experimental environment which does not provide any 3-D objects with familiar angular relations. We probably can be sure that e.g. a presented cube still would be recognized as a cube even if we were tilted 150° sideways. However, the data does imply that a subject experiencing the gravitational force not along the body axis can no longer be expected to estimate angles correctly. Since large interindividual differences were found, it might be necessary to calculate individual distortion matrices to describe angular properties of perceptual space and use them to create virtual environments. An attempt to extract the non-orthogonal portion of the space transformation performed by the CNS is presented in Bucher et al. (1991). An alternative to deal with this problem is to provide an appropriate artificial frame of reference on the visual channel "forcing" the brain to a more orthogonal perception.

Generally the visual display format has a large effect on spatial perception. One has specially to take care of this fact when using graphic displays as planning tools. Ellis, McGreevy and Hitchcock (1987) and Ellis, Kim, Tyler, McGreevy & Stark (1985) have clearly shown the benefits of graphical 3-D space information in an air traffic avoidance experiment. Still it might have to be expected that body tilts affect these very same tasks. Therefore we have to be careful in using absolute angles as analog information in physical environments which are likely to be tilted away from the upright as e.g. high performance jet cockpits are.

The errors in depth perception in pure roll conditions might be due to a vestigial compensatory mechanism, the ocular counterrolling: when turning our head sideways our eyeballs try, by counterrolling around their visual axes, to compensate although never matching more than about 10% of the tilt. This causes a vertical shift of the retinal images relative to each other which could be responsible for the observed failure in depth perception. Experiments to clarify this matter are in progress.

Concerning further investigations in spatial perception, this non-orthogonality means that we are to measure all three perceptual axes rather than only the vertical or the horizontal, whenever we want to learn about it under tilted body conditions or in micro- and hypergravity conditions. And, even for experiments with pure roll body tilts we should provide a device to set the apparent direction which allows as well manipulations in pitch direction.

The original motivation for the study was a system analytical approach to the optic-vestibular interaction. In a *descriptive* approach we have pointed out here some important consequences for further analysis of perceptual space properties and implications for virtual environments.

ACKNOWLEDGMENTS

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