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Spatial updating of objects after rotational and translational body movements in virtual environments

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A B S T R A C T

Spatial reasoning in architectural design can be better understood by considering the factors that affect the spatial updating process of the individual in an environment. This study focuses on the issue of spatial updating of viewed and imagined objects after rotational and translational body movements in a virtual environment (VE). Rotational and translational movements based on an egocentric frame of reference where there is no control of the user are compared in a desktop VE. Moreover, preference in architectural drawing medium and gender are analyzed as the factors that affect the spatial updating of objects in each body movement type. The results indicated that translational movement was more efficient than the rotational movement in judgment of relative directions in viewed objects. Furthermore, the viewed objects were more correctly spatially updated than the imagined ones both in translational and rotational body movements. In comparison of hand, computer and both as the drawing media, findings indicated that preference in computer medium in architectural design drawings was an effective one in spatial updating process in a VE. Contrary to the previous studies, it is found that there was no significant difference between gender and movement types.

1. Introduction

The architectural design process, as a problem solving activity, requires imagining of spatial changes as well as making inferences related to spatial relationships. The spatial changes may occur

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as a result of one's body movement or movement of objects in the environment. In order to understand the spatial reasoning in architectural design process, one needs to consider the factors that affect the spatial updating process of an individual in an environment. This study examines the differences in spatial updating between a viewer's rotational and translational movements based on an egocentric frame of reference (i.e. one's body) during navigation in a virtual environment (VE). A pointing task is utilized, in order to assess the spatial updating performance of both viewed and imagined objects in two movement types. In previous studies, rotational and translational movements were compared either in a real environment or in a VE where the user is integrated to a keyboard, mouse or head mounted display. However, this study emphasizes the importance of acquiring spatial knowledge from navigation through a VE by one-time route specification and its effects on the acquaintance of the three-dimensional VE's during design process.

2. Updating of the spatial orientations

As people travel through an environment, they continuously update the spatial relations between them and the environment and the relations between the objects in the environment. In previous research, spatial updating was described according to a specific reference system. Creem-Regehr (2003) defined spatial updating with respect to the egocentric reference frame as "the human ability to keep track of spatial locations relative to oneself during one's own movement or movement of objects in the environment" (p. 941). Spatial updating is determined by the intrinsic reference frame of the individuals that continuously computes the egocentric locations of objects as people move in the environment (Avraamides, 2003; Waller & Hodgson, 2006). In addition, Shelton and McNamara (2001) proposed the environmental reference frame where "learning and remembering the spatial structure of the surrounding environment involve interpreting the layout in terms of a spatial reference system" (cited in Mou, Zhang, & McNamara, 2004a, p. 172). Therefore, spatial updating can be specified relative to the viewer (egocentric reference frame), to the objects in the environment (intrinsic reference frame) or to the environment itself (environmental reference frame). In this study, spatial updating of individuals only based on an egocentric frame of reference is examined in rotational and translational movements.

2.1. Movements types and spatial updating

When a person moves in the real world, the orientation of the person's body, direction of view and the travel technique should be identified. In this study, 'view direction travel' is used where view and directions are coupled, allowing the user to look at the direction traveled (Darken & Sibert, 1996a; Witmer, Bailey, Knerr, & Parsons, 1996). The objects that are viewed at the direction traveled are called viewed objects and the objects that are not coupled with the view of the subject are called imagined objects. Therefore, pointing tasks can be chosen so that the direction of pointing to objects is either the same as viewed or not with the directions that would have been experienced during the observation period.

Bowman, Davis, Hodges, and Badre (1999) categorized virtual travel techniques in a VE as discrete target, continuous and one-time route specifications. In discrete target specification, "the user controls the two-end points of motion and leaves the path between those points up to the system" (p. 620). In continuous specification, there is a complete control of the user on the process of moving through an environment. In one-time route specification, there is no control of the user over the motion. In order to eliminate individual differences, one-time route specification was chosen as the traveling technique of the body movements in the study.

2.1.1. Rotational movements

Creem-Regehr (2003) stated, "pure rotational movements involve a change in orientation with respect to a reference axis, without linear displacement" (p. 941). The spatial updating of rotational movements, which consist of turning clockwise or anticlockwise, are involved either as imagined or viewed rotations.

In the imagined rotations, individuals can either imagine a rotation of their own viewpoint (imagined viewer rotation) or imagine a rotation of the object itself (imagined object rotation). In the imagined viewer rotation, the intrinsic frame remains fixed and the relative frame moves with respect to the environment since the front–back and right–left axes of the relative frame belong to the observer. However, in the imagined object rotation, the intrinsic frame moves with respect to the environment, whereas the observer's relative frame remains fixed (Wraga, Creem, & Proffitt, 1999; Wraga, Creem-Regehr, & Proffitt, 2004). Studies have shown that updating during imagined self rotation is faster and more accurate than imagined rotation of the object (Amorim & Stucchi, 1997; Creem, Wraga, & Proffitt, 2001; Sancaktar, 2006; Wraga et al., 1999, 2004). Therefore, the locations of objects are easily updated after imagined rotations of the viewer rather than imagined rotations of the object. Also, Amorim and Stucchi (1997) found that their participants had faster response rate and less errors in the imagined viewer rotation compared to the imagined object rotation tasks. The reason for imagined viewer rotations being less problematic is related to the structure of the relative reference frame (egocentric). But when an observer imagines rotating to a new viewpoint rather than physically rotating, spatial updating is relatively slow, cognitively effortful and more error-prone (Klatzky, Loomis, Beall, Chance, & Golledge, 1998; Rieser, 1989; Wraga, 2003).

2.1.2. Translational movements

Translational movements involve a linear displacement without a change in orientation. Presson and Montello (1994) did not find a difference in spatial updating between viewed and imagined translations. They indicated that with imagined translation, the axes of an individual's primary frame of reference remain parallel to the secondary frame of reference, which is a new front, back, right and left, allowing for ease of pointing to an object from a new viewpoint. Likewise, Rieser (1989) reported that participants were equally good at pointing to objects from an imagined novel location and from their actual location.

According to Creem-Regehr (2003), imagined viewer translations were performed more quickly and accurately than imagined object translations in real environments. The participants were faster and more accurate at updating the positions of objects after imagined viewer translation than after object translation. She explained that the distinction between viewer and imagined translations could result from people's differential ability to predict the outcome of a moving frame of reference other than the one with which people have extensive experiences. However, "in updating tasks involving visual translation without body movement, participants appear to treat the information about a translating display in a similar way as information about translation resulting from the physical movement of one's body" (Creem-Regehr, 2003, p. 947).

Easton and Sholl (1995) and Rieser (1989) concluded that the imagined translations were easier to perform and faster than the imagined rotations. Also, May (2004) found that pointing to object locations after imagined egocentric rotations and egocentric translations resulted in larger pointing latencies and errors for imagined rotations than imagined translations.

2.2. Gender differences in spatial updating

Previous studies showed that there are gender differences in the ability to acquire spatial information and navigate through real and VE's. This may be the result of the different type of information that males and females focus within their environments (Sandstrom, Kaufman, & Huettel, 1998; Saucier, Bowman, & Elias, 2003; Tlauka, Brolese, Pomeroy, & Hobbs, 2005). When people give navigational directions to others, females refer more to landmarks and other visual objects along a route. They also show greater accuracy in recalling landmarks and in estimating distances to landmarks, and report using a route-based navigation strategy. On the other hand, it is reported that males use more cardinal directions and an orientation strategy (Dabbs, Chang, Strong, & Milun, 1998; Iachini, Sergi, Ruggiero, & Gnisci, 2005; Lawton & Morrin, 1999; O'Laughlin & Brubaker, 1998; Sandstrom et al., 1998; Saucier et al., 2003). There has been a significant advantage of males for spatial route learning through an unfamiliar environment and on tasks requiring survey knowledge, for example, pointing directions, drawing a sketch map and estimating travel distances

(Cubukcu & Nasar, 2005; Devlin & Bernstein, 1995; Lawton & Morrin, 1999; Moffat, Hampson, & Hatzipantelis, 1998; O'Laughlin & Brubaker, 1998; Tlauka et al., 2005). However, Iachini et al. (2005) found no gender difference in object recognition and in remembering absolute distance and categorical spatial relations, but the males were better than females in remembering the distance between the objects and the size of the layout.

Tlauka et al. (2005) expressed that gender was a predictor of spatial performance in the real world and in the VEs. With respect to the acquisition of spatial knowledge through virtual navigation, an inconsistent pattern of gender differences was revealed. Some studies reported a male advantage in a virtual maze navigation task (Lawton & Morrin, 1999; Moffat et al., 1998; Sandstrom et al., 1998; Waller, 2000); however, no gender difference was indicated in spatial knowledge tests in VEs (Darken & Sibert, 1996b; Wilson, Foreman, & Tlauka, 1997).

2.3. Previous experience in spatial updating

Another factor that can affect spatial updating is the previous spatial experience of people that can enhance their spatial abilities. "Different sources and amounts of experience may result in spatial knowledge and different usage of spatial knowledge over time" (Chen & Stanney, 1999, p. 676).

Also, males and females show differences in spatial knowledge and abilities due to the different utilizations of previous experience. "Males have more extensive experience with activities that help develop spatial skills, such as model planes and carpentry and video games" (Lawton & Morrin, 1999, p. 75). Lawton and Morrin (1999) showed that prior experience with video games involving navigation through VE resulted in higher pointing accuracies for males since video games were perceived as a masculine domain.

It is reported that computer-related experiences, such as computer-games, computer applications (computer-aided design and drawing) and video games improve the spatial abilities of individuals (Quaiser-Pohl, Geiser, & Lehmann, 2006). Quaiser-Pohl et al. (2006) proposed that "individuals' admission of playing certain types of computer-games is a useful predictor of spatial abilities" (p. 617), also playing computer-games was seen as a boy's toy and a male domain since males indicated that they played computer-games more frequently than females. Since males have more experience with video games, they report that they have more comfort and confidence with the computer (Waller, Hunt, & Knapp, 1998). The relationship between computer-game experience and spatial ability revealed an advantage for males. Their results indicated that spatial ability could be developed and be improved with prior computer experience (Quaiser-Pohl et al., 2006). As a result, previous experience or training may decrease gender differences and increase individuals' environmental familiarity (Chen & Stanney, 1999; Lawton & Morrin, 1999).

3. Research questions

A case study was conducted based on the egocentric rotations and translations that are experienced on a desktop VE. In order to assess the spatial updating performance in two movement types, a pointing task was utilized. The research issues consisted of the movement types and their relation to gender, computer abilities and spatial updating. Furthermore, it is aimed to answer the following questions:

1. Is there a significant difference between visual rotational and translational movements and spatial updating of an object (either viewed or imagined)?
2. Is there a significant difference between viewed and imagined objects in a movement type (either rotational or translational)?
3. Is there a significant relationship between gender and on the spatial updating of the viewed and imagined objects in a movement type (either rotational or translational)?
4. Is there a significant relationship between the preferred drawing medium and on the spatial updating of the viewed and aligned objects in a movement type (either rotational or translational)?

4. The experiment

4.1. The sample

The sample group consisted of the senior students of the Department of Interior Architecture and Environmental Design at Bilkent University. Eighty students were chosen randomly among 114 senior year students. The students were free to utilize any media, which consist of hand, computer or both, during the design process of the project and for the jury submissions in design courses. As senior students, they were familiar with computer-based environments, due to the computer-based courses that they took during the second and third years of their education and had sufficient design education background. In the sample, there were 42 (52.5%) females and 38 (47.5%) males whose age range was from 20 to 38. The mean age was 23.81, the median age was 23.00 and the standard deviation was 2.45.

4.2. Procedure

The study was conducted in two phases. In the first phase, the participants filled a computer usage questionnaire. Information was collected about the computer usage frequency, computer abilities, registered computer courses, media type and computer software preferences in 2D and 3D architectural drawings of the participants.

The sample was distributed into three groups according to the medium they preferred to use in their interior design studio submissions (i.e. hand, computer or both). Each group was evenly distributed among the two movement types (i.e. rotational and translational), considering a similar gender distribution of the participants. The distribution of the participants according to the preferred medium for the design submissions in the rotational and translational movement experiment groups is depicted in Table 1.

In the second phase, the evenly distributed participants in each group experienced the desktop VE with one of the viewer-based movement types. The participants were seated at the computer and were tested individually. A restaurant was selected as the experimental environment because it was a public place that had a simple plan in which the objects were distinct in their shapes and colors, where the participants were unfamiliar with the restaurant. They were asked to watch the virtual tour of the interior of the restaurant three times to learn the spatial locations of the objects in the VE. The rotational tour consisted of a counterclockwise rotation with the viewer at the center of the space. In the translational tour, the restaurant on the desktop was observed as analogous to the scene of a customer who is entering from the door, circulating all around and leaving the restaurant from the same door (see Fig. 1). Each tour lasted approximately a minute. In both movement types, only the viewer's viewpoint changed. At the end of the third trial, the computer was closed and a pointing task was conducted by using the direction circle method.

Waller, Beall, and Loomis (2004) indicated that the direction circle method is an effective tool for assessing knowledge of relative directions. In the direction circle method, participants are shown a circle; they have to imagine being at the location indicated at the center of the circle marked as X and facing to the direction of the location indicated at the top of the circumference of the circle marked as Y. The participants draw an arrow from the center of the circle (X) to the target object (Z). This arrow represents the relative direction of the target object (see Fig. 2). "The first two objects established

Table 1
Preferred media for the design drawings

Movement	Medium			
	Hand	Computer	Both	Total
Rotation	13	10	17	40
Translation	14	10	16	40
Total	27	20	33	80

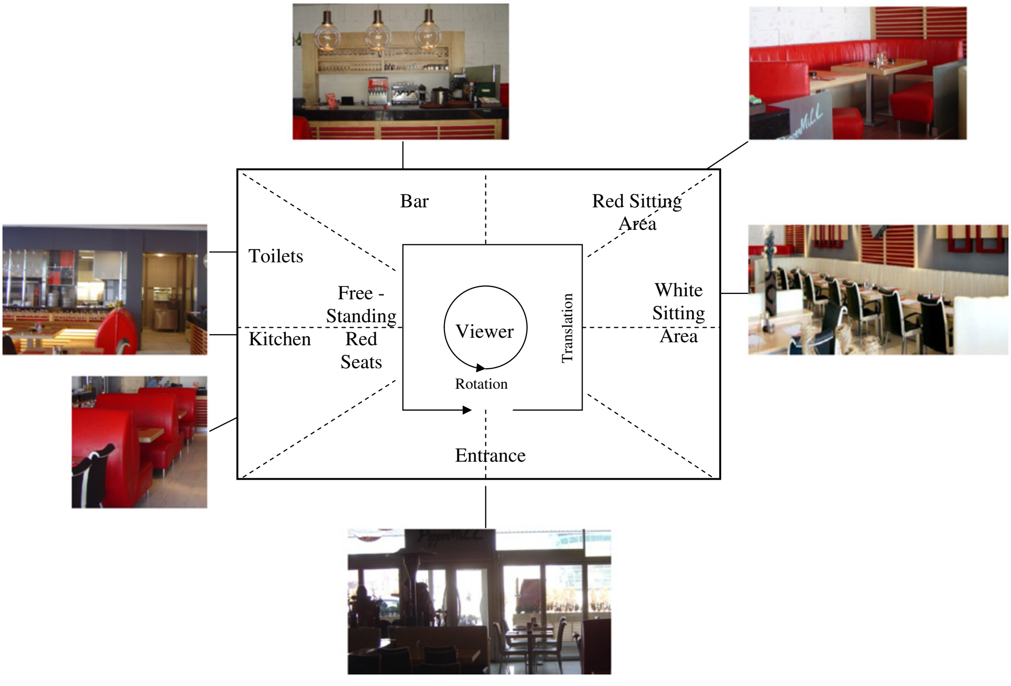


Fig. 1. Spatial layout of the experimental environment.

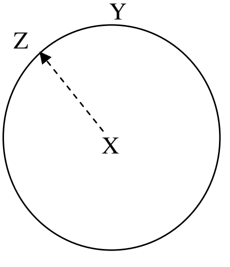


Fig. 2. Example of the direction circle method for assessing directional knowledge.

the imagined vantage point and heading and the third object was the target" (Shelton & McNamara, 2001, p. 282).

The pointing task, which utilized the direction circle method, consisted of two parts each with eight questions. In all of the questions, the participants were asked to imagine being at a location, turning to face a different orientation and point to the target object. Participants had to acquaint themselves with the imagined location and environmental surrounding. The questionnaire consisted of seven objects: the white sitting area, the red sitting area, the bar, the toilets, the kitchen, the free-standing red seats and the entrance (see Fig. 1).

In the first part, the objects in the questionnaire were in the order that the participants viewed them. For example, "imagine you are at the white sitting area (X) and facing the red sitting area (Y), point to the bar". The second part consisted of questions on objects that were in the reverse order of what the participants had viewed, for example, "imagine you are at the kitchen (X) and facing the toilets (Y), point to the white sitting area (see Appendix A). The questions were always presented to the subjects first at the viewed order than the reverse order.

The pointing direction (the direction of the target object relative of the heading) was varied systematically with 45° increments. A circle was divided into eight sections: 0°, 45°, 90°, 135°, 180°, 225°, 270° and 315°, and the right answer for each question was at one of these degrees (see Fig. 1). The pointing task took approximately 5–10 min in total. Each correct answer was marked as one point and the maximum point was 8 for both question types. The participants were evaluated according to the number of right answers they gave.

Two separate pilot studies were conducted before the tasks were assigned to the original sample. The first pilot study was carried out with 12 participants to test the clarity of the computer usage questionnaire. The second pilot study was done with 5 participants to check if they understood the objects in the pointing task after watching the virtual tours.

5. Results

5.1. Results related to computer usage questionnaire

In the computer usage questionnaire, the participants indicated that they mostly (95%) used the computer more than once a week. Their first priority in using the computer was Internet, the second was for drawing their interior design projects, the third was using the office programs and lastly for playing games. The participants mostly took the Computers and Geometry course two years ago, and the Computer-Aided Design (CAD) course either two years ago or last year. Thirty-seven and a half percent of the participants took extra lessons consisting mainly of 3D Max, Photoshop and AutoCad. For the 2D drawings, 51.3% of the participants preferred to use the both media, mainly utilizing the AutoCad program. Forty-seven and a half percent of the participants preferred to use the both media for the 3D drawings, mainly utilizing AutoCad and 3D Max together. Some of the participants (41.3%) again preferred to use the both media for their Interior Design jury submissions, mainly using AutoCad and 3D Max. This preference of using both media is followed by 33.8% in hand medium and 25.0% in computer medium.

5.2. Results related to correctly answered questions

5.2.1. Related to movement types

In order to test whether rotational or translational movements were efficient in the VE with respect to the correctly answered questions on viewed and imagined objects, an independent sample *t*-test and a bivariate correlation test were conducted. The mean of the correctly answered questions on viewed objects in the translational movement ($M = 4.80$, SD = 1.52) was significantly higher than that of the rotational movement ($M = 4.05$, SD = 1.26) as seen in Table 2. According to the questions on viewed objects, there was a significant difference in the rotational and translational movements ($t = 2.40$, df = 78, two-tailed $p = 0.019$). With respect to the correlation test, there was a low negative significant relationship between the translational and rotational movements in the correctly answered questions on viewed objects ($r = -0.26$, df = 78, $p < 0.019$). According to the questions on imagined objects, there was no significant difference with respect to the rotational and translational movements ($M = 3.30$, SD = 1.07 and $M = 3.58$, SD = 1.71, respectively and $t = 0.86$, df = 78, two-tailed $p = 0.390$).

Table 2
Mean (*M*) and standard deviation (SD) values for the correctly answered questions on viewed and imagined objects in each movement type

Movement	Objects	*M*	SD
Rotation	Viewed	4.05	1.26
	Imagined	3.30	1.07
Translation	Viewed	4.80	1.52
	Imagined	3.58	1.71

5.2.2. Related to viewed and imagined objects

The questions on viewed and imagined objects were assessed within each movement type by using a correlated *t*-test. In the rotational movement, the two means differed significantly ($t = 3$, df = 39, two-tailed $p < 0.005$) and there was no correlation between the correctly answered questions on viewed and imagined objects. The mean of the correctly answered questions on viewed objects was at 4 ($M = 4.05$, SD = 1.26) and imagined was at 3 ($M = 3.30$, SD = 1.07) as seen in Table 2.

For the translational movement, there was a significant difference between the correctly answered questions on viewed and imagined objects ($t = 5.66$, df = 39, two-tailed $p < 0.001$). The mean of the correctly answered questions on viewed objects was at 5 ($M = 4.80$, SD = 1.52) and imagined was at 4 ($M = 3.58$, SD = 1.71). The correlation test showed that there was a positive medium relationship ($r = 0.65$, df = 38, $p < 0.001$) between the correctly answered questions on viewed and imagined objects.

5.3. Results related to gender differences in each movement type

The gender differences were examined between the correctly answered questions on viewed and imagined objects in each movement type. In the rotational movement, the mean score for the correctly answered questions on viewed objects was rounded off to 4 ($M = 4.05$). There were 10 female and 8 male participants below the mean, and 11 female and 11 male participants above the mean. The mean score for the correctly answered questions on imagined objects was rounded off to 3 ($M = 3.30$). There were 6 female and 5 male participants below the mean, and 15 female and 14 male participants above the mean.

Chi-square analysis was used to find out if the success of the correctly answered questions on viewed and imagined objects were independent of gender in rotational movements. According to the chi-square test, there was no significant relationship between gender and the correctly answered questions on viewed and imagined objects ($\chi^2 = 0.12$, df = 1, $p = 0.73$ and $\chi^2 = 0.025$, df = 1, $p = 0.87$, respectively) in the rotational movement.

In the translational movement, the mean score for the questions on viewed objects was rounded off to 5 ($M = 4.80$). There were 10 female and 7 male participants below the mean, and 11 female and 12 male participants above the mean. For the questions on imagined objects, the mean score was rounded off to 4 ($M = 3.58$). There were 13 female and 9 male participants below the mean, and 8 female and 10 male participants above the mean.

The chi-square analysis indicated that there was no significant relationship between gender and the correctly answered questions on viewed and imagined objects ($\chi^2 = 0.47$, df = 1, $p = 0.49$ and $\chi^2 = 0.85$, df = 1, $p = 0.36$, respectively) in the translational movement. Therefore, it can be concluded that gender is independent from the correctly answered questions on viewed and imagined objects within the rotational and translational movements.

According to the independent *t*-tests, there were no significant differences in gender with respect to the correctly answered questions on viewed and imagined objects in rotational movements ($t = -0.76$, df = 38, two-tailed $p = 0.45$ and $t = 0.21$, df = 38, two-tailed $p = 0.84$, respectively) and in translational movements ($t = -1.00$, df = 38, two-tailed $p = 0.33$ and $t = -0.75$, df = 38, two-tailed $p = 0.46$, respectively).

5.4. Results related to interior design medium in each movement type

The mean (M) and standard deviation (SD) values for the correctly answered questions on viewed and imagined objects in each movement type are depicted in Table 3. The participants, who preferred computer as a medium, had the highest means at each category in each movement type. To determine if there was a significant relationship between the preferred drawing medium and the correctly answered questions on viewed and imagined objects, with respect to the rotational and translational movements, chi-square analysis tests were conducted.

In the rotational movement, there was a significant relationship between the preferred medium and the correctly answered questions on viewed objects ($\chi^2 = 8.06$, df = 2, $p = 0.018$). Participants who used the computer medium answered more questions correctly that were above the mean.

Table 3
Group statistics for viewer groups and medium

Movement	Objects	Medium					
		Hand		Computer		Both	
		M	SD	*M*	SD	*M*	SD
Rotation	Viewed	3.69	1.18	4.50	1.08	4.06	1.39
	Imagined	3.08	1.12	4.20	0.79	2.94	0.90
Translation	Viewed	4.36	1.39	6.60	0.70	4.06	1.06
	Imagined	3.57	1.16	5.70	0.95	2.25	1.00

However, there was no significant relationship between the preferred medium and the correctly answered questions on imagined objects ($\chi^2 = 5.10$, df = 2, $p = 0.078$).

In the translational movement, there were significant relationships between the preferred medium and the correctly answered questions on viewed and imagined objects ($\chi^2 = 9.86$, df = 2, $p = 0.007$ and $\chi^2 = 19.08$, df = 2, $p = 0.001$, respectively). In both question types (i.e. viewed and imagined), the computer medium users answered more questions correctly that were above the mean.

The uncorrelated analysis of variance (ANOVA) test was conducted to find if the number of correctly answered questions on objects in the three media have different means. In the rotational movement, there was a significant difference between the three media only for the questions on imagined objects ($F_{2,37} = 6.05$, $p = 0.005$). In the translational movement, there was a significant difference between the three media in questions on viewed and imagined objects ($F_{2,36} = 17.43$, $p = 0.001$ and $F_{2,37} = 33.44$, $p = 0.001$, respectively).

Furthermore, correlated *t*-test analysis was conducted with each medium in order to see if there was a difference in answering the questions on viewed and imagined objects. In the hand medium, according to the paired-sample *t*-test, there was no significant difference between the questions on viewed and imagined objects within the rotational movement ($t = 1.34$, df = 12, two-tailed $p = 0.206$. However, there was a significant difference between the questions on viewed and imagined objects within the translational movement ($t = 2.24$, df = 13, two-tailed $p = 0.043$).

In the computer medium, there was no significant difference between the viewed and imagined objects within the rotational movement ($t = 0.58$, df = 9, two-tailed $p = 0.58$). However, there was a significant difference between the viewed and imagined objects within the translational movement ($t = 3.86$, df = 9, two-tailed $p = 0.004$).

In the both media, there was a significant difference between the viewed and imagined objects within the rotational movement ($t = 3.08$, df = 16, two-tailed $p = 0.007$) and the translational movement ($t = 4.65$, df = 15, two-tailed $p = 0.001$).

6. Discussion

Riecke, van Veen, and Bülthoff (2002) demonstrated that purely visual path integration was sufficient for basic navigation tasks like rotations and translations. According to the correctly answered questions within the rotational and translational movements, the translational movement was more efficient in the virtual navigation. Participants were able to accurately update rotations from navigation in a VE, but with reduced accuracy when compared to translation. It was hypothesized that rotational movement would be efficient in a VE with respect to Tlauka (2007), who stated that "rotations (without translations) are commonly used in small-scale environments, i.e. spaces of low complexity that can be learned relatively quickly" (p. 516). The translational movement was seen to be less error-prone than the rotational movement because the participants were able to visualize themselves in the VE. The results are in line with Creem-Regehr's (2003) study in which rotations are more difficult to process than translations. Klatzky et al. (1998) explained that the difficulty in spatial updating during rotational movements is due to the lack of proprioceptive cues that assist self-rotation.

The questions on viewed objects were correctly answered more than the questions on imagined objects. This indicated that spatial updating of the VE was orientation-specific – the orientation in which it was learned, and the layout of the VE was mentally represented in terms of orientation-specific reference system as indicated by Shelton and McNamara (2001). Hutcheson and Allen (2005) stated that "if a participant is tested in the same orientation in which they learned the path, they should not have high latencies and errors in pointing" (p. 69). Likewise, Richardson, Montello, and Hegarty (1999) reported that the judgments of relative direction were more accurate when the orientation or the imagined heading was viewed with the original viewpoint seen at the beginning of the exploration (Mou, McNamara, Valiquette, & Rump, 2004b; Shelton & McNamara, 2001). In agreement with the previous studies, questions on viewed objects with the study proved to be more accurate. Spatial updating tasks mostly require participants to process a sequence of items. However, in the pointing task, the participants were asked to imagine themselves at an object location while facing another group of objects and point to the target object. These three object groups were temporary groups and did not follow a serial pattern. Therefore, the current study examined the spatial updating process of temporal object groups after rotational and translational movements in the VE rather than on memory for serial object information.

There was no relationship between gender and the movement types in the VE. Contrary to the previous studies (Saucier et al., 2003; Tlauka et al., 2005) that found gender differences in the ability to acquire spatial information and a male superiority in judgment of relative directions (Cubukcu & Nasar, 2005; Devlin & Bernstein, 1995; Lawton & Morrin, 1999; O'Laughlin & Brubaker, 1998), both genders within the two movement types performed equally well in the pointing task. Even though computers are seen as a male domain (Quaiser-Pohl et al., 2006), the present study revealed no gender differences. The reason for this indifference might be due to the similar computer experiences of the genders. Both genders were familiar with the computer since they used it more than once a week. Also, they had the same educational background and they were familiar with computer-based environments due to the compulsory computer-based courses that they took during the second and third years of their education.

The participants who used the computer medium in their Interior Design jury submissions were proven to be more successful in answering the questions on viewed and imagined objects within the translational movements and only the questions on imagined objects in the rotational movement. The computer users were more accurate because they drew their 2D and 3D drawings with the computer. Using the computer, particularly for doing the 3D drawings enabled the users to utilize the virtual tour property of the computer software programs. As a result, users of these programs were familiar with a virtual tour and they were able to visualize themselves within the VE. However, participants who used both media might not prefer to use the computer for their 3D drawings, but draw with their hands and use the computer for their 2D drawings. Because of this possibility they may not be familiar with the software programs and they might not have enough experience using the computer for their 3D drawings. The findings in this study also support the previous work of Bilda and Demirkan (2003) who reported that designers, who always used hand sketches as a cognitive tool throughout their education, limit their cognitive interaction with the digital media. Also, Ho, Eastman, and Catrambone (2006) stated that there is no evidence on "the effect of 2D and 3D spatial ability on design, or even how to effectively discriminate 2D and 3D spatial abilities" (p. 506). Their study also was in line with the previous studies that indicated that there is a strong overlap between 2D and 3D spatial ability.

7. Conclusion

According to the findings of the research, navigation in the form of translational movement in a desktop VE was found to be more accurate than rotational movement in spatial updating of the VE. The movement type in viewing the objects within the spatial layout of the VE had an effect on the question types. The questions on viewed objects were correctly answered more than the questions on imagined objects. It can be stated that spatial updating of the VE was orientation-specific. There was no gender difference between the male and female participants. Both genders performed equally well in the pointing task. The drawing medium was effective in answering the questions on viewed and imagined objects within the translational movement and only the questions on imagined objects in the rotational movement. Participants who used the computer medium performed better than the hand and both media in the pointing task.

VE technology offers the opportunity of controlling and manipulating the characteristics of a real world environment (Lessels & Ruddle, 2005; Waller, Knapp, & Hunt, 2001; Waller et al., 1998). Spatial knowledge acquired from the VE's can be effectively transferred to real world environments. With the VE's, designers and planners are able to assess and improve their designs and understand the environmental requirements that can ease the wayfinding difficulties for people with different characteristics (Jansen-Osmann, 2002; Ruddle & Peruch, 2004; Waller, Loomis, Golledge, & Beall, 2000). This study suggests that computer usage in architectural design drawings was an effective medium in the spatial updating process in a VE.

For further studies, navigation in different environments that can be complex based on the movement types and the drawing media can be compared. The effects of color and texture within the environments can be researched. The relationship between the angular disparity effect and the response times can be investigated with respect to the movement types and the drawing media.

Appendix A

Name

Pepper Mill Orientation Form

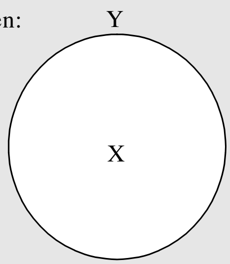
Please answer the following questions by drawing an arrow on the circle as shown in the example.

Part I

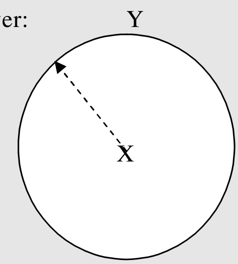
Example

Imagine you are at the middle of the white sitting area (X) and facing the red sitting area at the corner (Y), point to the bar.

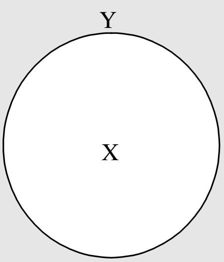
Given:



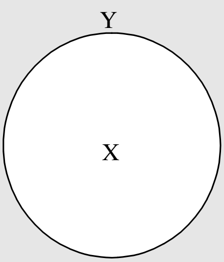
Answer:



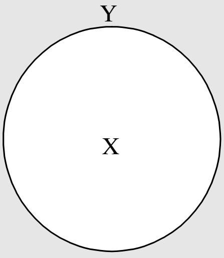
1. Imagine you are at the centre of the space (X) and facing the red sitting area at the corner (Y), point to the middle of the white sitting area.



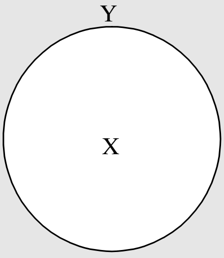
2. Imagine you are at the red sitting area at the corner (X) and facing the middle of the white sitting area (Y), point to the bar.



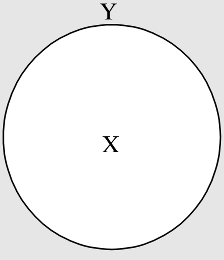
3. Imagine you are at the bar (X) and facing the red sitting area at the corner (Y), point to the kitchen.



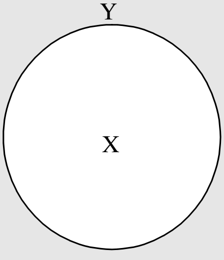
4. Imagine you are at the toilets (X) and facing the kitchen (Y), point to the bar.



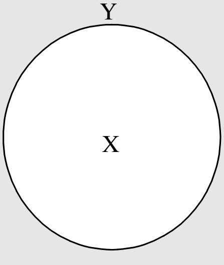
5. Imagine you are at the free-standing red seats (X) and facing the middle of the white sitting area (Y), point to the toilets.



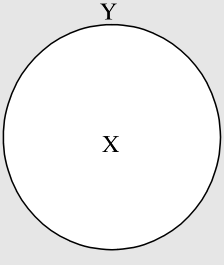
6. Imagine you are at the kitchen (X) and facing the free-standing red seats (Y), point to the toilets.



7. Imagine you are at the entrance (X) and facing the bar (Y), point to the kitchen.

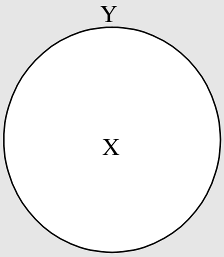


8. Imagine you are at the middle of the white sitting area (X) and facing towards the centre of the space (Y), point to the free-standing red seats.

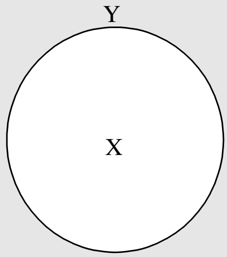


Part II

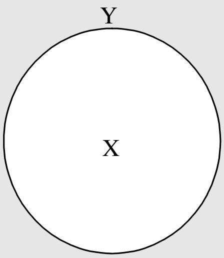
1. Imagine you are at the middle of the white sitting area (X) and facing the entrance (Y), point to the toilets.



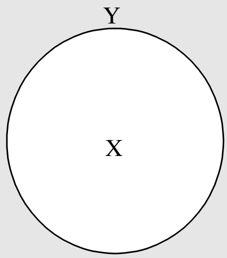
2. Imagine you are at the entrance (X) and facing the kitchen (Y), point to the middle of the white sitting area.



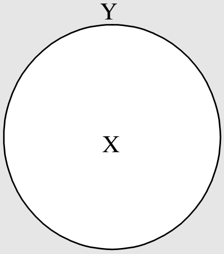
3. Imagine you are at the kitchen (X) and facing the toilets (Y), point to the entrance.



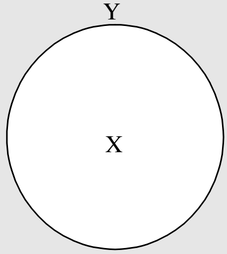
4. Imagine you are at the free-standing red seats (X) and facing the middle of the white sitting area (Y), point to the kitchen.



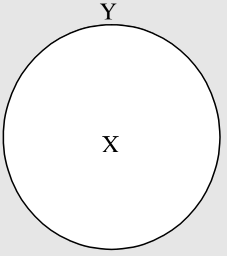
5. Imagine you are at the toilets (X) and facing the kitchen (Y), point to the red sitting area at the corner.



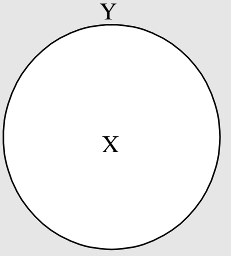
6. Imagine you are at the bar (X) and facing the toilets (Y), point to the free-standing red seats.



7. Imagine you are at the red sitting area at the corner (X) and facing the kitchen (Y), point to the entrance.



8. Imagine you are at the centre of the space (X) and facing the free-standing red seats (Y), point to the kitchen.



References

Amorim, M., & Stucchi, N. (1997). Viewer- and object-centered mental explorations of an imagined environment are not equivalent. *Cognitive Brain Research, 5*, 229–239.

Avraamides, M. N. (2003). Spatial updating of environments described in texts. *Cognitive Psychology, 47*, 402–431.

Bilda, Z., & Demirkan, H. (2003). An insight on designer's sketching activities in traditional versus digital media. *Design Studies, 24*(1), 27–50.

Bowman, D. A., Davis, E. T., Hodges, L. F., & Badre, A. N. (1999). Maintaining spatial orientation during travel in an immersive virtual environment. *Presence, 8*(6), 618–631.

Chen, J., & Stanney, K. (1999). A theoretical model of wayfinding in virtual environments: Proposed strategies for navigational aiding. *Presence, 8*(6), 671–685.

Creem, S. H., Wraga, M., & Proffitt, D. R. (2001). Imagining physically impossible transformations: Geometry is more important than gravity. *Cognition, 81*, 41–64.

Creem-Regehr, S. H. (2003). Updating space during imagined self- and array translations. *Memory and Cognition, 31*(6), 941–952.

Cubukcu, E., & Nasar, J. L. (2005). Relation of physical form to spatial knowledge in large-scale virtual environments. *Environment and Behavior, 37*(3), 397–417.

Dabbs, J. M., Chang, E. L., Strong, R. A., & Milun, R. (1998). Spatial ability, navigation strategy, and geographic knowledge among men and women. *Evolution and Human Behavior, 19*, 89–98.

Darken, R. P., & Sibert, J. L. (1996a). Navigating large virtual spaces. *International Journal of Human-Computer Interaction, 8*, 49–71.

Darken, R. P., & Sibert, J. L. (1996b). Wayfinding strategies and behaviors in large virtual worlds. In *Proceedings of CHI '96*, pp. 142–149.

Devlin, A. S., & Bernstein, J. (1995). Interactive wayfinding: Use of cues by men and women. *Journal of Environmental Psychology, 15*, 23–38.

Easton, R. D., & Sholl, M. J. (1995). Object-array structure, frames of reference, and retrieval of spatial knowledge. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 21*, 483–500.

Ho, C. H., Eastman, C., & Catrambone, R. (2006). An investigation of 2D and 3D spatial and mathematical abilities. *Design Studies, 27*(4), 505–524.

Hutcheson, A., & Allen, G. L. (2005). Path memory in real-world and virtual settings. *COSIT 2005* LNCS 3693, 67–82.

Iachini, T., Sergi, I., Ruggiero, G., & Gnisci, A. (2005). Gender differences in object location memory in a real three-dimensional environment. *Brain and Cognition, 59*, 52–59.

Jansen-Osmann, P. (2002). Using desktop virtual environments to investigate the role of landmarks. *Computers in Human Behavior, 18*, 427–436.

Klatzky, R. L., Loomis, J. M., Beall, A. C., Chance, S. S., & Golledge, R. G. (1998). Spatial updating of self-position and orientation during real, imagined, and virtual locomotion. *Psychological Science, 9*, 293–298.

Lawton, C. A., & Morrin, K. A. (1999). Gender differences in pointing accuracy in computer-simulated 3D mazes. *Sex Roles, 40*(1/2), 73–92.

Lessels, S., & Ruddle, R. A. (2005). Movement around real and virtual cluttered environments. *Presence, 14*(5), 580–596.

May, M. (2004). Imaginal perspective switches in remembered environments: Transformation versus interference accounts. *Cognitive Psychology, 48*, 163–206.

Moffat, S. D., Hampson, E., & Hatzipantelis, M. (1998). Navigation in a "virtual" maze: Sex differences and correlation with psychometric measures of spatial ability in humans. *Evolution and Human Behavior, 19*, 78–87.

Mou, W., Zhang, K., & McNamara, T. P. (2004a). Frames of reference in spatial memories acquired from language. *Journal of Experimental Psychology: Learning Memory, and Cognition, 30*(1), 171–180.

Mou, W., McNamara, T. P., Valiquette, C. M., & Rump, B. (2004b). Allocentric and egocentric updating of spatial memories. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 30*(1), 142–157.

O'Laughlin, E. M., & Brubaker, B. S. (1998). Use of landmarks in cognitive mapping: Gender differences in self report versus performance. *Personality and Individual Differences, 24*(5), 595–601.

Presson, C. C., & Montello, D. R. (1994). Updating after rotational and translational body movements: Coordinate structure of perspective space. *Perception, 23*, 1447–1455.

Quaiser-Pohl, C., Geiser, C., & Lehmann, W. (2006). The relationship between computer-game preference, gender, and mental-rotation ability. *Personality and Individual Differences, 40*, 609–619.

Richardson, A. E., Montello, D. R., & Hegarty, M. (1999). Spatial knowledge acquisition from maps and from navigation in real and virtual environments. *Memory and Cognition, 27*(4), 741–750.

Riecke, B. E., van Veen, H. A. H. C., & Bülthoff, H. H. (2002). Visual homing is possible without landmarks: A path integration study in virtual reality. *Presence: Teleoperators and Virtual Environments, 11*, 443–473.

Rieser, J. J. (1989). Access to knowledge of spatial structure at novel points of observation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 15*, 1157–1165.

Ruddle, R. A., & Peruch, P. (2004). Effects of proprioceptive feedback and environmental characteristics on spatial learning in virtual environments. *International Journal of Human-Computer Studies, 60*, 299–326.

Sancaktar, I. (2006). Updating spatial orientation in virtual environments. Unpublished Masters Thesis. Ankara: Bilkent University.

Sandstrom, N. J., Kaufman, J., & Huettel, S. A. (1998). Males and females use different distal cues in a virtual environment navigation task. *Cognitive Brain Research, 6*, 351–360.

Saucier, D., Bowman, M., & Elias, L. (2003). Sex differences in the effect of articulatory or spatial dual-task interference during navigation. *Brain and Cognition, 53*, 346–350.

Shelton, A. L., & McNamara, T. P. (2001). Systems of spatial reference in human memory. *Cognitive Psychology, 43*, 294–310.

Tlauka, M. (2007). Rotational movements in real and virtual environments. *Computers in Human Behavior, 23*(1), 515–524.

Tlauka, M., Brolese, A., Pomeroy, D., & Hobbs, W. (2005). Gender differences in spatial knowledge acquired through simulated exploration of a virtual shopping centre. *Journal of Environmental Psychology, 25*, 111–118.

Waller, D. (2000). Individual differences in spatial learning from computer-simulated environments. *Journal of Environmental Psychology, 25*, 111–118.

Waller, D., Beall, A. C., & Loomis, J. M. (2004). Using virtual environments to assess directional knowledge. *Journal of Environmental Psychology, 24*, 105–116.

Waller, D., & Hodgson, E. (2006). Transient and enduring representations under disorientation and self-rotation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 32*(4), 867–882.

Waller, D., Hunt, E., & Knapp, D. (1998). The transfer of spatial knowledge in virtual environment. *Presence, 7*(2), 129–143.

Waller, D., Knapp, D., & Hunt, E. (2001). Spatial representations of virtual mazes: The role of visual fidelity and individual differences. *Human Factors, 43*, 147–158.

Waller, D., Loomis, J. M., Golledge, R. G., & Beall, A. C. (2000). Place learning in humans: The role of distance and direction information. *Spatial Cognition and Computation, 2*, 333–354.

Wilson, P. N., Foreman, N., & Tlauka, M. (1997). Transfer of spatial information from a virtual to a real environment. *Human Factors, 39*(4), 526–531.

Witmer, B. G., Bailey, J. H., Knerr, B. W., & Parsons, K. C. (1996). Virtual spaces and real-world places. Transfer of route knowledge. *International Journal of Human-Computer Studies, 45*, 413–428.

Wraga, M. (2003). Thinking outside the body: An advantage for spatial updating during imagined versus physical self-rotation. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 29*, 993–1005.

Wraga, M., Creem, S. H., & Proffitt, D. R. (1999). The influence of spatial reference frames on imagined object- and viewer rotations. *Acta Psychologica, 102*, 247–264.

Wraga, M., Creem-Regehr, S. H., & Proffitt, D. R. (2004). Spatial updating of virtual displays during self- and display rotation. *Memory and Cognition, 32*, 399–415.