A Study of Orientation in a Zero Gravity Environment by means of Virtual Reality Simulation

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Abstract. This study intends to clarify how people acquire visual information and recognize their orientation in a zero gravity environment. An experiment was conducted using virtual reality. In Study 1, each subject was given tasks in which a subject moves through virtual reality from the central room into one of six rooms such as operation room and habitation room. Textures composed by alphabetical letters were stuck on the six surrounding surfaces of the central cubic room. Visual information of the cubic room and the degree-of-freedom of motion were varied, and the subjects' performance was measured. To some extent, the experiment produced a subjective sense of weightlessness. Moreover, we identified different strategies of spatial cognition and behavior under conditions of virtual weightlessness. In Study 2, subjects' orientational skills were tested with pointing and orienting tasks. Subjects followed virtual routes that were constructed of three or four rectangular modules that were connected by the cubical modules. Each subject moved from one end to the other end, and pointed to the start point and reproduced the experienced route using a scale model. The shapes of the routes were changed systematically. Analyses of the results indicate that the ability of special cognition changes with such variables as the number of corners of routes, the geometric number of fields and the number of fields with consideration to the body posture.

INTRODUCTION

The International Space Station (ISS) began construction on Nov. 20, 1998 and will be completed in 2004. When the ISS is completed and starts its operation, crew members will be stationed for three months or more in orbit aboard the ISS. As they stay longer in the space environment, "habitability" for them will become most important in the design of the interior space. One of the problems about habitability in a zero gravity (0G) environment is disorientation. Crew members have difficulty in discriminating between "up" and "down" and more serious disorientations may cause space motion sickness. Crew members rely on visual perception to orient themselves because they can't use their sense of equilibrium in a 0G environment. Although color and the direction of equipment of Space Shuttles or modules has been considered, no systematic study has been conducted on interior space (NASA, 1995).

This study intended to clarify how people acquire visual information and recognize their orientation in a 0G environment by an experiment in which a subject wears a head-mounted display (HMD) and enters a virtual weightless state represented by computer graphics (CG). In Study 1, visual information of a room and the degree-of-freedom of motion were varied to examine the influence of the conditions on such a simple task as movement through several connected modules, and the performance and the behavior of each subject were investigated. In Study 2, pointing and modeling tasks were conducted to study subject orientation along several routes.

STUDY 1

This study intends to examine the influence of visual information and the degree-of-freedom of motion on orientation under conditions of virtual weightlessness. Each subject is set such a simple task as moving through

CP552, *Space Technology and Applications International Forum–2001*, edited by M. S. El-Genk

several connected modules.

Method

The experiment was conducted by means of virtual reality simulation. The specification of equipment, the making of virtual weightless spaces and the procedure of the experiment are described as follows.

Equipment

Experiment spaces were modeled by CG workstation shown in Table 1 and each of six surfaces of the spaces was textured by image-editing software. The image of the room was presented to a subject, who sat down in the reclining chair, through a HMD (Figure 1). With VR software, a subject can enter into the CG-generated room and move around by operating a controller in hand. The controller is an input device with six-degree-of-freedom, and a subject can move to front and rear (Z-axis), right and left (X-axis), and the upper and the lower (Y-axis) and rotate on each axis by controlling the ball on the controller (Figure 2).

TABLE 1. Specification of equipment.

	Manufacturer	**Products**
Hardware	SGI	O2 R10000/250MHz (Graphic workstation)
	Labtec	Spaceball 2003 (Control Device)
Software	Alias Wavefront	Explorer Professional (Modeling)
	Media Lab	Clovis VR (Virtual Reality)
Head-Mounted Display	Shimadzu	See-Through Vision STV-ES
Digital Video	SONY	WV-D10000

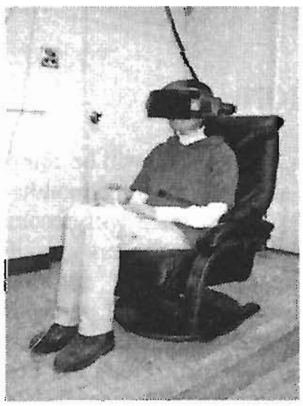


FIGURE 1. A Subject wearing a HMD.

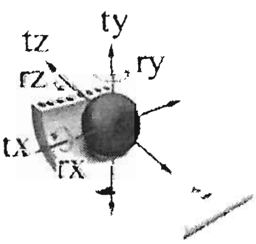


FIGURE 2. Controller.

Procedure

A cubic room of 3x3x3 meter in size was modeled by CG software, and each of six surfaces has texture composed by different letter of the alphabet. A gray circle, which is represented as a hatch to other room, is placed the central part of each surface, and a subject can enter six rooms such as operation room, habitation room and workroom (Figure 3, 4). While getting used to operation of the controller, a subject moves through the gray circle from the central cubic room to the six adjacent rooms and memorizes the location of each room. Then, a subject was asked to do a series of tasks to move from one of the six rooms to the other rooms via the central cubic room (it took about five minutes). This experiment consisted of five sessions and visual information of the cubic room and the degree-of-freedom of motion were varied as shown in Table 2. The letters of the alphabet used to make the textures of the central cubic room and the arrangement of the six rooms were changed in every setting.

The performance of the tasks and the subjects' behavior were investigated and an interview was conducted after the experiment. The data for the first study were collected from 20 students, of whom 11 were male and 9 were female.

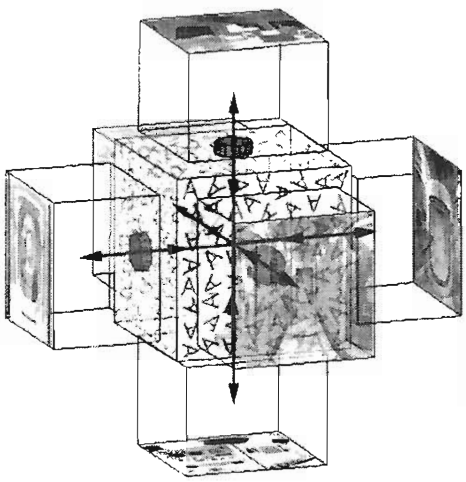


FIGURE 3. Experiment model.

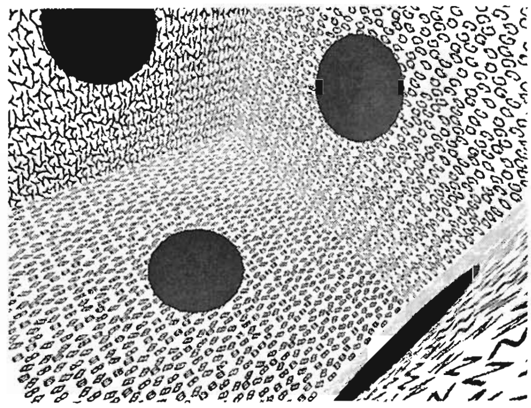


FIGURE 4. Experiment image (Setting 5).

TABLE 2. Experiment settings.

Settings	Floor and ceiling color	Direction and row of the alphabet	Flexibility of viewpoint's	Number of accessible rooms
1	No	Random	Ground*	4
2	No	Random	Space	4
3	No	Grid	Space	6
4	Colored	Random	Space	6
5	No	Random	Space	6

(Notes) "Ground" means the flexibility of a motion was restricted to **four**
(Translation of front and rear, right and left and looking around, up and down)

Preliminary experiment

In order to examine the validity of the simulation, a preliminary experiment was conducted. In this experiment, the results of the following settings 1 and 2 were compared. In the setting 1, which test wayfinding performance on the ground, the degree-of-freedom of motion was restricted to four; horizontal movement to front and rear, right and left, and looking around, up and down. Whereas in the setting 2, which simulated a weightless state, the subjects allowed to have two more degree-of-freedom of motion; vertical movement to up and down and rotation around Z-axis. It was revealed that some subjects mistook the surfaces which were initially located up and down (ceiling and floor) for walls which had entrances to other rooms. Thus, this virtual weightless state was valid to some extent.

Results

Although the influence of the five different conditions on the subjects' performance was not very clear due to the variance among subjects, most subjects seemed to recognize their posture easier in setting 4 which gave a clue by colored ceiling and floor.

From the interview at the end of the experiment to know how the subjects memorize the rooms behind, four main types of strategies for spatial cognition were obtained:

1. The rooms behind the surface were judged by the letters.

2. One surface was memorized as an anchor point and the layout of other rooms was memorized by spatial relation to it.
3. Each adjacent surface was memorized, although these orientations were not memorized.
4. Two surfaces facing to each other were memorized and these orientations were also memorized.

After the session of setting 5, each subject was asked to make a scale model (10cmx10cm) whose surface layout was identical to the experimented cubic space.

From these results, the subjects using strategy type 4 was good at both making model and identification of the rooms behind. On the other hand, the subjects using strategy type 1 was not good at making models but identification of the rooms behind.

Moreover, Figure 5 shows that the different behaviors of two subjects in a task of the session 3. The subject A, using strategy type 4 was conscious of one's body orientation in the space and did not rotate around more than one axis at the same time. By contrast, the subject B using strategy type 1 does not care about the orientation in the space and rotate around more than two axes at the same time, i.e., he/she moved diagonal to the axes of the space.

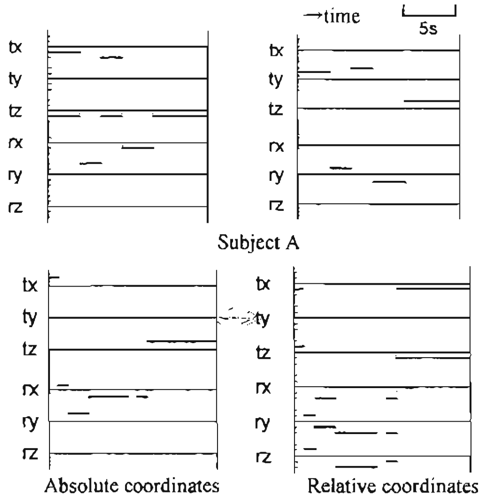


FIGURE 5. Behaviors of two subjects.

STUDY 2

The previous study shows subjects who were conscious of one's body orientation in the space understood the space well. It was thought that movement especially in the vertical direction influenced on the orientation because movement in the vertical direction is unfamiliar in a gravity environment on the earth. In Study 2, pointing task and modeling task were conducted in several routes to examine individual orientational skills.

Method

The routes were constructed of three or four rectangular parallelepiped modules (3x3x15 meter) which were connected by the cubical modules (3x3x3 meter). The difference in the shape of routes might be influenced on a subject's orientation. Each subject moved from one end to the other end, and pointed to the start point and reproduced the experienced route using a scale model. Although the equipment used in this experiment was the same as that of the previous study, in order to represent the motion like weightlessness more, inertial movement was programmed in parallel translation ("front and rear", "right and left" and "upper and lower"). Since operation became difficult, rotational inertia was not taken in. Moreover, the surface of all walls is the same in order to examine only the influence of the shape of route on orientation (Figure 6).

These factors were taken into consideration when selecting the shapes of route as follows: 1. the number of corners, 2. the geometric number of fields of the shape, 3. the number of fields with consideration to the body posture, 4. subject's movement and 5. starting point and posture. Figure 7 shows all shapes of routes used in this experiment. The subjects were consisted of six graduate students, of whom four were male and two were female.

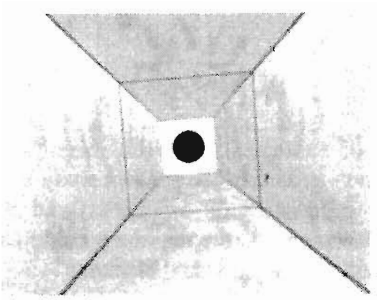


FIGURE 6. Presentation image in Study 2.

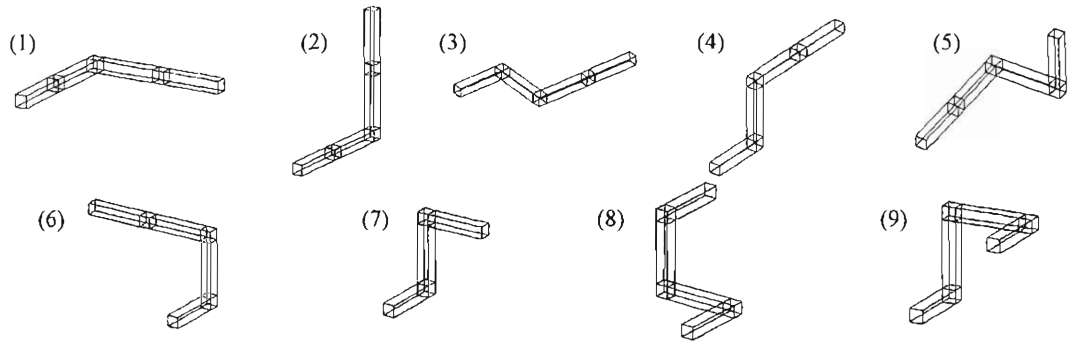
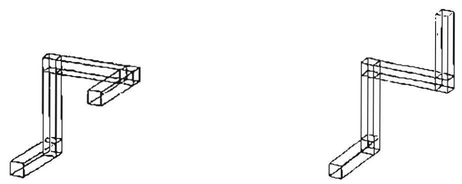


FIGURE 7. The shapes of route selected in Study 2.

Results

The tendency that mistakes in a horizontal direction and a vertical direction was increased as the number of corners, the geometric number of fields of the shape and the number of fields with consideration to the body posture was seen, which explains a hypothesis mostly. Especially in such shapes in which a subject moved upward as (2), (5), (6), (7), (8) and (9), even when the starting point was located in the diagonally upper direction to the arrival point in fact, some subject pointed out to the diagonally lower direction, probably because of the consciousness that a subject moved upwards.



The right shape The wrong shape

FIGURE 8. The right shape and the wrong shape in the shape of route (9).

From the result of reproducing the experienced route using a scale model, the clear difference did not appear except for the shapes (8) and (9), which seems to be difficult because they have many curves and a lot of geometric numbers of fields. This is considered because it is not necessary to grasp overall the shape of route but necessary just to think of in which direction the following module is connected in the modeling task, compared with the pointing task which requires to understand the shapes of route and one's position and posture in the route.

The mistakes in reproducing of the shape of route (8) were similar to that of the shape of route (9). At the third corner of the shape of route (9), where subjects move upward to themselves, three subjects mistook to connect a module "above" because they did not care about their posture in the space. Nevertheless the right shape is that shown in Figure 8.

SUMMARY

In Study 1, we observed different types of strategies for spatial cognition and human behavior under a virtual weightless state. Although visual information treated in the present study was quite limited, if we accumulate more knowledge about the influence of visual information on orientation and navigation by simulator experiments, it would allow us to design interior space effectively. Crew members could easily know their posture in a room and positions in a station by means of intentionally arranged visual elements.

Analyses of the results of Study 2 indicate that the ability of special cognition changes with such variables as the number of corners of routes, the geometric number of fields and the number of fields with consideration to the body posture. It is required which color and signs are effective in the orientation after this. Moreover, although only the square shape is treated and there is no fork in a route in this experiment, it is also required to consider them if a module becomes large from now on.

ACKNOWLEDGMENTS

This study is carried out as a part of "Grand Research Announcement for Space Utilization" promoted by Japan Space Forum.

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