University of Twente
Enschede - The Netherlands

6th October, 2008 .

The Role of Texture Fidelity on Spatial Learning in Synthetic Environments

Author:

Branko Lennart Geudeke bgeudeke@gmail.com

Tutors:

Frank Meijer f.meijer@gw.utwente.nl

Egon L. van den Broek vandenbroek@acm.org

Department of Cognitive Psychology and Ergonomics, Faculty of Behavioral Sciences, University of Twente, P.O. Box 217, 7500 AE, Enschede, The Netherlands

Abstract

Synthetic environments are slowly adopted for experimental use, cooperative product design and rapid prototyping. However, the influence of single variables on spatial learning is not fully known. The current study investigated the role of texture fidelity on spatial learning in a virtual supermarket. Participants were tested on route and survey knowledge in either a High Fidelity condition, containing high-resolution photos, or a Low Fidelity condition consisting of gray tones. It was hypothesized that better spatial knowledge will form in the High Fidelity condition than in the Low Fidelity condition, and that spatial ability would positively influence spatial learning. Main results indicate that in the High Fidelity condition, both the time to walk the learning route, and the number of survey knowledge errors made, measured by a route reverse task, increased. Pretest data shows an influence of gender on several test completion times. Males take less time to complete the tests than females. Observations during the experiment suggest that the formed cognitive map is incomplete, with a preferred mental frame of reference. Together, the results indicate that the High Fidelity condition does impact spatial learning in a synthetic environment negatively. It increases both the learning time and the number of errors made. Because it does not seem to aid spatial learning, High Fidelity texture conditions in a synthetic environment may not be necessary for navigational applications

1.1 Introduction

Being unable to read a license plate from more than a meter away, when not wearing contact lenses, I can still cycle into the city and go shopping, without crashing or getting lost. As this example illustrates, it is possible to rely on previously acquired spatial information, and navigate normally despite impaired visual input. This raises the question as to what degree of fidelity is needed to successfully navigate through an environment.

Many factors influence spatial learning both in real and virtual conditions; e.g. landmarks, lighting and viewing distance (Vinson, 1999; Christou & Bülthoff, 2000; Gillner & Mallot, 1998). Still, not all influential factors are known. Now, advances in computer technology enable the creation of evermore realistic virtual environments, also called synthetic environments (SE). Parameters that are difficult to alter in a real setting can be manipulated relatively easy in a SE. Therefore, a SE can aid the field of experimental psychology in determining what factors are needed for a credible representation of an environment. SE's originated for military applications, i.e., simulations, interfacing, and visualizations. They are defined as a linked set of models, simulations, people and equipment (Munro, 2003), with a certain degree of fidelity, needed to achieve a credible representation of the real world. Commercial applications of SE's lie in cooperative product design (Van den Broek et al., 2008) and rapid prototyping, using the environments as an early design and communication tool, involving all relevant stakeholders. SE’s are slowly adopted for experimental use (Loomis & Blascovich, 1999), but the amount of fidelity needed to create a realistic environment is not fully known. Researchers like Christou and Bülthoff (1999) have begun answering this question by using realistic virtual environments to determine the impact of optical flow and realistic 3D objects on environment learning, and texture on depth perception (Christou & Bülthoff, 2000). For SE’s to become an important cost and time effective research tool, more research is needed to determine what degree of fidelity is needed to create a realistic SE.

The current study is the second part of the project ‘Synthetic Environments’, a cooperation of SenterNovem and T-Xchange (T-Xchange, 2008) with the University of Twente. T-Xchange engages in rapid prototyping with what they call ‘serious gaming’: the use of SE’s to test the impact of design decisions during early development of a product. For this purpose, a virtual supermarket, the ‘Urban Mobility Game’, has been developed by T-Xchange to test a personal transportation device. One of the most time and resource consuming factors in the development, was to make a realistic, high fidelity environment. To create a high fidelity environment, texture was added: high resolution photos were mapped onto the 3D objects. These photos created recognizable objects and object categories in the environment where without it there would have been none. This is referred to as intrinsic semantic value. Because little is known about the role of texture fidelity, and its addition significantly increases the time of rapid prototyping, its role on spatial learning in a SE will be tested.

1.2 Spatial learning

The contact lenses example illustrates that bad eyesight almost does not influence my ability to navigate through an environment. We do not depend solely on things we see directly, in order to find our way in an environment. Navigating to a place out of view requires a view independent representation of objects and their spatial relationship (Satalich, 1995). In unfamiliar places, we can use a map or GPS navigation system. For a familiar environment, we can rely on previously acquired knowledge and plan a route through a familiar environment, even without visual input. We do this by means of a mental representation of an environment, called a cognitive map. So how do we form this cognitive map? The landmark-route-survey (LRS) of Siegel and White (1975) is the most accepted theory of spatial learning. It explains how egocentric information is converted to allocentric information. In other words, it explains how we use the things we see to construct a mental map. An unfamiliar environment is learned in three successive stages: 1) descriptive landmark information acquisition, 2) formation of route knowledge: a set of paths, turns and directions to reach a destination, and 3) formation of survey knowledge from which unique solutions for a given navigational problem can be inferred. Following the LRS, cognitive maps are generally divided into route and survey knowledge. The former can be seen as composed of egocentric sensory experience. The latter is abstract, generalized beyond sensory experience (Bülthoff & Christou, 2000). Survey knowledge is believed to form after sufficient sensory experience (Christou & Bülthoff, 1999).

The term cognitive map may be confusing, as it implies a faithful representation of an environment. In fact, a cognitive map is not a map per se. A review of the available literature on cognitive maps reveals a more detailed description. First of all, a cognitive map is a view dependant knowledge structure (Albert et al., 1999), meaning it is hard not to adhere to a learned perspective (Van Asselen, 2006). Spatial knowledge is usually egocentric (Christou & Bülthoff, 1999; Diwadkar & McNamara, 1997) with a strong preference for the initial orientation in a (virtual) environment (Richardson et al., 1999). Second, a cognitive map contains incomplete, abstract, and distorted data, with different levels of detail and integration (Kitchin, 1994; Gillner & Mallot, 1998; Vinson, 1999). Hence, a cognitive map is no faithful representation of the real world. Third, a cognitive map is dynamic and constructed for a goal. Constant cognitive transformations acquire, code, store, recall, and decode spatial information into a cognitive map (Billinghurst & Weghorst, 1995). The acquired spatial information can later be used to suit specific events (Christou & Bülthoff, 2000). Thus, there is no single cognitive map, but a map is constructed from acquired knowledge to form a solution to a given task or event. In this regard, a cognitive map is dynamic (Kitchin, 1994). Summarized, these finding suggest that a cognitive map is a view dependant, goal-directed knowledge structure, founded on incomplete, abstract, and distorted data.

Spatial learning in a virtual environments faces some limitations, but enables the detailed study of single environmental variables on spatial learning. One reported disadvantage is that route knowledge develops more slowly in a virtual environment than in an equivalent real environment (Ruddle et al., 1997). The disadvantages of older virtual environments, i.e., poor resolution, low quality, reduced peripheral view (Billinghurst & Weghorst, 1995), are countered by modern synthetic environments with wide, high resolution displays. Other problems, such as the lack of feedback from one's balance system or body position, are not easily solved by advances in technology (Ruddle & Péruc, 2004). Despite the possible limitations of a virtual environment compared to a real situation, learning of either environment depends on the same principles. Learning a simple virtual environment seems highly predictive for learning a real environment, as knowledge transfers between both conditions (Darken et al., 1998; Richardson et al., 1999).

1.3 The current study

The following research question is to be answered: What is the influence of texture fidelity conditions on spatial learning in a synthetic environment? To investigate this, the formation of route knowledge and the subsequent transformation to survey knowledge has to be measured in a High Fidelity and a Low Fidelity condition. Low Fidelity conditions consist of gray toned shapes. High Fidelity conditions incorporate high resolution photos, mapped onto the environment. They add intrinsic semantic value; they create recognizable objects and object categories, a group of similar objects, within the environment. These reference points and categories can be stored in one’s mental map as type of landmark, called districts (Vinson, 1999). Inline with the LRS of Siegel and White (1975), we expect that this information, present only in the High Fidelity condition, improves the acquisition of route knowledge, compared to the Low Fidelity condition without such cues (Ruddle et al., 1997). The first hypothesis is formed: better spatial learning is expected in the High Fidelity environment than in the Low Fidelity condition. Following the claim of Darken & Banker (1998) that ability is more important than training, both inherent spatial ability and learned skills will be tested. We expect that spatial ability will positively influence spatial learning. Moreover, as gamers are used to navigating virtual environments, it is expected that they are less influenced by the inherent limitations of virtual environments, and show better spatial learning. Summarized, it is expected that high scores on ability tests will correspond with better spatial learning.

To test both hypotheses, participants' spatial abilities and game experience will be measured beforehand, then the formation of route and survey knowledge will be measured after exposure to the SE. The following tests were selected because of their adaptability for this experiment. Route knowledge was tested by drawing the walked route on a map (Van Asselen et al., 2006). Survey knowledge was scored by two tests. One where the correct map of the environment must be selected from a number of alternatives (Christou & Bülthoff, 1999), and one where participants had to walk a route in the opposite direction, as this can indicate dependence on route knowledge (Van Asselen et al., 2006). To control for personal factors, a questionnaire to determine the amount of game experience, and a spatial ability test has been included in the experiment.

2. Methods

2.1 Participants

32 Students of the University of Twente (20 females and 12 males), aged 18 to 29, with a mean age of 21.9 participated in the research. Participants were equally divided between the conditions. All participants were right handed, and reported no known neurological or visual disorders.

2.2 Apparatus

A 3.0 Ghz Pentium IV computer was connected to a 42 inch Panasonic TH-42PY70 plasma screen, with a resolution of 1920x1080 pixels and a frame rate of 60 frames per second. The keyboard arrows were used to walk, a mouse to look around. The distance between the participant and the monitor was kept constant at 150 centimeters.

2.3 Stimuli

As environment, a virtual supermarket, based on Thales T-Xchange´s ´Urban Mobility Game´ (T-Xchange, 2008) was used, as is shown in Figure 1. A variety of high and low shelves stood against the walls of a15x15 meters area. Six long vertical and three horizontal isles were formed by the supermarket shelves. An extrusion with a low table created a separate shopping area. Four cash registers were placed near the exit in the bottom right corner. Overall ambient light was present and complemented by some spots. Realistic light calculation methods were regarded unnecessary for a realistic environment (Christou & Bülthoff, 2000).

The supermarket was rendered in two manners: in High Fidelity and in Low Fidelity. The High Fidelity condition contained high-resolution photos, see also Figure 2. In the Low Fidelity condition, these photos were absent, and plain shelves of a gray tone replaced them, as shown in Figure 3. Following a basic supermarket layout (Larson et al., 2005), a distinction was made between several product categories: fruit and vegetables, meat, milk products, cheese, bakery, frozen goods, drinks, canned products, cleaning supplies, and animal food.

The virtual supermarket enabled participants to navigate at walking speed, in a first person view. Viewpoint height was on 180 centimeter. Movements as jumping or kneeling were impossible.

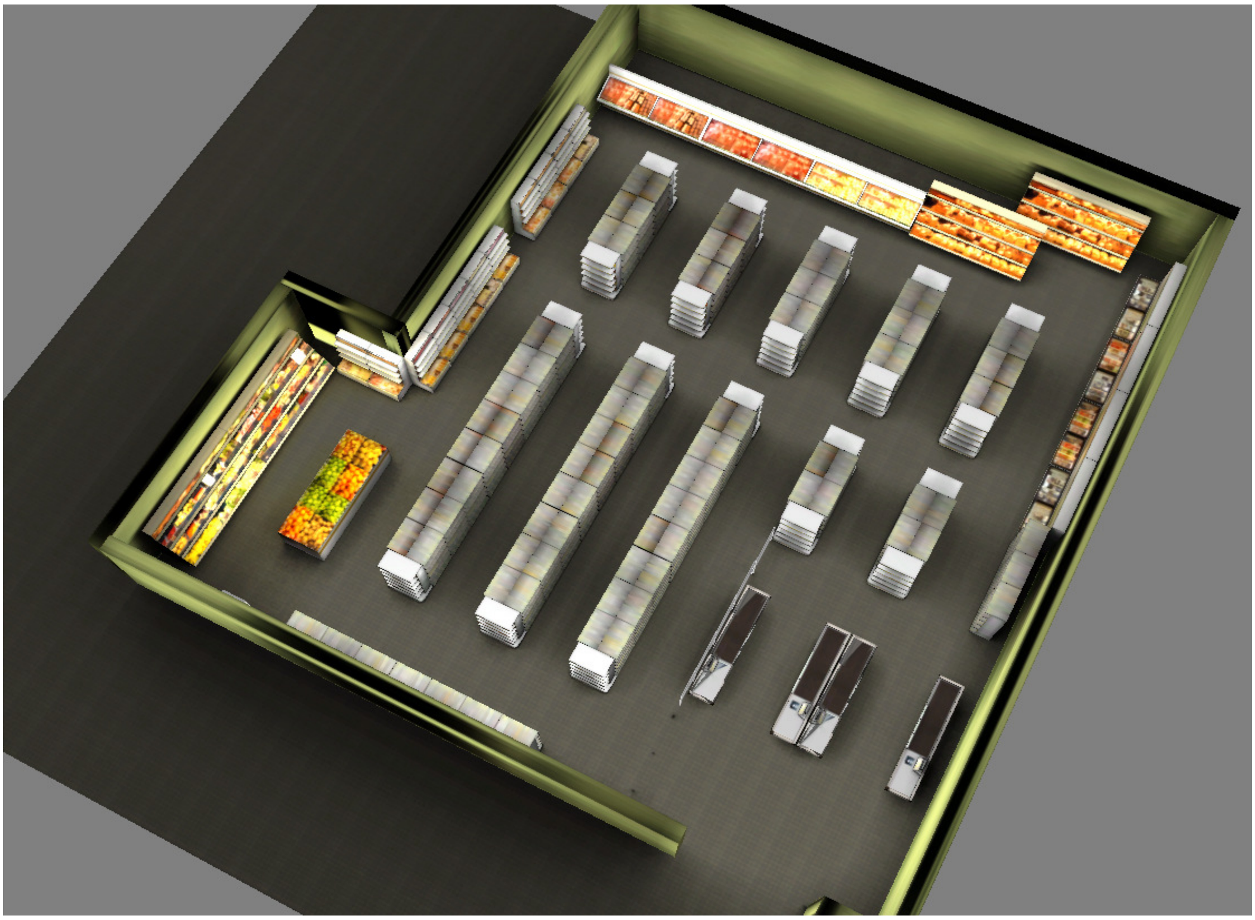

Figure 1. Bird's eye view of the virtual supermarket used for this experiment.

Figure 2. A picture of the virtual supermarket as used in the High Fidelity condition.

Figure 3. A picture of the virtual supermarket as used in the Low Fidelity condition.

2.4 Task and procedure

The experiment consisted of three phases; the pre tests, acquisition, and test phase. Before the experiment started, each participant was assigned to either the High Fidelity or Low Fidelity condition. Participants were tested in a predetermined, standard manner, with scripted instructions. They were informed of the general purpose of the study and signed an informed consent.

2.4.1 Pretest phase

All pre-tests were offered on a paper handout. First, age and sex were filled in, followed by a short game experience questionnaire on paper. This game questionnaire was created for this experiment, in order to determine how often participants play video games, and assess their self reported skill. Subsequently, the spatial ability test was made. The Hegarty ‘perspective taking and spatial orientation test’ (Hegarty & Waller, 2004) was used to determine one’s ability to imagine the relative position of objects in egocentric perspective from an exocentric image on paper. Participants received verbal instruction in Dutch. Within five minutes, 15 test questions had to be answered. After the experiment, the Hegarty test was scored through:

- The absolute difference between a participant’s response and the correct direction;
- Participant’s final score: the calculated average error in degrees.

2.4.2 Acquisition phase

After verbal instructions on how to move in the virtual supermarket, participants walked outside the supermarket to get accustomed to the controls. To acquire spatial knowledge, the participants were guided through the virtual supermarket on a fixed learning route, see Figure 4. Verbal instructions were used (e.g., left, right, or turn), to prevent that the participants were distracted by visual instructions (Satalinch, 1995). In order to promote active learning of the virtual supermarket, participants were asked to pay as much attention to the environment as possible. Also, they were instructed to walk at their preferred pace and keep looking around. The learning route was designed to be logical, with a clear start, middle and end section (Larson et al., 2005), but still be challenging enough to avoid a ceiling effect. Starting at the entrance, the learning route followed the outside isles, both horizontal and vertical, as is shown in Figure 4. The middle section of the learning route incorporated one 180 degrees turn and a loop. Three isles were not passed through; two parts of an isle were traveled two times, once in the same, once in the opposite direction. The learning route ended after passing the cash register; note that this was not outside the supermarket.

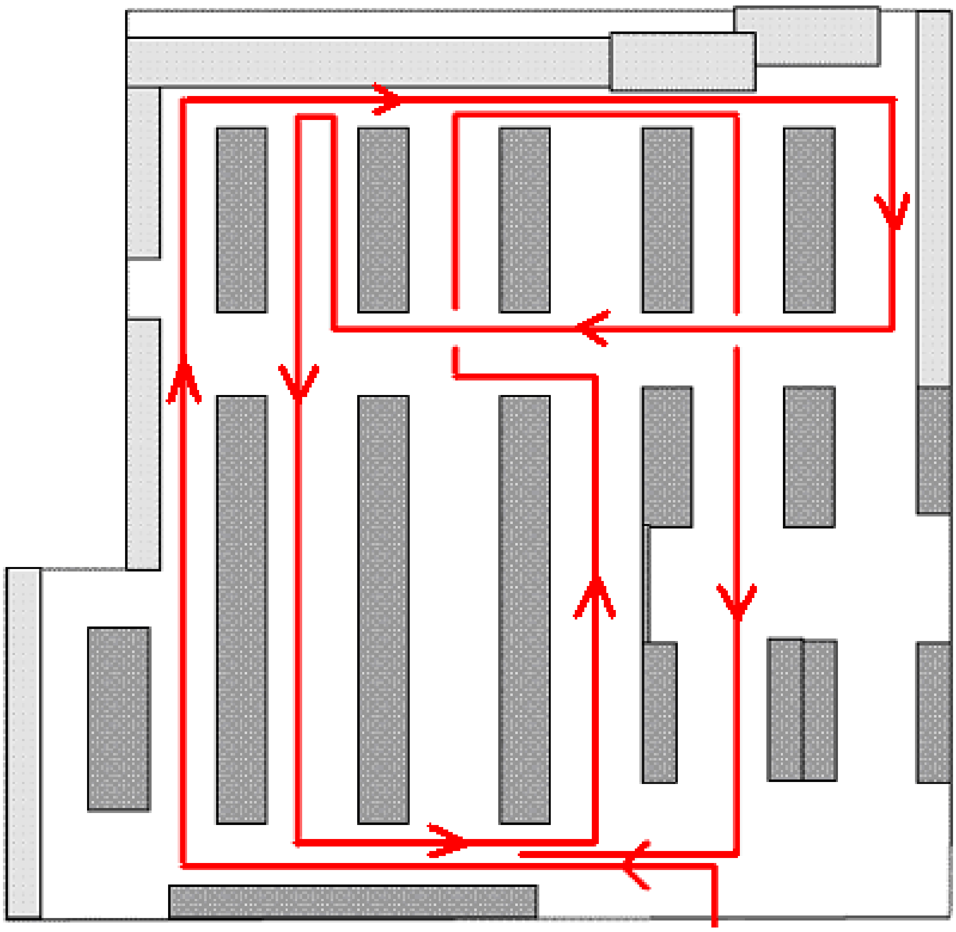
Figure 4. The learning route through the virtual supermarket.

2.4.3 Test phase

After the participants completed the learning route, they proceeded with the first survey knowledge test: the route reverse task. Participants were asked to walk the learning route in reverse. Completion time, the route followed, and handedness were recorded. The amount of errors in the reverse route were scored with an adapted version of Van Asselen et al.'s (2006) method, where one point was awarded per correct decision. In this experiment, one error point was scored for following an incorrect direction. In addition, the following information was recorded: the total number of turns made, the number of times an unused isle was traveled, whether the 180 degree turn had been remembered, and whether the end location was correct.

Second, survey knowledge was measured using the map select task. Participants were asked to select the correct map out of ten possible paper maps (Christou & Bülthoff, 2000). In case a false map was chosen, the participant could try once more. If the participant selected a false map on both tries, the correct map was shown before continuing with the third test. All maps were offered on a square piece of paper, so participants were able to rotate it to fit their mental reference view. Nine incorrect maps had either a square outline, one too many rows of shelves, single long shelves, ninety degree rotated shelves, were mirrored, or had a combination of these errors. Besides the test completion time, the map numbers as chosen by the participant were noted. This data offers a good/false score and error categories. Also, it was noted whether or not participants kept rotating the paper maps during the task.

The third test was a route knowledge test: the draw route task. Participants were asked to draw the original learning route on the correct paper map (Van Asselen et al., 2006). Furthermore, the same information as in the route reverse task was recorded: the total number of turns made, the number of times an unused isle was traveled, whether the 180 degree turn had been remembered, and whether the end location was correct. Additionally, it was noted whether the drawn start location was correct and whether participants kept rotating the map during the draw route task or not.

The fourth test was a combined route and survey knowledge test: the view draw task. Participants were asked to indicate on a map (using a dot and an arrow), the correct location and direction of fifteen photos, made in the virtual supermarket. Drawing time and the total number of errors were recorded. Errors were defined as: the incorrect isle, the incorrect location within the isle, and a viewing direction pointing into the wrong quadrant. After completing all tests, the preliminary results for each test were disclosed to the participant.

3. Results

Three Multivariate ANalyses Of VAriance (MANOVA) were performed to investigate the main hypothesis, two of which investigated the effect of the fidelity condition on both the error data and the test completion times and one for the effect of pre test data. Furthermore, several observations made during the experiment are summarized and reported here as a separate section.

3.1 Results for the error data

First, the reverse route task showed a significant main effect of the fidelity condition (High Fidelity, Low Fidelity), $F(1, 31) = 5.14$, $p = .031$. Participants made more errors in the High Fidelity condition (M = 7.62, SD = 5.02) than in the Low Fidelity condition (M = 4.19, SD = 3.41). Second, the map select task showed no difference between the High Fidelity condition (M = .50, SD = .52) and the Low Fidelity condition (M = .38, SD = .50). Third, the draw route task showed a comparable amount of errors in the High Fidelity condition (M = 6.69, SD = 3.16) and in the Low Fidelity condition (M = 5.81, SD = 3.10). Last, on the view draw task, participant errors were equal in the High Fidelity condition (M = 5.69, SD = 2.41) and in the Low Fidelity condition (M = 5.69, SD = 2.60).

3.2 Results for the task completion time

Time to complete the learning route showed a significant main effect of the fidelity condition $F(1,31) = 6.29$, $p = .018$): Participants walked through the virtual supermarket slower in the High Fidelity condition (M = 291, SD = 138.5s) than in the Low Fidelity condition (M = 199, SD = 50.0s). The completion times for the four tasks (route reverse, map select, draw route, draw views), showed no significant main effect for the fidelity condition.

3.3 Results for the pre test data

Various testing times showed a significant main effect of gender (Table 1): Male participants completed the tests faster than the female participants. Learning time showed a significant interaction effect of fidelity * gender ($F(1, 28) = 10.26$, $p = 0.03$) (M = 245, SD = 112.6s). Male participants spent less time walking through the virtual supermarket M = 174, SD = 37.2s) than the female participants (M = 288, SD = 121.7s). The game experience questionnaire showed a significant main effect of how often games were played on the time to walk the learning route in reverse ($F(4, 10) = 4.064$, $p = .033$), with (M = 206, SD = 110.1). The Hegarty test results showed no significant effect on testing times. None of the pretest data showed any significant main or interaction effects on error scores.

Table 1. MANOVA results for the effects of gender on task completion times in seconds.

Dependent Var.	F (1, 31)	p	M		SD	
			Male	Female	Male	Female
Learning Time	10.97	0.002*	174	248	37.2	121.4
Route Reverse Task	10.04	0.003*	140	244	59.5	102.4
Map Select Task	.66	0.423	150	174	73.5	82.5
Route Draw Task	6.44	0.016*	98	181	42.3	108.2
View Draw Task	2.26	0.143	421	512	153.8	170.1

* $p < .05$

3.4 Observations during the experiment

In the reverse route task, participants often did not remember the exact correct end location of the learning route (n = 12, 37.5%). However, when disregarding the correct end location, it becomes apparent that large segments of the beginning and the end of the learning route could be remembered. Of all participants, 20 (62.5%) remembered the first 3 to 8 to turns correctly and 23 (71.9%) remembered the last 3 to 8 to turns correctly on the reverse route task.

The results of the map selection task show that 14 (43.8%) of the 32 participants were able to select the correct map. For the first choice, common errors lied in selecting a map with six rows of shelves (N = 19, 59.3%) or a square outline (N = 11, 34.3%), but none with long undivided shelves. Of the 21 participants who reported a second choice, six row errors were persistently common (N = 13, 61.9%), but square map outline errors less (N = 3, 14.3%).

In the draw route task, participants often did not remember the exact correct end location of the learning route (N = 7, 21.9%). The start location was correct for most participants, with (N = 25, 78.1%) correct answers. Participants also remembered large segments of the beginning of the learning route. Equal to the reverse route task, 20 participants (N = 20, 62.5%) remembered the first 3 to 8 to turns correctly. Only 5 participants (15.6%) remembered the last 3 to 8 to turns correctly on the draw route task. A paired t-test showed a significant difference between the last occurrence of errors between the route reverse and the route draw task with better performance in the reverse task ($t(31) = -5.42$, $p < .001$).

As the last three tests included a paper map, it was noted whether participants kept rotating the maps. In the map selection task (n = 6, 18.8%) participants rotated the map, but during route drawing none. 21 Participants rotated the map in the view draw task (n = 21, 65.6%).

4. Discussion

In the current study, the role of High Fidelity and Low Fidelity texture conditions on spatial learning in a synthetic environment, a virtual supermarket, was investigated. Participants were tested on route and survey knowledge in two groups, either High Fidelity or Low Fidelity. Results showed that participants made more errors in the route reverse task in High Fidelity condition than in the Low Fidelity condition. Participants walked the learning route through the virtual supermarket slower in the High than in the Low Fidelity condition. Moreover, pretest data showed that gender influenced test completion time: male participants were faster than the female participants. Observations during the experiment suggest that participants persistently selected maps with six isles, remember large portions of the beginning of the learning route, and often rotate maps during the view drawing task but not during the route draw task.

The significant difference in survey knowledge between the High Fidelity and Low Fidelity conditions, leads to three conclusions. First, it suggests that the formation of route knowledge is unaffected by the fidelity condition, as the scores on the route draw task were not significantly different between both conditions. Second, because impaired reversal performance is linked to dependence on route knowledge (Van Asselen et al., 2006), it is concluded that participants are more dependent on route knowledge when a High Fidelity environment is learned. Hence, Low Fidelity enables better formation of survey knowledge than the High Fidelity condition. Third, as participants acquired survey knowledge, after relatively short exposure to the environment, the hierarchical character of the landmark-route-survey (LRS) theory of spatial learning (Siegel & White, 1975) is not supported. This finding has been confirmed by previous studies (Darken et al., 1998).

Participants spent more time completing the learning route in the High Fidelity than in the Low Fidelity condition. This indicated the usage of a different learning tactic, or focus. Participants were instructed to actively learn the environment. Therefore, the increased learning time is not simply due to the fact that more visual stimuli were present to attend to. Participants' comments after and during the test, indicate they included the High Fidelity cues when learning the environment. However, the increased learning time did not affect error scores.

The pretests showed a significant difference in both the learning route completion time and test completion times between both genders. In the current experiment, male participants completed tests faster than the female participants, but their score remained the same. Previous research shows gender differences in spatial performance for tests with a mental rotation component (Voyer 1995), in favor of males. Spatial ability, measured by the Hegarty test, was expected to coincide with better spatial learning, as performance is dependant on spatial ability (Darken & Banker, 1998). However, in the current experiment, this relation was not found. This supports Richardson's claim that that there is currently no psychometric spatial abilities test that is a good predictor of environmental spatial ability (Richardson et al., 1999).

Gaming was expected to positively influence the formation of spatial knowledge, since gamers are more accustomed to navigating through virtual environments. However, participants' gaming experience did not predict spatial learning, as error scores were no different for gamers. Instead, a decrease in reverse route completion time was found for participants who often played games. Previous research showed a causal relationship between long term game expertise and a mental spatial visualization task score (Greenfield et al., 1994). Data seem to support a connection between long term game experience and spatial abilities.

The observations during the experiment seem to confirm that mental maps of an environment are incomplete (Kitchin, 1994), as it is imagined overly complex with too many isles, or simplified with a square outline. The fact that none of the participants rotated the paper map while drawing the learning route, indicates that they adhere to a single preferred frame of reference. This supports Richardson's claim that the lack of vestibular information in VR makes rotational updating of the mental map difficult. As a result, participants rely on a fixed frame of reference, with a preference for their initial orientation in a virtual environment (Richardson et al., 1999). This preferred frame of reference could also account for the fact that the beginning of the learning route was remembered best, as the participant's initial orientation was the supermarket entrance. Compliant with the LRS of Siegel and White (1975), the entrance is an environment feature, which participants could use as a landmark in their formation of route knowledge.

In the view drawing task, most participants kept rotating the map to suit the presented image. This test required a different orientation, or reference frame, for each photo. Participants could rotate the map to aid mental representations, i.e. they used the map for cognitive offloading. These results imply that different tactics can be used to process the acquired spatial knowledge, to suit the demands of the task. This adds further support to the claim that spatial representations are stored uninterpreted for later recall or processing (Christou & Bülthoff, 2000).

Together, the results of this experiment suggest the High Fidelity condition does influence spatial learning, though not in a way that was expected. Instead of aiding the formation of spatial knowledge, it was found to increase environment leaning times, and decrease survey knowledge scores, as found in the route reverse task. The results support the LRS theory of spatial learning (Siegel & White, 1975), but not its hierarchical character. Furthermore, participants' mental maps of the environment were imperfect and showed a preferred frame of reference.

In terms of rapid prototyping using synthetic environments, the addition of high-resolution photos is a time consuming process. The current research shows these High Fidelity cues do impact spatial learning in a SE. Contrary to the hypotheses it does not seem to aid spatial learning. In fact, in the influence of High Fidelity conditions in SE's, in terms of spatial learning, was found to be detrimental. Future SE fidelity studies should focus on further understanding the components required for the acquisition of spatial knowledge, and how those components affect the specific content of cognitive maps. This experiment showed that High Fidelity texture conditions in a SE may not be necessary for navigational applications. With this knowledge, a realistic synthetic environment can be created against reduced resources. This benefits both the field of rapid prototyping and experimental psychology, as it reduces the costs and time span of projects which use synthetic environments.

5. Acknowledgments

I would like to sincerely thank both tutors Drs. Frank Meijer and Dr. Egon van den Broek for the opportunity to finish my masters degree under their supervision. Thanks for your teaching, advice, recommendation and editing. Next I would like to thank Dr. Johan de Heer, ing. Taco van Loon, and ing. Thomas de Groot from T-Xchange for providing the Synthetic Environment and for the many hours they invested in the project.

I would like to thank my parents for their constant support and help in all aspects of my life and study, thanks you for always being there when I need you. My sister, the ”stok achter de deur” for her advice and especially for keeping me motivated. I especially like to thank Shanna who would follow me to the ends of the earth with her love and support.

6. References

Albert, W. S., Rensink, R. A. & Buesmans, J. M. (1999). Learning relative directions between landmarks in a desktop virtual environment. *Spatial Cognition and Computation,* 1**:** 131–144.

Billinghurst, M. & Weghorst, S. (1995). The use of sketch maps to measure cognitive maps of virtual environments. *Virtual Reality Annual International Symposium, 1995. Proceedings*, 40-47.

Bülthoff, H. H. & Christou, C. G. (2000). The perception of spatial layout in a virtual world. *Lecture Notes in Computer Science, (*1811), 10-19.

Christou, C. G. & Bülthoff, H. H. (1999).View dependence in scene recognition after active learning. *Memory & Cognition,* 27(6), 996-1007.

Christou, C. G. & Bülthoff, H.H. (2000). Perception, representation and recognition: A holistic view of recognition. *Spatial Vision*, 13(2,3), 265 –275.

Darken, R. P. & Banker, W. P, (1998). Navigating in Natural environments: A virtual environment training transfer study. *Proceedings of Virtual Reality Annual International Symposium (VRAIS), 1998*.

Darken, R. P., Allard, T. & Achille, L. B. (1998). Spatial orientation and wayfinding in large-scale virtual spaces: An introduction. *Presence*, 7(2), 101-107.

Diwadkar, V. A. & McNamara, T. P. (1999). Viewpoint dependence in scene recognition. Psychological science, 8(4), 302-207.

Greenfield, P. M., Brannon , C. & Lohr, D. (1994). Two-dimensional representation of movement through three- dimensional space: The role of video game expertise. *Journal of Applied Developmental Psychology*, 15(1), 87-103.

Gillner, S. & Mallot, H. A. (1998). Navigation and acquisition of spatial knowledge in a virtual maze. *Journal of Cognitive Neuroscience*, 10(4), 445–463.

Hegarty, M. & Waller, D. (2004). A dissociation between mental rotation and perspective-taking abilities. *Intelligence*, 32, 175-191.

Kitchin, R. M. (1994). Cognitive maps: What are they and why study them? Journal of *Environmental Psychology*. 14, 1-19.

Larson, J. S., Bradlow, E. & Fader, P. (2005). An exploratory look at supermarket shopping paths. *International Journal of Research in Marketing*, 22(4), 395-414.

Loomis, J.M., Blascovich, J. J. (1999). Immersive virtual environment technology as a basic research tool in psychology. *Behavior Research Methods, Instruments, & Computers,* 31(4), 557-564.

Munro, D. (2003). The army synthetic environment – utility and status. *SimTecT Papers 2003*.

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

Ruddle, R. A., Payne, S. J. & Jones, D. M. (1997). Navigating large-scale 'desktop' virtual buildings: Effects of orientation aids and familiarity. *Presence*, 7(2), 179–192.

Ruddle, R. A. & Péruc, P. (2004). Effects of proprioceptive feedback and environmental characteristics on spatial learning in virtual environments. *International Journal of Human-Computer Studies*, 60(3), 299-326.

Satalich, G A. (1995). *Navigation and wayfinding in virtual reality: Finding proper tools and* *cues to enhance navigation awareness.* Retrieved 2008, from University of Washington. Web site: http://www.hitl.washington.edu/publications/satalich

Siegel, A. W. & White, S .H. (1975). The development of spatial representations of large-scale environment. *Advances in Child Development and Behavior*, 9-55, New York: Academic Press.

T-Xchange (2008). *T-Xchange methode en werkwijze.* Retrieved August 2008, from T.Xchange, engineering Innovation. Web site: http://www.txchange.nl/

Van Asselen, M., Fritschy, E. & Postma, A. (2006). The influence of intentional and incidental learning on acquiring spatial knowledge during navigation. *Psychological Research*, (6), 151-156.

Van den Broek, E. L., Meijer, F., Miedema, J., Wang, H., Van der Voort, M. C., Vergeest, J. S. M. (2008). Synthetic Environments for Cooperative Product Design. *Lecture Notes in Computer Science,* 5220, 1–10.

Vinson, N. G. (1999). Design guidelines for landmarks to support navigation in virtual environments. *Proceedings of CHI 1999, Pittsburgh*.

Voyer, D. & Voyer, S. (1995). Magnitude of sex differences in spatial abilities: A meta-analysis and consideration of critical variables. *Psychological Bulletin*, (117), 250-270.