REORIENTATION IN AN IMMERSIVE VIRTUAL REALITY

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INTRODUCTION

Before a person can begin efficiently navigating toward a destination, they need to know where they are in the environment so they know which way to go; this knowledge of self in an environment is known as *orientation*. People can use either the geometry of an environment, i.e., distance and direction, and/or the features of the environment, i.e. the shape and color of individual landmarks in the environment. To study orientation and reorientation skills, researchers usually train participants to learn the path to a rewarded location in an environment; then test them while introducing a perturbation such as a change in the geometry or features of the environment

While some studies use a physical environment to investigate reorientation skills [1, 2], a more common and versatile method employs virtual reality (VR) to simulate real-world environments. To date, most reorientation research has used desktop displays, either showing a series of static images [3, 4] or including active movement via joystick or mouse control [5]. Although these setups provide reliable perception of a three-dimensional environment, they are relatively non-immersive in that they do not allow for physical sensations of movement such as body translation and rotation, as well as enhanced field of view [6]; these qualities can play an important role when acquiring spatial knowledge [7].

Advances in VR technology have enabled researchers to render high resolution VR environments on a Head Mounted Display (HMD). We used an HMD in conjunction with a specialized wheelchair [8], for this study. Our experimental setup fully immersed people in the VR environment by providing a full range of head rotation as well as body translation, rotation, and wider field of View. With this setup, we investigated reorientation skills of adults in different conditions where geometrical or featural cues (or both) were altered.

METHOD

Participants

A total of 32 University of Manitoba psychology undergraduate students (20.1±2.3 yrs; 16 females) participated in this study. Each participant provided an informed consent, approved by the Biomedical Research Ethics Board of the University of Manitoba, prior to experiments. Each participant was trained and tested individually.

Experiment setup

We used the custom designed wheelchair, called VRNChair, designed by our team [8]. This specialized wheelchair replaces a joystick in a game environment. Experiments were carried out in a large empty room so that the wheelchair could be moved without hitting any obstacles. An HMD (Oculus Rift DK2) was first calibrated for each participant before the first trial. During all trials, participants wore the HMD and sat in the VRNChair. The encoders of the VRNChair allowed movements in the real environment to be translated to movements in the VR environment.

For this study, a custom game engine was developed on Unity 4.6 and rendered a rectangular virtual room 3.30 (width) × 6.87 (length) × 3.00 (height) as measured in Virtual Units (VUs). The scale was calibrated to match 1 meter in physical room to 1 virtual unit in the VR room. To choose a corner in the VR room, participants had to move to within a predetermined distance to that corner and click a button on a wireless mouse attached to their finger. During all training trials, each corner contained one of the following 3D objects: a blue cylinder, a yellow cone, a green sphere and a red cube. The overhead schematic view of the environment and the VR setup are depicted in Figure 1.

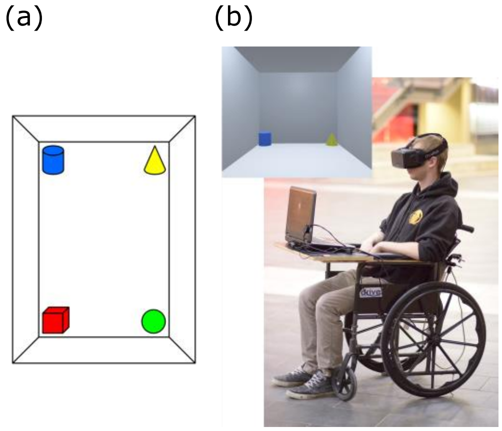

Figure 1: (a) An overhead schematic view of the experimental room. The correct corner was assigned for each participant and was counter-balanced across participants. (b) The VR experimental setup. The participant sat in a wheelchair, while looking at the VR environment through the headset.

Experiment Procedure

Participants started each trial from one of the four possible starting positions located at the middle of each wall; successive four starting positions were blocked and counterbalanced across the trials. After each trial, participants took a short break by removing the HMD to avoid possible simulator sickness.

Training occurred in the first 8 trials, in which one of the corners of the rectangular room was assigned as the correct corner and the others as incorrect corners. The location of the correct corner was counterbalanced across all participants. During the training trials, the designed game engine provided three different types of feedback when the participant clicked the button, depending on the position of the participant. When the participant moved within 1.5 VUs from the correct corner, the game engine played a voice and showed a dialog “Good job”; within 1.5 VUs from an incorrect corner, it played a short beep sound and showed a dialog “Wrong” and the participant was encouraged to choose another corner. The trial ended when the participant chose the correct corner.

If the participant chose the correct corner with their first choice on both of the 7th and 8th training trials, they advanced to the testing phase. Otherwise, another set of 8 training trials were given. If a participant could still not pass the 7th and 8th trials of the learning set correctly, the experiment ended and the participant was excluded. Figure 2 depicts overhead views of test trials; each condition occurred once with pseudo randomized order across the participants.

Following successful completion of the training trials, the participants experienced 6 test trials. During test trials, the environment was altered as described in the following subsections. No feedback was provided except the one encouraging the participant to move closer to choose a corner, when necessary. Each test trial ended following a single choice, whereby the participant chose any one of the corners.

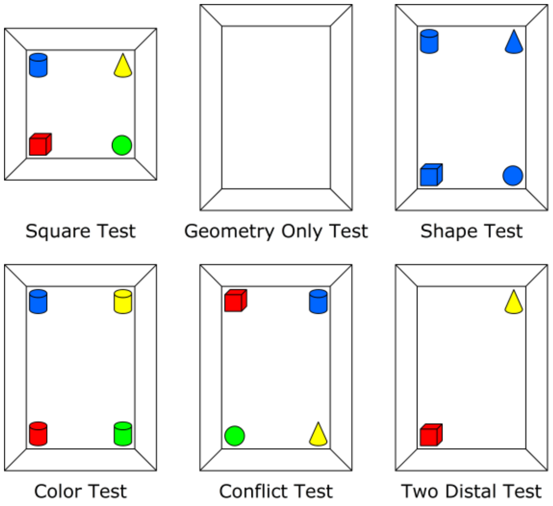

Figure 2: Overhead schematic view of the test conditions. For ease of illustration, this figure shows test conditions when the top right corner was assigned as the correct corner during training.

Square Test

In this test, the shape of the environment changed from a rectangle to a square. This test examined whether the participants could use features to locate the correct corner when geometry was made uninformative. One point was awarded if participants chose the corner with the object associated with the correct corner during the training trials.

Geometry Only Test

In this test, all the objects (features) were removed from the corners of the rectangular room. This test examined whether the participants could use only geometry to find the correct corner. Note that in this case, two corners (the correct one along with its diagonally opposite corner) would be the correct choices. One point was awarded if they chose either of the geometrically correct corners.

Shape Test

In this test, all the four objects located at the corners of the rectangular room had the identical color of the object located at the correct corner during training trials. This test examined whether the participants could use the shape of the objects to find the correct corner independent of their colors. One point was awarded if they chose the corner with the shape of object associated with the correct corner during training.

Color Test

In this test, all the four objects located at the corners of the rectangular room had the identical shape of the object located at the correct corner during training trials. This test examined whether the participants could use the color of the objects to find the correct corner independent of their shape. One point was awarded if they chose the corner with the color of object associated with the correct corner during training.

Conflict Test

In this test, each object was relocated to the adjacent clockwise corner; thus, placing each object in a geometrically incorrect corner relative to that in training trials. This test examined whether the participants relied more on features or geometry when the two were placed in conflict. One point was awarded if they chose the corner with the object associated with the correct corner during training.

Two Distal Test

In this test, two of the objects, one at the correct corner and the other diagonally opposite, were removed, and only the other two objects remained. This test examined whether participants could use the features outside their correct corner to locate the correct corner. One point was awarded if they chose the correct corner.

Data analysis

We scored the choice of the corner with the criteria described in the previous section to investigate how participants used different cues provided during the test trials. Using binomial statistical tests, we investigated whether the measured scores were equal to the score that would be expected by chance (chance score). The chance score was the probability of choosing a corner as the correct one by chance, assuming that choices were independent. Thus, the chance score was 0.25 for all test trials except for Geometry Only Test where the chance score was 0.5 since participants were rewarded when they chose two of the four corners. Also, in the Geometry Only Test, since geometric-based choices provided two possible correct choices, Wilcoxon signed-rank test was used to compare the proportions between correct corner and its diagonal opposite to investigate whether participants learned the correct corner or selected either of the two plausible correct corners by chance.

RESULTS

All participants passed training trials successfully, and proceeded to testing without the need to repeat training for a second time. None of the participants reported any symptoms of simulator sickness. Table 1 summarizes the Binomial tests comparing the average scores to the chance scores for each condition.

In the Geometry Only Test, the results indicate that participants chose either of the two geometrically correct corners significantly more than chance ($p<0.001$). Also, in the

Square, Color, Shape and Conflict tests, the probability of selecting the correct corner was significantly higher than chance (p<0.001 for all conditions). These results show that participants encoded the geometric cues as well as the feature cues. Wilcoxon signed-rank tests revealed the choices between the correct corner and its diagonal opposite were not significantly different in Geometry Only Test (p=0.532). The results show that the participants did not distinguish the two geometrically correct corners, as expected.

The results of Conflict Test show that participants relied more on feature cues when the two cue types were placed in conflict. The Two Distal Test revealed near significant results (p=0.080), suggesting that participants could not find the correct corner when the object directly associated with their correct corner and its diagonal opposite, were removed.

Table 1: Average scores, chance scores and Binomial tests for each condition

Conditions	**Binomial tests results**		
	Average score	***Chance score***	***p-values***
Square Test	0.97	0.25	p<.001
Geometry Only Test	0.72	0.50	p=.020
Shape Test	0.97	0.25	P<.001
Color Test	0.94	0.25	p<.001
Conflict Test	0.94	0.25	p<.001
Two Distal Test	0.38	0.25	p=.080

DISUCSSION

The results of this study confirmed that participants encoded both geometrical and featural cues in our VR setup. Also, they encoded color and shape of the featural cues associated with their correct corner. When the cues conflicted, the participants preferred to use featural cues over geometric cues. Interestingly, when featural cues associated with the correct corner and its diagonal corner during the training trials were removed, participants could not use the features outside their correct corner, implying that they had only learned about the feature in their correct corner.

Although the participants encoded both featural and geometrical cues in our VR setup, the fact that HMDs may produce reduced depth perception [10], may explain a reduction in saliency of geometric cues compared to features. Employing similar experiments in physical environments would reveal whether depth perception in the VR setup is comparable to that in physical environments.

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