Layout of reference points during navigation: Effects of a central reference point as anchor

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Abstract

This study examined the effects of two variables on spatial learning: the objects' array (with or without a central reference point) and the learning method (virtual walk through or seeing still images). After learning the objects' locations and their positional relations in a virtual room in egocentric reference frames, participants judged the directions to a target from an imaginary position in the room. The results revealed that having a central reference point facilitated learning, especially in the virtual-walk condition with a central node. The findings are discussed in terms of the interactions between the effect of the central reference point and virtual walk and the relationship between intensive encoding in egocentric reference frames and stored representations of the layout in environmental reference frames.

Keywords: spatial learning; layout; reference frames; reference points; anchor points

Introduction

In everyday life, people move about in their surrounding space, they get out of bed, walk into the kitchen for coffee, go into the garage, and drive to their office. Such daily spatial behavior is based on spatial cognitive functions in which we comprehend positional relations between our bodies and objects. Because spatial locations are essentially relative, reference systems to describe position and orientation are important (Pani & Dupree, 1994). In the areas of human navigation, wayfinding, and spatial memory, two types of reference systems have been distinguished in the literature: egocentric and environmental (or allocentric) (Werner & Schmidt, 1999). In egocentric reference systems, locations are defined with respect to one's body (e.g., there is a table in front of me); in environmental reference systems, locations are defined with respect to external objects and, in some cases, an objective coordination such as an azimuth orientation (e.g., Denmark is located to the north of Germany).

When walking around a familiar town, people rely on their spatial memory of the environment, including elements such as routes, landmarks, and their layouts. Many studies indicate that spatial layouts tend to be organized in the frame of environmental reference systems rather than egocentric reference frames (e.g., Kelly, Avraamides, & Loomis, 2007; Montello, 1991; Shelton & McNamara, 2001). However, when moving through a space, we also rely heavily on egocentric reference frames, and both types of frames are available for recalling the relations of spatial elements. For example, when walking from the station to a nonvisible destination located east of the station, one can head to the east based on environmental reference frames or one can find a direction toward the destination from memory by imagining oneself standing with one's back against the station and recalling the route from there.

Learning spatial layouts has been a major topic of spatial cognition, and much research has been conducted with respect to the reference frames. However, fewer studies have examined a layout's own effect on spatial learning. Some studies have focused on layouts of objects in learning tasks set in middle-scale spaces. Mou and McNamara (2002) and Mou, Zhao, and McNamara (2007) reported that when a layout of targets has an intrinsic axis of configuration (e.g., desks in a classroom arranged vertically and horizontally represent a line-column axis), the intrinsic reference frame is given priority over viewing perspectives in layout learning. Kelly, Avraamides, and McNamara (2010) reported that features of a layout learned in advance affect subsequent learning. In these studies, participants learned the layouts from single or multiple viewpoints. Therefore, one could argue that the layout features and an alignment effect in an egocentric reference frame were compared, rather than comparing multiple layouts on the acquisition of representations.

In the present study, we examined whether differences in layout of objects affect spatial learning, using a free-exploring task that invokes egocentric reference frames in a middle-scale virtual space. Specifically, using post-tests, we compared the learning results of two different layouts: one consisting of four objects arranged like spots on a die and the other consisting of five objects in which one more object was added at the center.

Our previous research using a real labyrinth (Ohtsu & Ouchi, 2010) suggested that a particular layout condition may facilitate spatial learning. In our experiment, participants explored the fylfot-shaped labyrinth (Figure 1), found four targets, and revisited them; they executed either one of two kinds of visiting orders during the learning phase. The first corresponded to the Circle-Order procedure in which participants revisited the targets in a clockwise and counter-clockwise order (i.e., visiting A→B→C→D→A, and then A→D→C→B→A), so that at the central intersection of the labyrinth, they constantly updated their position relative to the destination targets situated in the same self-to-object relation and turned to the left or right. The other order (i.e., visiting A→B→D→C→A, and then A→C→D→B→A) represented the Non-Circle-Order procedure in which, at the intersection, participants updated their position relative to the multidirectional destination targets in the different self-to-object relations and turned right or left or went straight ahead. In the post-tests, the participants in the Non-Circle-Order condition performed better than those in the Circle-Order condition.

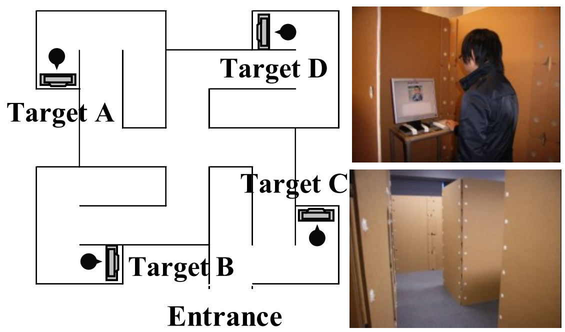

Figure 1: Layout and Images of the Labyrinth.

Although our experiment was conducted to investigate the effects of the different types of directional inference (unidirectional versus multidirectional), in the course of examining the results, we conceived a hypothesis that along with the updating, the difference in the reference points' layouts recognized by the participant as a consequence of their inferences might also have resulted in the superiority of the Non-Circle-Order condition. In particular, we presumed that the participants in the Non-Circle-Order condition recognized the intersection as a fifth reference point in addition to the target locations, whereas those in the Circle-Order condition recognized only four reference points in the target locations. In our experiment, the locations of the targets ought to have been recognized as important reference points, but the significance of the intersection might depend on the conditions. For those in the Non-Circle-Order condition, the intersection was more important than for those in the Circle-Order condition, because it was only in the former condition that the participants needed to pay extra attention to determine the multidirectional relation in the egocentric reference frame and choose their way. In contrast, in the Circle-Order condition, the participants could automatically turn left or right during the revisiting after perceiving the layout.

The term "reference points" was originally used in categorization in cognitive science (Rosch, 1975). Subsequently, Sadalla, Burroughs, and Staplin (1980) proposed describing notable landmarks and places whose locations are relatively better known among others as reference points; the reference points serve to define the location of adjacent points. Among those reference points, there might be a difference in the level of importance. Golledge and Spector (1978) proposes, in the anchor point theory, that distinctive locations, features, path segments, or familiar districts become an anchor of the cognitive map, and they influence encoding, storage, and decoding processes used when accessing stored information in a decision-making context (Couclelis, Golledge, Gale, & Tobler, 1987; Golledge, 1999). Learning apparently becomes difficult when reference points increase in number, but the ease of learning is not influenced solely by the number of reference points. Lindberg and Gärling (1981) investigated spatial learning during locomotion with differences in the number of reference points. In their experiment, participants walked paths along reference points guided by experimenters, and at the stopping points designated by the experimenters, they estimated distances and directions to the reference points (one to three). The results revealed that the number of reference points did not affect the accuracy of the directional estimations.

If the central point acts functionally like an anchor point that organizes other spatial information into a layout (Golledge, 1999), the positional relation of the reference points can be recalled more easily and more accurately with the central point than without it. In addition, considering that people can form configurations of reference points from information acquired in egocentric reference frames as well as environmental ones when learning an environment through navigation or wayfinding (Sholl, 1996), it would be more efficient to encode the relations when one puts oneself in the space and exerts sufficient egocentric reference frames than when learning the relations from restricted viewpoints.

Based on the hypothesis that the fifth central reference point added to the four reference points serves as an anchor that organizes other points into a layout and facilitate spatial learning through navigation, we conducted an experiment to examine the effect of the central reference point when learning via virtual navigation and from multiple vantage points using still images. Via virtual navigation, one might well be able to recognize the relations between the reference points in egocentric and environmental reference frames, whereas via still images, one basically see the objective relations of the reference points shown by images.

Experiment

Factors

One factor was the array of objects: Square or Central Node (Figure 2). The other factor was the learning method: Virtual-Walk or Still-Image.

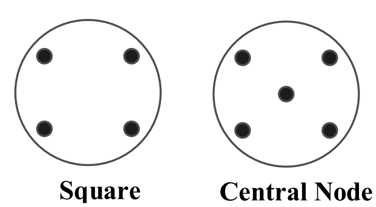

Figure 2: The Arrays of Objects.

Environmental Setup and Materials

A virtual circular room with a diameter of 12 m (Figure 3), generated by CAD software (shade dreamhome 2.0.3) was used in all the conditions. Four common objects (Figure 4) and curbs indicating the front of the objects were placed, and a central node object (Figure 4) was added at the center of the room only in the Central Node conditions. Six kinds of rooms that included all combinations of the placement of common objects were prepared, and each one was assigned to four participants in four groups. In the Virtual-Walk conditions, participants were seated in front of a computer display and operated a keyboard for the virtual walk through in which continuous images from the perspective of a virtual camera (height: 1500 mm, field-of-view: 80 degrees) were shown according to the key operation. The starting points in the Virtual-Walk conditions were in front of a common object that varied between the four participants assigned to each kind of room. In the Still-Image conditions, still images of the six kinds of rooms from 12 vantage points (three perspectives for each common object, see Figure 5) were shot by the virtual camera in the same terms as the Virtual-Walk conditions. Each participant watched the four sets of three images in front of the same display. For practice in all the conditions, another virtual circular room with a diameter of 5 m in which three objects and curbs were placed was used. Images of the practice room for Still-Image conditions were shot similarly as for the experimental room.

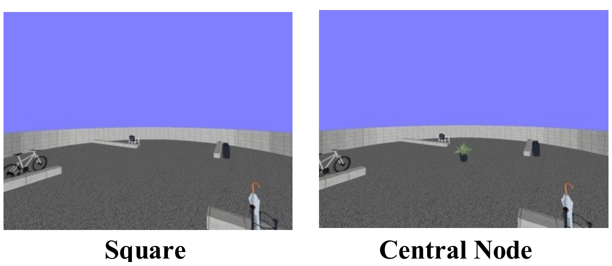

Figure 3: Images of the Virtual Circular Room from Virtual Camera.

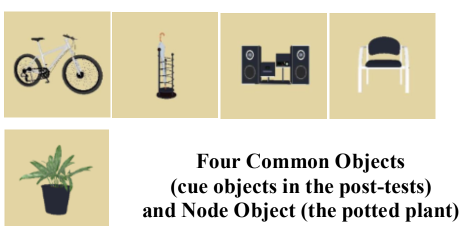

Figure 4: The Objects Used in the Experiment.

Participants

Ninety-six undergraduate and graduate students with normal vision were randomly assigned to each group. The ratio of male to female was the same in each group (12 male and 12 female). The average ages of each group were 22.5 (SD: 4.65; Square-Walk), 22.4 (SD: 4.02; Square-Still), 21.0 (SD: 3.60; Central Node-Walk), and 21.4 (SD: 2.74; Central Node-Still).

Procedure

The experiment was divided into three phases: practice, exploring, and post-test. At the beginning, participants were instructed to remember the objects, their locations, and the positional relations between them.

Practice Phase The participants in Virtual-Walk conditions explored the practice room for one minute, whereas those in the Still-Image conditions saw images of the room for one minute. Then, participants in both conditions took Post-test 1 so that they would consciously remember the relative positons of all objects in the exploring phase. Throughout the practice phase in both conditions, experimenters monitored and checked whether the participants understood what they needed to judge in the post-test.

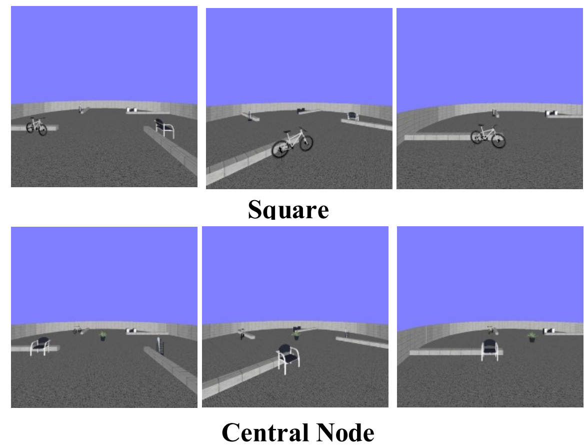

Figure 5: Still Images of Three Perspectives.

Exploring Phase At the beginning of the phase, the participants in the Virtual-Walk conditions were instructed to move to four positions where they could see each common object in front of them, and then allowed to move around the room freely. Their walking trajectories were recorded by a screen capture program. The overall time of the virtual-walk was four minutes. In contrast, those in the Still-Image conditions randomly saw the four sets of three images showing each object from three vantage points. Each set was presented four times for 15 seconds each (5 seconds per image) so that the overall viewing time would be four minutes.

Post Test Phase Two post-tests and a sketch map test were conducted for each group. In Post-test 1, participants were asked for directions to one of the common objects from imaginary locations. A cue target was presented first, followed by a fixation point, and then the target object (Figure 6). The participants selected one of the keys to indicate directions to the target objects as if they were standing and facing a cue object. One set of 12 randomized trials, including all possible combinations of two objects, was conducted twice.

In Post-test 2, participants were asked for directions to one of the common objects while assuming they were standing in the center of the room and seeing a cue object in a particular position. The cue object indicated which direction one was facing. After the first picture showing the cue object, the target object was displayed following a fixation point, and the participants selected one of the directions in the same manner as in Post-test 1. One set of 24 randomized trials with all possible combinations of two objects was conducted twice.

Finally a Sketch Map Test was conducted in which participants wrote down, on a circular piece of paper, the names of the objects and curbs in the position they experienced during the exploring phase.

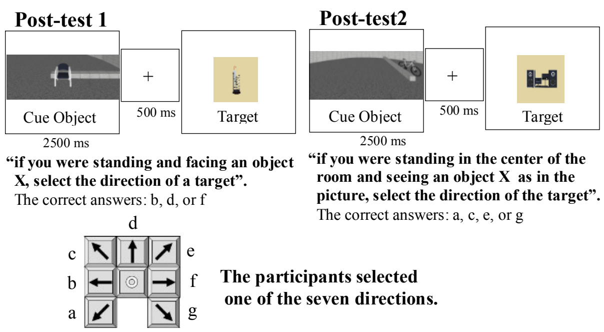

Figure 6: The Post-tests.

RESULTS

Sketch Map Test

The sketch maps drawn by the participants were checked to determine whether the locations of objects were recalled correctly. Eleven participants (three in Square-Walk, three in Square-Still, three in Central Node-Walk, and two in Central Node-Still) could not recall the objects and/or put them in the wrong positions. Since some of the 11 participants seemed to abandon the judgment in the post tests (e.g. selecting the same directions in any trial), we decided to exclude the participants from the analyses based on the success or failure of the map.

Judgments

After the angular transformation, the mean error rates in each post-test were analyzed by a two-way ANOVA. Results for Post-test 1 revealed a main effect of the learning method [$F(1,81) = 38.69$, $p < 0.01$] and a significant interaction effect [$F(1,81) = 4.98$, $p < 0.05$] (Figure 8). Results for Post-test 2 revealed main effects of the array [$F(1,81) = 11.40$, $p < 0.01$] and learning method [$F(1,81) = 5.74$, $p < 0.05$], and a significant interaction effect [$F(1,81) = 5.10$, $p < 0.05$] (Figure 8). Another two-way ANOVA was performed with only the results of the Virtual-Walk conditions in Post-test 1, using the following factors: the array and correct directional responses (front, diagonally forward left and left-hand side). The analysis revealed only a main effect of the layout [$F(1,40) = 6.15$, $p < 0.05$].

Response Time

The mean response time (Figure 9) in each post-test was also analyzed by a two-way ANOVA, and a main effect of the learning method was detected in Post-test 1 [$F(1,81) = 7.73$, $p < 0.05$] and Post-test 2 [$F(1,81) = 4.95$, $p < 0.05$].

Walking Trajectory

Except for two participants' trajectories that could not be recorded due to technical difficulties, 40 recorded trajectories (19 in the Square-Walk and 21 in the Central Node-Walk) were examined by the experimenters. In both the Virtual-Walk and Still-Image conditions, after visiting the common objects as instructed, some participants kept moving from one zone to another (see Figure 8) with short stops, while others were more likely to stay at some locations longer and overlook the room. Among the behavioral patterns common to the groups, frequencies of zone migration and staying at the center zone (turning left or right to overlook the room for more than 10 seconds) were counted (Table 1). Two-sample t-tests were performed on the mean values of the zone migration and staying, and there was a significant difference only in the frequencies of staying [$t(38) = 2.19$, $p < 0.05$]. Analysis of the correlations between each value and the mean error rate in each post-test was performed, and a significant possible negative correlation was found only between the migration frequency and the mean error rate in Post-test 2 in the Central Node-Walk condition; however, a regression analysis revealed no significant relationship between the variables.

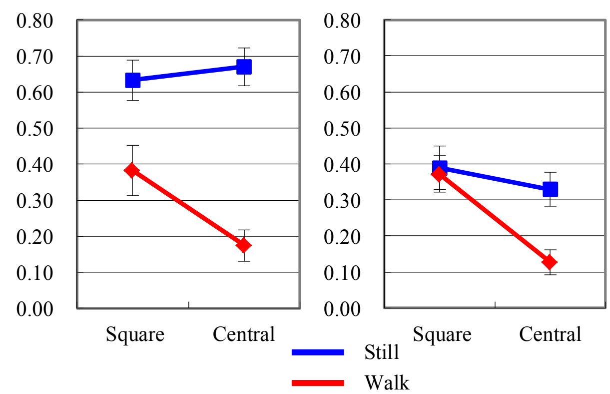

Figure 7: The Mean Error Rate and Standard Error.

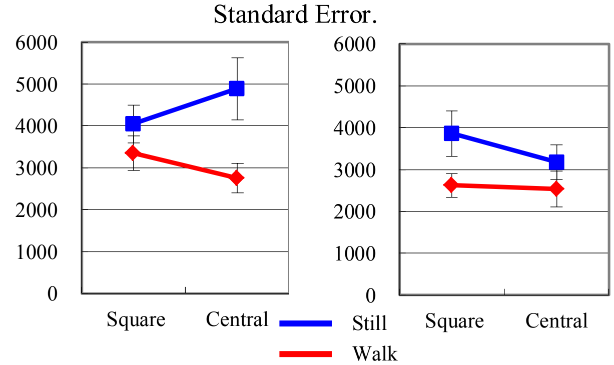

Figure 8: The Mean Response Time (ms) and Standard Error.

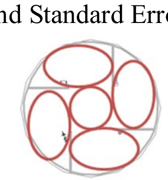

Figure 9: The Zones in Analyses of Walking Trajectory.

Table 1: The Mean Frequency and Standard Error.

	zone migration			staying at center		
Square	6.58	(.53)	n=19	1.05	(.21)	n=19
Central	5.90	(.49)	n=21	0.52	(.14)	n=21

Discussion

We hypothesized that, when learning the reference points through navigation, the central point would serve as an anchor that organizes other points into a layout, which then facilitates layout learning. The results supported the hypothesis and suggested that the central reference point is more effective when learning the spatial relations of objects via virtual virtual-walk than via still images from multiple viewpoints. The number of participants who failed the sketch map test in each group indicated that, regardless of condition, nearly equal numbers of participants could remember and recall the objects' locations. However, in Post-test 1, when participants were asked to indicate the direction to a target object, the presence of the central reference point led to a major difference in the judgments, which varied according to the learning method. When learning occurred via still images, the central point did not affect the judgments, as suggested by the absence of a main effect of array; however when learning via virtual-walk, the central point seemed to affect learning. This could be explained by an interaction between the factors, in which mean error rate in the Central Node-Walk condition was notably lower than the rates of the other groups, and a main effect of the layout in the ANOVA with only Virtual-Walk conditions.

In Post-test 1, learning method affected the judgments due to the large difference between Virtual-Walk and Still-Image conditions in the error rates and the response times. The difference in the error of judgments would arise from a qualitative difference in layout representations between the learning conditions. The cognitive manipulation performed by the participants in the first test can be speculated as follows: recalling a layout stored in the environmental reference frames, reorienting a target object in the egocentric reference frames from the layout, and imagining being in front of a cue object. Of course, one could provide the directions using representations only in the egocentric reference frames by remembering 12 possible positional relations from one target to the others, but it is rather unlikely that many participants would have applied such a cumbersome and uneconomic strategy. Instead, it seems that participants remembered what they were asked in the first test and made an effort to remember the layout for the post-test. Considering that the participants in both conditions remembered the layouts equally well, it could be inferred that those in the Virtual-Walk condition could reorient a target object in egocentric reference frames from the imaginary locations more easily and faster than those in the Still-Image condition. This would mean that the representations in environmental reference frames in the Virtual-Walk condition were more elaborated than those in the Still-Image condition. However, the most influential condition was the Central Node-Walk; participants' representations in that condition might have been the most elaborated. Indeed, the ANOVA performed on the Virtual-Walk conditions using the correct directional responses as an extra factor suggests that overall positional relations of the objects as layout were learned better in the Central Node-Walk than in the Square-Walk.

In Post-test 2, the participants did not know that they would be asked for directions to common objects from the center of the room, so they could not intentionally remember the positional relations from the center point in egocentric reference frames during the exploring phase. Therefore, when they judged directions, they had no choice but to reorient the positional relations between one's body and the targets using the representations of the layout in environmental reference frames. The results of the second test also support the hypothesis. Although there were main effects of the two factors, the significant interaction effect and the finding of the highest percentage of correct answers in the Central Node-Walk condition showed that the two factors had positive effects on mainly the Central Node-Walk condition. In contrast, the error rates did not differ greatly between the Square-Still, Square-Walk, and Central Node-Still conditions, although the participants in the Virtual-Walk conditions, including the Square-Walk, could answer quicker than those in the Still-Image conditions.

Analyses of the participants' trajectories suggest that the participants in Square-Walk recognized that the center zone was an important vantage point for layout learning, as they tended to stay in that zone and overlooked the room with a higher frequency than those in Central Node-Walk. It could be interpreted that, at the center zone, they paid attention to the positional relations of the four common targets in their view and tried to remember the layout in environmental reference frames, instead of thinking of the relations between the targets and themselves—standing at the center—in egocentric reference frames. In contrast, the participants in Central Node-Walk who thought they had to remember the relations, including the central node object, would have intensively encoded the relations from the central node object to the others in environmental reference frames at the center zone near the object.

Lastly, we would like to suggest the process whereby the central reference point act like an anchor point in our experiment. The first factor lies in the general feature of the layout. When connecting the objects with a straight line, the lines in both conditions overlap each other. However, the diagonal relations in the Central Node Array are segmented by the central node object. The segmented components might result in elaborate layout representations and facilitate accurate judgments because the components allow one to describe and encode more diverse positional relations. The second factor lies in the superiority of the virtual walk through over learning by still images. Learning structures via navigation and wayfinding involves the integration of local perspectives and views that a traveler has learned independently (e.g., Meilinger, 2008; Poucet, 1993). The Virtual-Walk conditions provided more diverse relations between the objects due to one's own movement compared to the Still-Image conditions. This would have led to the superiority in forming the layout representations. Considering all the factors together, the Central Node-Walk condition might have led to the elaboration in which one can efficiently manipulate the layout representations, reorients oneself, and judges directions by using both environmental and egocentric reference frames.

The present study revealed the effect of differences in layouts with and without a central reference point under the condition of a virtual walk through. The intensive encoding of the positional relations from the central reference point by virtual navigation apparently results in elaborated layout representations. In our previous experiment using a real labyrinth, a process similar to that in this experiment would have occurred, although there was no obvious central object indicating a prominent location in the labyrinth. Future work should confirm the speculations arising from the present findings by clarifying (1) that the layout contains a distinctive reference point that serves as an anchor, and (2) the relationship between encoding a reference point in egocentric reference frames and stored representations of the layout in environmental reference frames.

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