Orientation Specific and Geometric Determinant of Mental Representation of the Virtual Room

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Abstract. Subjects in the experiment reported observed the same spatial layout in the rectangular room and the cylindrical room from the exocentric (45^0) perspective first and then the egocentric (0^0) perspective. The mental representations of space were testified by the judgment of relative direction between objects. The results showed that subjects represented the spatial horizontal relation more accurately along the imagined direction that paralleled to the wall in the rectangular room but along the imagined direction that was ever faced in the cylindrical room. The rectangular room better facilitated the coding of spatial vertical information than the cylindrical room. Subjects could respond faster when retrieving the spatial relations in the direction faced during the observation. The data indicated that the orientation-specific representation was constructed and the environmental geometry could influence the accuracy of spatial direction in mind.

Keywords: Virtual Reality, Mental Representation, Perspective, Geometry.

1 Introduction

Understanding the structure of space is one natural activity when people explore the three-dimensional (3D) space. Although large numbers of studies have brought insights into the mechanisms of spatial memory during navigation, most of them concerned two-dimensional (2D) navigation. The main reason might be that the height of perspective is not changed during the navigation. For instance the navigator on the plane observes the space constantly through the eye-level perspective while the orientation may update dynamically. Thus most research pays no much attention to the effect of verticality on the representation of space. The present study approaches the verticality of space by changing the viewpoint from the exocentric perspective to the egocentric perspective.

The egocentric perspective means the perspective of a ground-level observer within the space, whereas the viewpoint of exocentric perspective is external to the space, for example the viewpoint of map reader. Subjects in the study of Shelton and McNamara [8] learned the spatial layout of a large-scale virtual environment from either the egocentric perspective or the exocentric perspective. They found that

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subjects seemed to represent the space according the direction faced in the first leg of route. Luo and Duh [5] classified the exocentric perspective in more details. In their study subjects observed the spatial layout in the room through one of five perspectives distributed on the vertical plane, and then took the direction judgment task. They found that the accuracy of representation of the vertical link among the spatial layout decreased as the perspective elevated in the room. Subjects with the mid-exocentric (45^0) perspective better encode the horizontal link among the spatial layout in the rectangular room. The perspective changed along the vertical dimension affects the spatial process of verticality on space. The process of verticality in memory was observed to be independent of the process of horizontal dimension [3]. The change of verticality could be a source of disorientation in space. Subjects in the Passini study [6] needed knowledge about vertical relationships to make decisions about the use of stairways and elevators.

Perspective elevation can also influence the performance of the task in the 3D space. In the research about designing the format of the aviation display, Wickens and colleagues found that the display showing the view from the egocentric perspective better supports the local guidance in which the egocentric frame of reference plays the critical role [10]. The display showing the view from the exocentric perspective, especially when the degree of elevated viewpoint is 45^0, enhances the understanding of spatial structure and support the awareness in space, in which the exocentric frame of reference takes main functions [4]. Further, they proposed that the split-screen display that depicted the space from both the egocentric and exocentric perspectives at the same time may resolve the perceptual ambiguities. The experimental result suggested that this split-screen display provide the better support for the continuous task of local awareness and guidance and poor support for some of global situation awareness (SA) tasks [9].

From a spatial reference point of view, the environmental geometry can take function as the exocentric frame of reference to influence the representation of space. Hartley, Trinkler and Burgess [1] changed the geometry of the arena that was enclosed by walls, and found that subjects marked the cue object based on the distance to the walls. They suggested that geometry of the arena acted as a cue to the orientation. One salient feature of room space is the external constraint, the room wall. The geometry of room is assumed to influence the representation of the spatial layout in the room. But Shelton & McNamara [7] found that after the wall was changed from rectangular shape to the cylindrical shape, the orientation-specific representation of space was still observed.

To summarize the previous findings, perspective elevation could influence the representation of space, but providing the exocentric view during the navigation could improve the spatial awareness. In the present study, the effect of combining the exocentric and immersive (egocentric) views on the representation was studied further. Subjects observed the spatial layout in the room first from the exocentric perspective and then the egocentric perspective. The mental representation was tested by the same spatial task. It was assumed that the orientation-specific mental representation could be constructed after the observation. Another objective of the present study was to investigate the role of environmental geometry in representing the spatial layout. Two rooms, the rectangular room and the cylindrical room, were simulated by computer software. The room axes defined by the wall were more salient in the rectangular room than in the cylindrical room. The salient room axes might interfere the coding of space. It was hypothesized that subjects could better represent the spatial layout in the cylindrical room than in the rectangular room.

2 Method

2.1 Participant

There were 24 students, 12 males and 12 females, from Beijing Jiaotong University joining the experiment. They received 10RMB per one hour for participation.

2.2 Materials

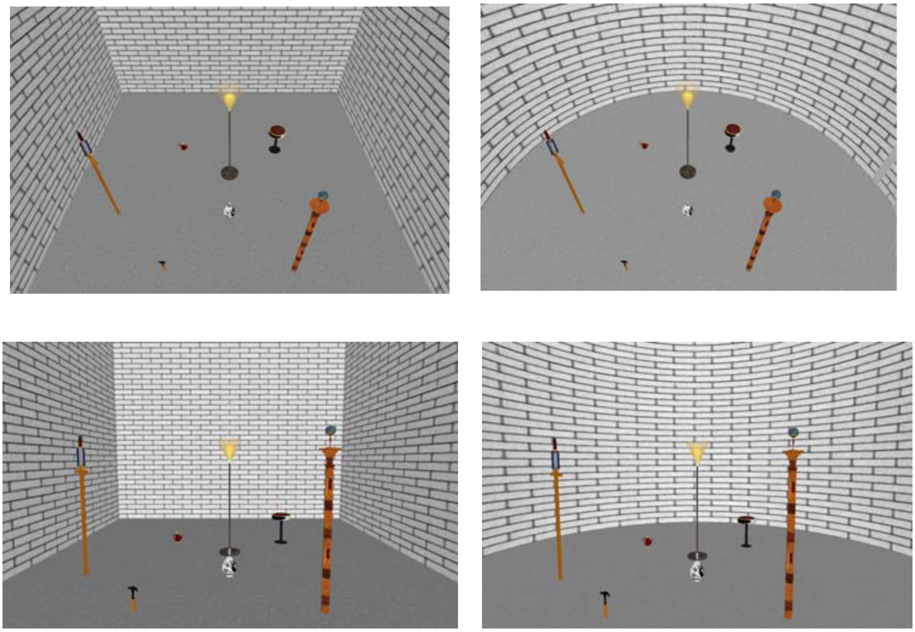
The virtual scene was constructed in EON (Eon Reality Company, 2004), and showed on the i-glass HMD (i-O Display Systems, LLC) with the 26.5^0 diagonal field of view. Four virtual environments were created: the experimental and practice rectangular virtual rooms, the experimental and practice cylindrical rooms. The difference between the experimental and practice rooms was that the experimental room comprised 7 virtual objects inside whereas the practice room was empty. The rectangular room was measured 8 m × 6 m × 6 m in virtual space. The radius of cylindrical room was 4m and the height was 6m in virtual space.

The exocentric view presented the layout of floor from the viewpoint at 4 meters above each floor. Specifically, the viewpoint was a view forward and downward from one short the wall in the rectangular room or was lying on the corresponding position in the cylindrical room, and its projection on the floor was 4 meters from the centre of floor. The elevation angle of viewpoint was 45^0 that was computed with respect to the floor. The egocentric view presented the layout of the floor from the eye-level height (1.7m) above the floor. The elevation angle of viewpoint was set to 0^0, meaning that participant's eyesight looked forward. The geometric field of view (GFOV) of both the exocentric and egocentric view was set at 75^0.

There were 7 objects located on the floor, including the lamp, teapot, chair, missile, stoneware, hammer and pillar. Three of objects were higher than the height of the egocentric perspective. The visual views used in the experiment are shown in Figure 1. When taking the test, subjects would point out the target direction in front of a board via a laser pointer.

2.3 Procedure

In order to assess participant's memory, subjects first took a memory test. Subjects were required to scan 9 objects printed on a paper for 30 seconds and then generated these objects at the corresponding positions on a blank paper with the same size.



(a) (b)

Fig. 1. (a) the exocentric view (above) and the egocentric view (down) in the rectangular room; (b) the exocentric view (above) and the egocentric view (down) in the cylindrical room

These 9 objects were not used in the virtual room. Subjects who correctly recalled more than 5 objects were allowed to proceed to the next phase. All subjects could recall more than 6 objects in this test.

Subjects were then randomly allocated into 2 groups with gender balance. One group subjects observed the spatial layout in the rectangular room and another observed the same layout in the cylindrical room. Subjects observed the 7 experimental objects printed as 3D objects on a paper. After they could associate each object with the unique name, they wore HMD and were instructed to first watch an empty virtual room. Subjects observed from the exocentric (45^0) perspective. After subjects were familiar with this perspective and felt comfortable with wearing HMD, the experimenter displayed the experimental virtual room containing 7 objects viewed from the same perspective. Subjects spent 2 minutes learning the location of each object. During observation the experimenter helped them to recognize the virtual objects if necessary. Then, experimenters would display the empty virtual room again and subjects would watch the empty room from the egocentric (0^0) perspective. After subjects were familiar with this perspective, the experimenter displayed the experimental virtual room viewed from the egocentric perspective. They also spent 2 minutes observing the experimental spatial layout from the egocentric perspective.

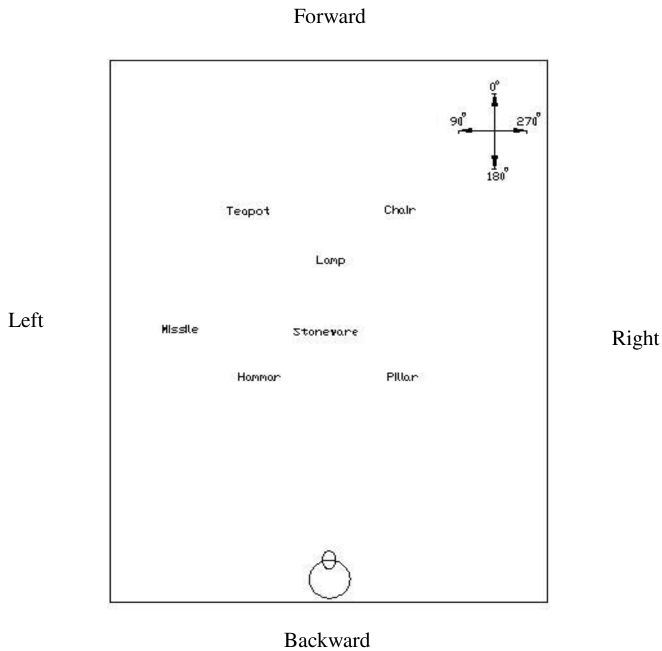


Fig. 2. The spatial layout in the rectangular room and four imagined facing directions

After observing visual scenes, all subjects' mental models of the space were assessed by the judgment of relative direction task (JRD, e.g. "Imagine you are standing at A object and facing B object, point to C object", [2]). Subjects were required to point to the specific position of the target object, for example, the top of the stoneware. When performing the task, subjects stood at the mark in front of a board and used a laser pointer to point out the direction. The coordinate of the centre of two eyes was recorded. Each test trial was constructed from the names of three objects. The experimenter recorded the response time and the coordinates of the laser point on the board. The judged direction of each trial could be computed by the coordinates of the laser point and the centre of two eyes. The total time for the experiment was approximately 60 minutes.

The experimental design manipulated the room style (two different rooms, the between-subjects variable) and the imagined facing direction (the within-subjects variable). The imagined facing direction included there categories, the forward, left/right, and backward directions. The direction defined by the standing position (the A object above) and the facing object (the B object above) required in the JRD task was labeled. The 0^0 direction was defined from Stoneware to Lamp (paralleling to the long walls of the rectangular room) and the degree of direction increased counterclockwise (see Figure 2). The 90^0 direction was defined from Stoneware to Missile model, paralleling to the short wall of room. The 180^0 direction was opposite to 0^0 direction while the 270^0 direction was opposite to the 90^0 direction. The backward direction includes all directions at the range from 90 degree to 270 degree.

The left/right direction includes the two directions: 90^0 and 270^0. The forward direction includes the other directions at the range from 270^0 to 360^0 and from 0^0 to 90^0.

The dependent variables were the horizontal and vertical angular errors and the response latency. The angular error was measured as the angular difference between the actual direction of target and pointing direction. The response latency was measured as the time from the presentation of question to the end of response.

3 Result

All dependent measures were analyzed using a split-plot factorial ANOVA with terms for the room style and imagined direction. Room style was between-participant and imagined direction was within-participant. An α level of .05 was used.

As shown in figure 3, the effect of imagined direction on the judgment of horizontal direction was significant, $F(2,44) = 3.64$, $p = .034$. The main effect of room was not significant. Interaction between the imagined direction and room style was significant, $F(2, 44) = 9.23$, $p < .01$. Further ANOVA was computed in each room. In the rectangular room, subjects performed worse when imagining forward than when imagining left or right or backward direction; in the cylindrical room, subjects performed worse when imagining left or right direction than when imagining forward or backward direction.

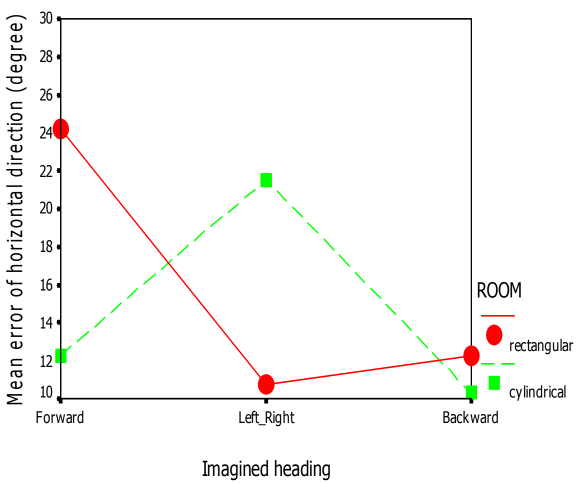


Fig. 3. Angular error in judgments of relative horizontal direction as a function of imagined direction and room style

The effect of room style on the judgment of vertical direction was significant, $F(1,22) = 35.91$, $p < .01$, depicted in Figure 4. The mean of vertical angular error (M = 18.25) in the cylindrical room was larger than that (M = 10.58) in the rectangular room. The effect of imagined direction on the judgment of vertical direction was also significant, $F(2,44) = 10.54$, $p < .01$. Interaction between the imagined direction and room style was significant, $F(2,44) = 10.32$, $p < .01$. Further ANOVA was computed in each room. The significant effect of the imagined direction was only observed in the cylindrical room. The performance was worse when subjects imagined left and right direction, whereas better in the backward direction.

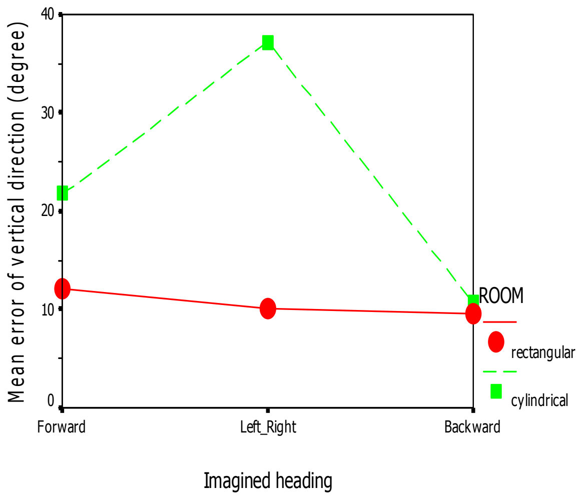


Fig. 4. Angular error in judgments of relative vertical direction as a function of imagined direction and room style

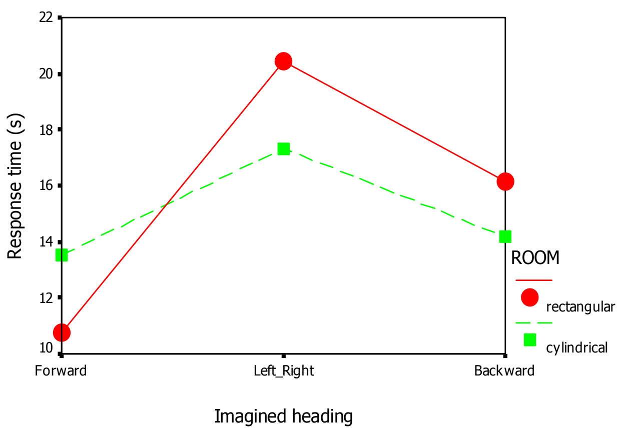


Fig. 5. Response latency to perform the task as a function of imagined direction and room style

The effect of imagined direction on the response time was significant $F(2,44) = 6.74$, $p < .01$; depicted in figure 5. Subjects were faster to response when imagining forward direction than when imagining left or right or backward direction. The effect of room style was not significant. There was no interaction between the room style and imagined direction.

4 Discussion

The goal of study was to determine the role of perspective change and the room geometry on the mental representation. Subjects in the experiment observed the spatial layout first from the exocentric perspective and then from the egocentric perspective. The result showed that the spatial relations among objects could be represented more accurately in memory along specifically preferred orientations. Moreover, subjects could respond faster when imagining forward direction than left or right or backward direction. The room geometry interacted with the participant's orientation in the room to influence the representation of spatial layout.

The representation of spatial horizontal links among the layout was influenced by both the orientation to observe the layout and the room geometry. In the rectangular room, performances were better for the two directions paralleled to the room walls than for the directions misaligned with room walls. This finding was consistent with the previous study, revealing the effect of salient room axes defined by room walls on the representation of space [7]. But in the cylindrical room where the room axes defined by the room walls were not as salient as those in the rectangular room, the main effect of the egocentric orientation was observed. The data related with the horizontal links among objects supported the first hypothesis that the orientation-specific representation of spatial layout was constructed after the observation.

Performance of judging the vertical direction was different in two rooms. The performance to judge the vertical direction was better in the rectangular room than in the cylindrical room. The result did not support the second hypothesis. The data suggested that the salient room axes could facilitate the coding of vertical information among the layout. Easton and Sholl [2] pointed out that people need to construct the exocentric coordinate over the reference object to retrieve the direction information when they judged the relative direction between objects. Luo and Duh [5] suggested that the spatial vertical information was mainly interpreted with respect to the exocentric reference provided by the environment. The efficiency of constructed exocentric coordinate was determined by the ecological properties of structure, such as the height information. Therefore, if the room wall provided better cues for the height information, the room wall could take main function to affect the coding of spatial vertical information. Compared with the cylindrical wall, the linear wall of the rectangular room better provided cues to explain the height information. It was demonstrated by the result: there was no the main effect of the egocentric direction on the judgment of vertical direction in the rectangular room whereas the effect of the egocentric direction was observed in the cylindrical room.

It was noteworthy that the patterns between the judgments of the spatial horizontal and vertical directions were different in the present experiment. The results revealed that coding of the spatial vertical information was independent with the spatial horizontal information among the same layout, as suggested in the study [3]. Few studies investigated the spatial process on the vertical dimension, but Wilson et al [11] took a preliminary study about the vertical information represented asymmetrically in memory. The additional evidence for this difference was also drawn from the later description of strategies subjects used to perform the spatial task. Most subjects (90%) reported that they first retrieved the horizontal direction of target and then judged the vertical direction.

Subjects responded fastest to retrieve the spatial relations when imagining the forward direction. It further supported the orientation-specific property of the mental representation of spatial layout. Subjects faced the forward direction when they observed the spatial layout. The familiar view should be more salient in memory than the novel views that were imagined from the new viewpoints. The process to imagine the view from the new viewpoint might involve either the viewer rotation or the object rotation [12]. The additional mental process delayed the response to figure out the direction of target.

5 Conclusion

The important conclusion of present study includes two aspects. First, the orientation-specific representation was constructed when people observed the virtual room-sized space first from the exocentric perspective and then from the egocentric perspective. Second, the room geometry tended to interact with the orientation facing the spatial layout to influence the mental representation of the space. In terms of the spatial vertical knowledge, the study suggested that the coding of spatial vertical information was affected by both the orientation to the space and the environmental geometry.

Subjects observed the same spatial layout from two static viewpoints on the vertical dimension in the present experiment. Our future study will investigate whether the continual change of perspective from the exocentric viewpoint to the egocentric viewpoint influences the representation of space. The successful views during the vertical movement might improve the spatial knowledge about the verticality.

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