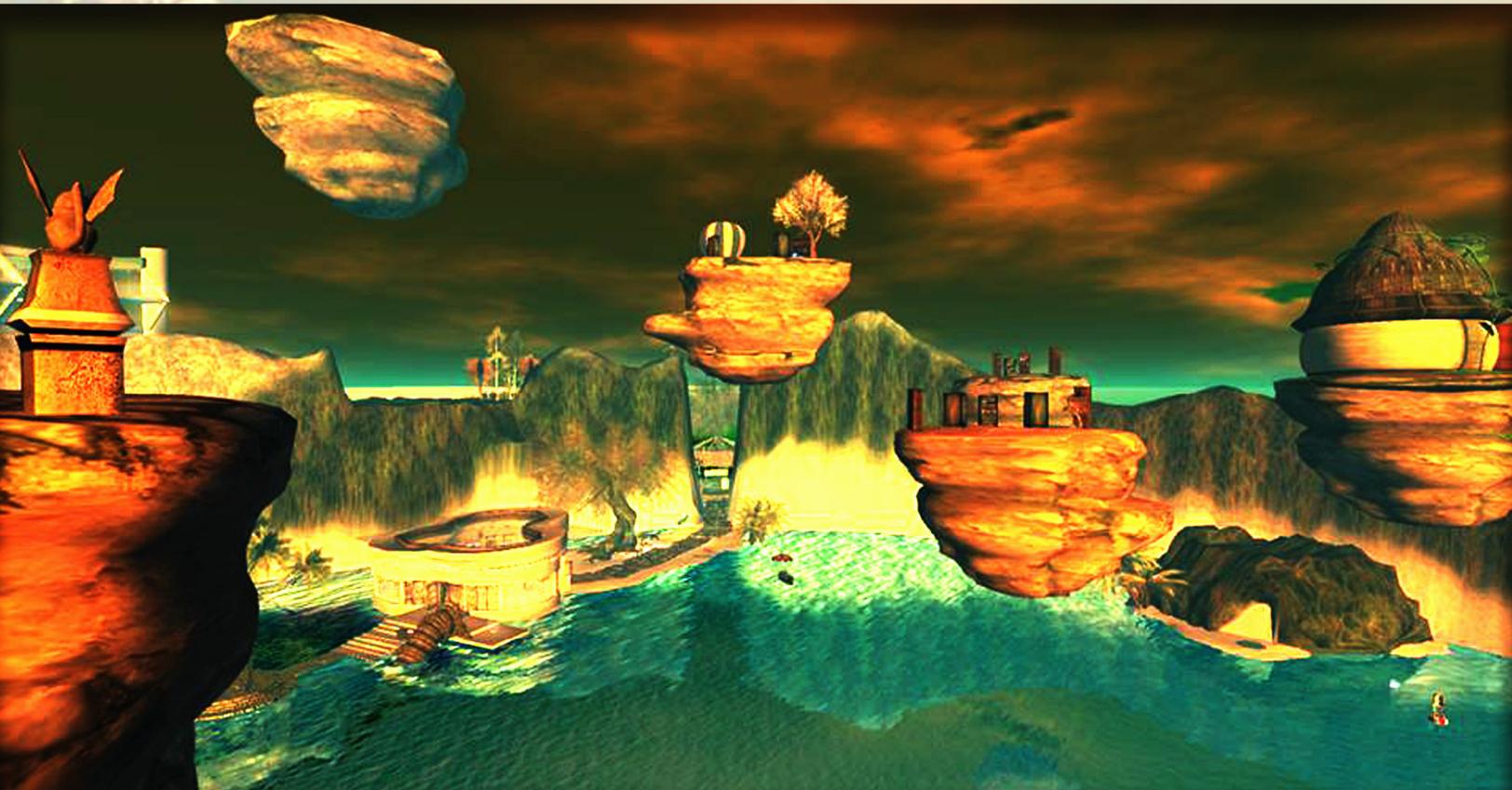


Journal of • Virtual Worlds Research

jvwresearch.org ISSN: 1941-8477

Assembled 2015

February 2015
Volume 8 No. 1



From: Alexandria - A Virtual Repository of Knowledge



Volume 8, Number 1

Assembled 2015

February 2015

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Volume 8, Number 1

Assembled 2015

February, 2015

Gaming Experience and Spatial Learning in a Virtual Morris Water Maze

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Abstract

Experience playing video games has been associated with perceptual and cognitive improvements (e.g., Castel, Pratt, & Drummond, 2005; Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Colzato, van den Wildenberg, & Hommel, 2013; Oei & Patterson, 2013). For instance, video gamers show superior spatial abilities than non-gamers (Greenfield, Graig, & Lohr, 1994; Feng, Spence, and Pratt, 2007; Green & Bavelier, 2003). Given that such abilities have been associated with educational and vocational success in STEM fields (Wai, Lubinski, & Benbow, 2009), it is important to understand the relationship between them and video game experience. In past research, virtual versions of the Morris Water Maze (VMWM) have been used to investigate spatial learning in non-human subjects. Yet, the extent of VMWM's ability to reliably and validly assess human spatial learning is relatively unknown. We developed a VMWM within the Second Life (2015) virtual world and conducted a pilot study with 12 eighth grade students. In the experiment, the participants learned to find the location of a platform in the VMWM. We analyzed performance on the task to identify data trends indicative of spatial learning. Specifically, we compared performance between males and females with varying levels of gaming expertise. In this article, we report on an analysis of navigation strategies as measured by participants' path lengths and patterns, and we discuss the implications of these results in assessing spatial cognition.

1. Introduction

Educational success is central to individual and societal wellbeing, yet digital technologies are posing a challenge to traditional forms of education. They re-mediate our conceptions and constructions of knowledge, challenging how disciplinary knowledge is taught and understood. As is the case with video games, educators have often ignored the potential benefits afforded by these technologies (Squire, 2003). Despite the positive association between video game experience and cognition, we know little about best practices involving games for learning, and even less about the ways in which learning through games transmits knowledge or transforms learners' abilities. Past research has shown that video game players perform better than non-players on visual attention (Castel et al., 2005), visual memory (Ferguson, Cruz, & Rueda, 2008), spatial abilities (De Lisi & Wolford, 2002; Feng et al., 2007) and spatial visualization (Okagaki & Frensch, 1994). As Feng and collaborators (2007) point out, understanding the underlying mechanisms whereby spatial experience leads to changes in mental processes associated with spatial cognition is not only of scientific interest but also of practical value. Success in science, technology, engineering, and mathematics (STEM) may be associated with abilities in spatial cognition (McGee, 1979; Geary, Saults, Liu, & Hoard, 2000; Delgado & Prieto, 2004). In a review of research spanning from the 1950s to the present, Wai et al. (2009) found the following relationship between spatial abilities and success in STEM careers:

- Adolescents with high levels of spatial abilities chose educational and occupational fields in STEM domains.
- There was a strong relationship between spatial ability and professional development in STEM careers not only for intellectually talented individuals but also for the general population of adolescents.
- Talent selection criteria in schools tends to be restrictive and do not include spatial abilities, thus missing talented individuals.

If video game experience leads to changes in spatial abilities, and to corollary changes in learning and socialization (Greenfield et al., 1994), then it is important to understand how video game expertise mediates this process. We can then develop the effective tools necessary for assessment and training in spatial abilities. In this pilot study, we explore a virtual tool to assess spatial learning in participants with different levels of video game experience.

While video games are increasingly receiving attention as educational tools with potential pedagogical implications (Subrahmanyam & Greenfield, 1996; Castell, Jenson, & Taylor, 2007), their effect on knowledge and learning is still relatively unknown. As discussed, researchers have focused on the effect of video games on specific aspects of perception and cognition. Feng et al (2007), for instance, found that playing a three-dimensional (3-D) first person shooter improved performance on spatial attention and mental rotation tasks. Green and Bavelier (2003) found that action video game players had enhanced visual attention capacity as measured with enumeration tasks. Improvements in cognition have also been revealed in non-action video game playing (Oei & Patterson, 2013). This and other evidence (e.g., Castel et al., 2005; Ferguson et al., 2008; Colzato et al., 2013) suggest that video game experience leads to improvements in perceptual and cognitive processes (though some evidence such as that reported by Van Ravenzwaaij, Boekel, Forstmann, Ratcliff, & Wagenmakers (2014) has not found this close relationship). The implicit assumption of such findings is that although these processes are measured in isolation with simple tasks, they nevertheless have wider implications about the nature of information processing abilities in humans. Modern computer technology now provides us with the

opportunity to explore the effect of video games on more naturalistic measures of perceptual and cognitive processes.

Researchers have developed several methodological paradigms to investigate spatial learning and memory in settings that elicit naturalistic responses and behaviors in subjects. In a Morris Water Maze (Table 1), for instance, animal subjects are placed in a pool filled with opaque water and allowed to swim freely until they find a platform hidden under the water. The amount of time they spend searching for the platform (*search latency*) is measured. If the subjects develop a bias towards the location of the platform, they swim directly and accurately towards the platform location with each successive trial (Morris, 1984; Terry, 2009). Measures such as search latencies are considered an indication of the strength and accuracy of spatial learning and working memory (D’Hooge & De Deyn, 2001).

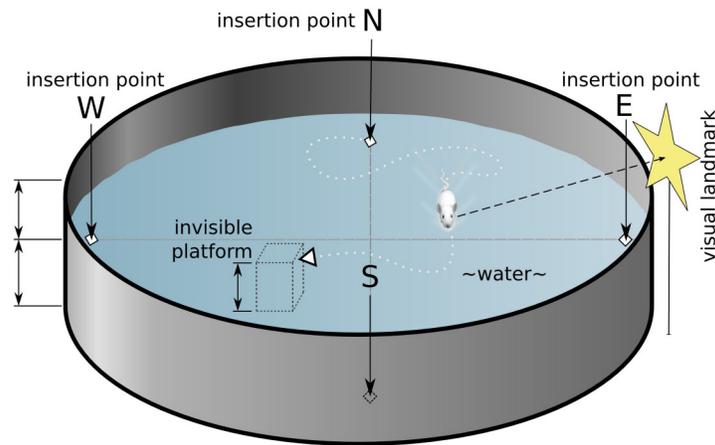


Figure 1. A Morris Water Maze (Adapted from Samuel, 2012)

Researchers often use rodents to test models of spatial learning, but the Morris maze paradigm is not easily applied to human participants. Therefore, to test spatial learning in humans, researchers have recently developed virtual versions of the Morris Water Maze (VMWM). Their research has shown the utility of VMWMs to examine spatial behaviour and abilities in human participants (e.g., Astur, Tropp, Sava, Constable, & Markus, 2004; Newhouse, Newhouse, & Astur, 2007; Driscoll, Hamilton, Yeo, Brooks, & Sutherland, 2005; Mueller, Jackson, & Skelton, 2008). This research is still in its infancy, and development of the precise approaches to investigating human spatial learning and memory in VMWMs is a matter of ongoing research.

One of the approaches used to determine the commonalities in spatial learning among specific populations is based on the analysis of search strategies in VMWM tasks (Kallai, Makany, Karadi, & Jacobs, 2005). Kallai and collaborators (2005) identified four strategies associated with performance in a VMWM, illustrated in Figure 2, including *thigmotaxis* (A), *circling* (B), *visual scan* (C), and *enfilading* (D). Thigmotaxis “represents a circular part of the path that is passed along close to the arena wall” and “keeps the person in constant contact with a stable element”; circling refers to an “arc shaped search path” that, unlike thigmotaxis, occurs away from the wall; visual scan occurs “when a subject remains in

a fixed position and turns”; and lastly, enfilading is “composed of relatively small position correction and non-strategic motions” that occur when a participant “zigzags” and searches “back and forth” in a limited area (Kallai et al., 2005, pp. 190-191). We sought to determine if and how these search strategies are applied in a VMWM designed with salient cues in the proximal region of the maze.

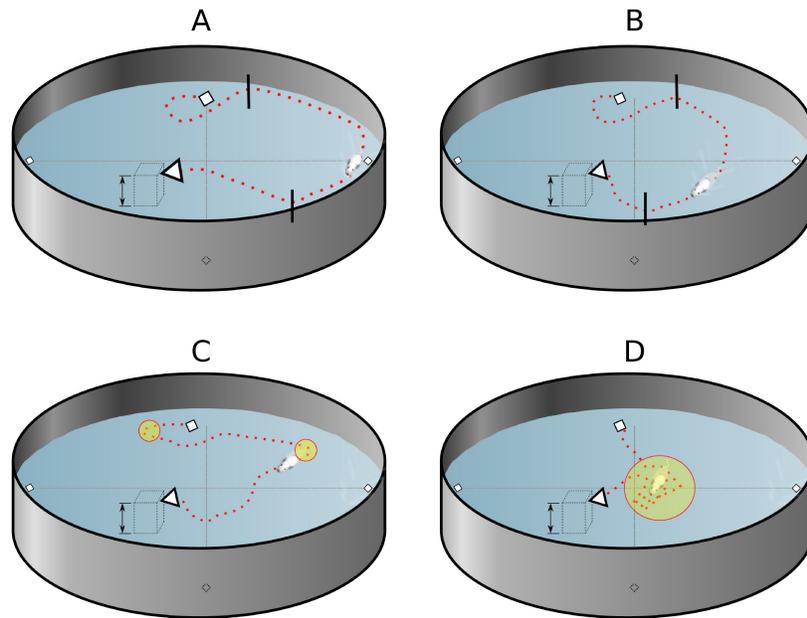


Figure 2. Search strategies in the VMWM as described by Kallai and collaborators (2005) A) Thigmotaxis, B) Circling, C) Visual scan, and D) Enfilading (Maze figure adapted from Samuel, 2012)

We conducted a pilot study with a VMWM developed in the Second Life (SL) virtual world, which enables users to create realistic 3D virtual environments. As we are unaware of SL being used for similar purposes, one of our aims was to determine the technical suitability of SL as a platform for a VMWM. This presented an opportunity to investigate maze performance by analyzing measures of path length and corresponding search strategies. We theorized that because of the similarities between video games and virtual environments, performance in the latter corresponds with expertise in the former. That is, video game experts are more adept than novices at learning the location of a hidden target in the VMWM. As past research has reported differences in performance between males and females, we analyzed the data in terms of the sex of the participant.

2. Methods

We tested 12 eighth grade students, with parental consent to participate in the study, from a suburban middle school in the lower mainland of British Columbia, Canada. Prior to the experiment participants were reminded that their performance did not affect their grades. Participation was later rewarded with a pizza lunch.

Video game expertise was determined by hours spent playing video games and the type of games played. Participants who reported playing 3D Role-Playing Games and First Person Shooters 10 hours

per week or more were classified as experts. Participants who indicated that they played video games for three hours or less per week were classified as novices. Participants included 5 males (2 experts and 3 novices) and 7 females (4 experts and 3 novices).

The VMWM (Figure 3) was displayed on a 15” MacBook and consisted of a practice pool, the experimental maze, and a small deck area with several buttons on the wall.

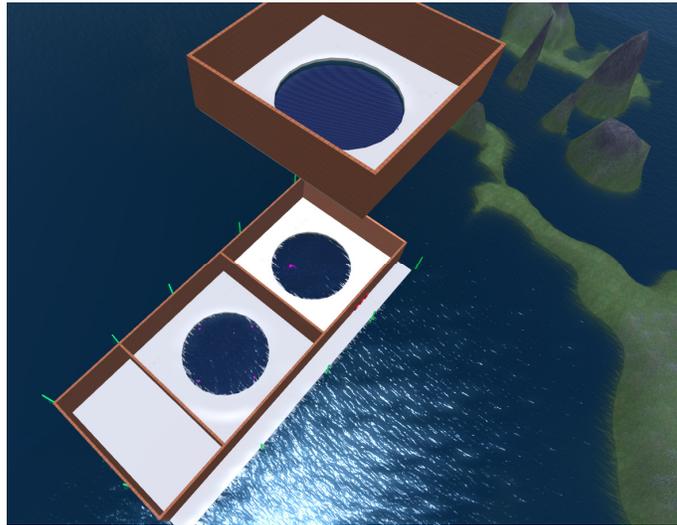


Figure 3. A Virtual Morris Water Maze in Second Life

As shown in Figure 4, the practice pool consisted of an empty 40 m circular pool located inside a rectangular room (60 x 60 x 17.5 m). The only object in the practice room was a flamingo object that participants clicked to teleport out of the room.

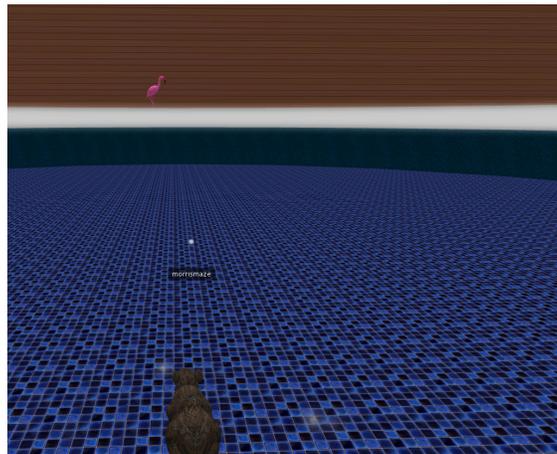


Figure 4. Practice pool in the VMWM

The experimental maze (Figure 5) consisted of a circular pool (40 m diameter) filled with water at a depth of 20 meters and bounded by a 1.5 m wall. A participant navigating with the avatar inside the pool was able to see the room walls and small portions of the sky.

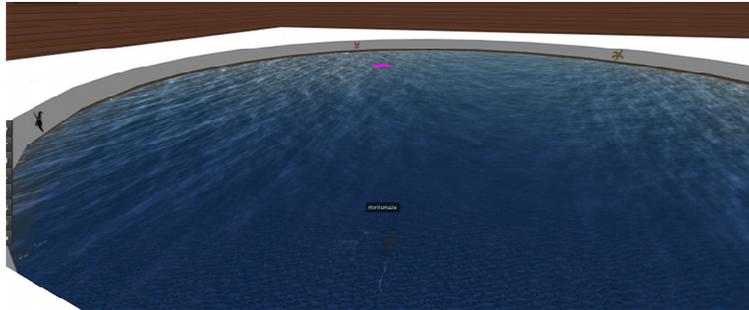


Figure 5. The VMWM pool

Proximal cues were asymmetrically placed along the pool wall, consisting of 5 images depicting sea creatures like the crab shown in Figure 6.

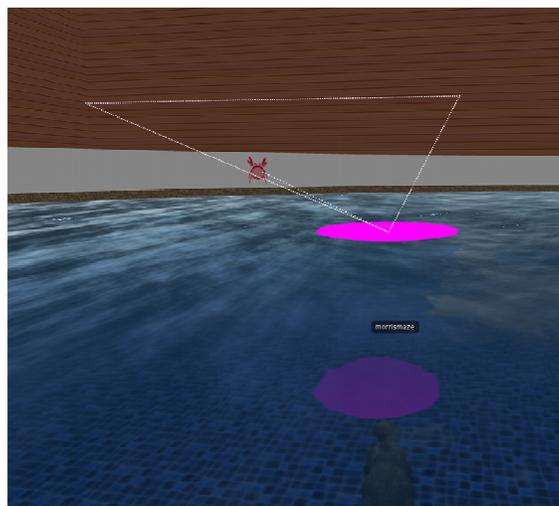


Figure 6. A proximal cue in the VMWM

The room did not have a roof and sunlight illuminated it from a 12 o'clock noon position. A “control” deck outside the rooms contained several buttons on the wall that provided access to different areas of the maze structure and control settings (Figure 7).



Figure 7. Control deck in the VMWM

To complete the tasks, participants used an avatar that resembled a rat (Figure 8). The rat was visible through the water. Participants used the keyboard arrow keys and trackpad to move the avatar and interact with the environment. All arrow keys were active, but to mimic how rodents swim in a real pool, participants were instructed not to use the “back” arrow.

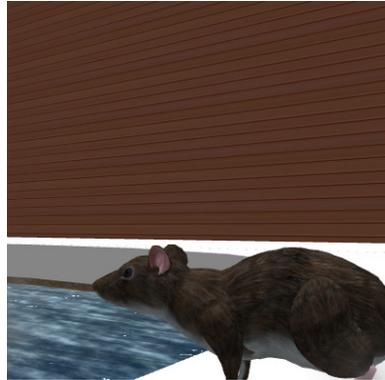


Figure 8. Rat avatar used by participants during search task

The experiment took place during class sessions in a computer lab at the school. The participant and the experimenter sat at a table with the laptop. During the experiment, the teacher and other students were in the same classroom where the experiment took place.

When the session began, the experimenter told the participant that he or she was going to play a game inside a 3D environment. The object of the game was to escape the water by finding and stepping on a platform as quickly and directly as possible before time ran out. The experimental protocol was as follows:

1. *Training trial*: In this single trial, the participant explored an empty pool using the keyboard arrows. The experimenter explained that the participant could only use the left, right, and up (forward) arrows. The participant could explore the pool as much as he or she liked. Once the participant was ready to proceed, he or she was instructed to teleport back to the control deck by clicking on the flamingo near the edge of the pool.
2. *Visible platform trial (VPT)*: The participant teleported into one of four randomly determined locations in the pool. A circular pink platform (1.5 m in diameter) was visible on the water in the NW quadrant at a distance of 7 m from the pool wall. When the participant stepped onto the platform, the avatar was held in place and a voice announced ‘Congratulations. You have found the platform and escaped from the water.’ The participant was instructed to look around, and after 20 seconds, a black screen appeared, which the participant clicked on to start the next trial. The VPTs consisted of four trials, starting from a random location each time. The platform changed location from trial to trial in the following order: NW, SE, NE, and SW. On the last trial, the participant was teleported out of the pool and onto the control deck.
3. *Hidden platform trial (HPT)*: The experimenter instructed the participant to find the platform, explaining that the platform would be hidden and become visible only when the participant stepped on it or when the time expired. When the participant found the platform, a voice announced ‘Congratulations. You have found the platform and escaped from the water.’ If the participant failed to find the platform within 3 minutes, the platform became visible and the participant had to move toward it. Once the participant stepped on the

platform, the avatar was held in place, and the participant was instructed to look around to learn the location of the platform, which would thereafter remain in the same location (SE quadrant). The participant was given these instructions only in the first trial. When the participant indicated that he or she was ready to proceed, the experimenter instructed him or her to type the word *ok* in the chat window and press enter. When the word *ok* was entered, a black ‘teleporter’ screen was activated and a voice instructed the participant to ‘right click and choose teleport’ to start the next trial. The participant completed four HPTs in a pseudo-random order. In this pilot study, we did not include a probe trial to measure quadrant dwell times.

3. Measures

One of our aims was to explore whether we could utilize an SL-based VMWM to test spatial learning. Although we captured search latencies, the focus of this article is on the analysis of search strategies through path lengths (measured in virtual meters) and path patterns. Path length was operationalized as the total distance travelled from the starting location to the platform. The x,y coordinates of the avatar’s position were recorded in SL’s chat log and the total displacement along these coordinates was calculated in Excel. To identify the four search strategies, we first plotted the paths that participants travelled. Then using these plotted paths and the chat log data, we identified instances of the four strategies. For the thigmotaxis, circling, and visual scan strategies we focused on the frequency with which the strategies were used and not on the sum of path lengths. Because enfilading is continuous and not a sequential strategy, we measured total path length rather than number of times used. Given the exploratory nature of this study and the low number of participants, we only reported the descriptive statistics.

4. Results

4.1 Visible Platform Trials

Figure 9 shows the path length averaged across the four VPTs. In the VPTs, the average path length was 17.9 m. The differences between males ($M = 17.1$) and females ($M = 18.5$) were small, and so were the differences between novices ($M = 16.7$) and experts ($M = 18.8$).

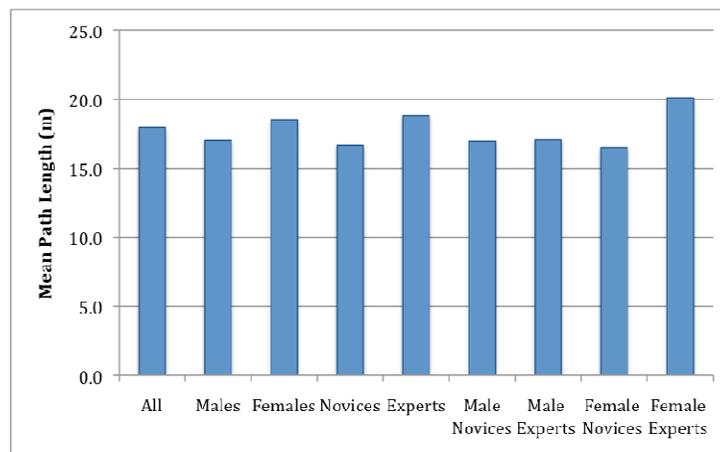


Figure 9. Mean path length across 4 visible platform trials

As shown on Table 1, there was little variation between groups on the average path length across the four visible trials.

Table 1: Mean Path Length (m) on the Visible Platform Trials

Group	Trial Mean				Avg
	1st	2nd	3rd	4th	
All	17.5	17.9	18.0	18.4	17.9
Males	10.4	15.2	21.4	21.2	17.1
Females	22.4	19.7	15.6	16.4	18.5
Novices	13.1	17.4	19.3	16.9	16.7
Experts	20.6	18.2	17.1	19.5	18.8
Novice males	11.1	15.5	18.8	22.5	17.0
Expert males	10.0	15.0	23.1	20.3	17.1
Novice Females	14.4	18.6	19.7	13.1	16.4
Expert Females	28.5	20.6	12.5	18.8	20.1

4.2 Hidden Platform Trials

In the first trial, participants were unaware of the platform location; therefore, path lengths were averaged across the last 3 HPTs (Table 2). The overall average was 105.6 m. Males ($M = 33.0$) travelled shorter paths than females ($M = 157.5$). Experts ($M = 79.0$) travelled shorter paths than novices ($M = 143.0$). Male experts ($M = 29.0$) travelled shorter distances than male novices ($M = 39.0$), and female experts ($M = 116.4$) travelled shorter distances than female novices ($M = 212.3$).

Table 2: Mean Path Length on the Hidden Platform Trials

Group	Trial Mean				Avg (omit 1)
	1	2	3	4	
All	275.1	146.3	95.2	75.3	105.6
Males	344.9	37.7	34.1	27.2	33.0
Females	225.2	223.9	138.9	109.7	157.5
Novices	350.6	133.8	155.6	139.5	143.0
Experts	221.2	155.3	52.1	29.5	79.0
Novice Males	451.7	57.0	33.6	26.4	39.0
Expert Males	273.7	25.0	34.5	27.7	29.0
Novice Females	283.2	185.0	236.9	215.0	212.3
Expert Females	181.8	253.1	65.4	30.8	116.4

Figure 10 shows the average path length on the last three trials.

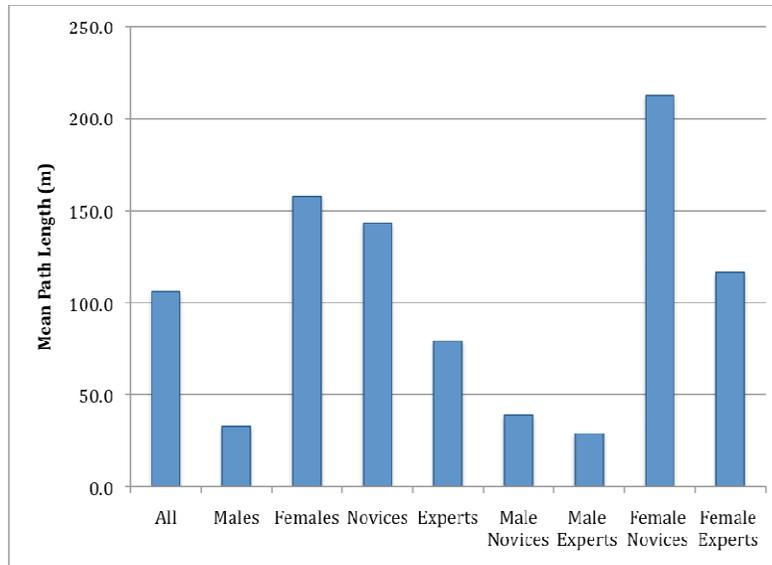


Figure 10. Mean path length on the last three hidden platform trials

Figure 11 illustrates the mean path lengths on each of the four HPTs grouped by sex. The progressively downward direction of the line indicates that participants were more accurate in finding the platform with successive trials. Males learned the location of the platform accurately by the second trial and maintained a consistent path length across the last three trials. In contrast, females showed a downward progression in path lengths indicating improvement in performance, but they did not reach parity with males.

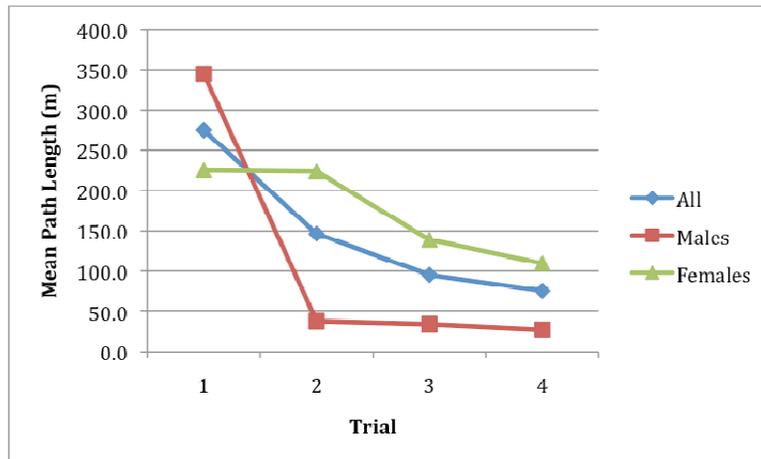


Figure 11. Mean path length across 4 hidden platform trials grouped by sex

When the data were examined by the group’s expertise, the results showed that the mean path lengths decreased steadily across trials for experts but not for novices (Figure 12). Male novices and male experts travelled short distances across the last three trials. Female experts travelled long paths in the second trial, and their paths became shorter with each successive trial until they reached near parity with males by the fourth trial. Female novices, on the other hand, did not decrease their mean path lengths greatly across trials and did not show trends that are associated with spatial learning and memory.

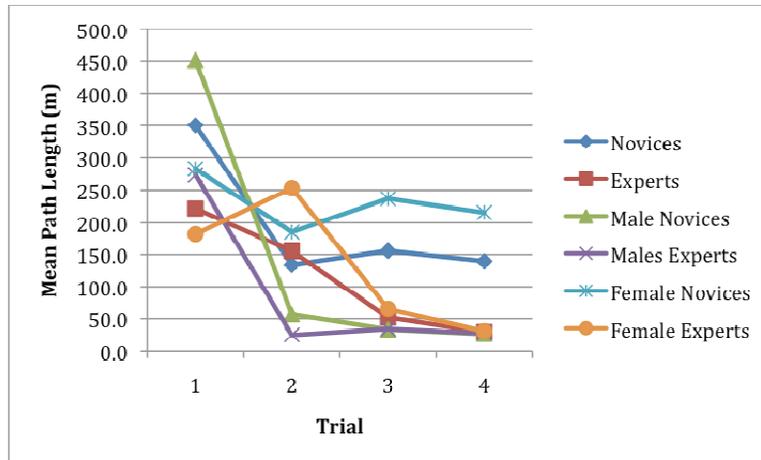


Figure 12. Mean path length across 4 hidden platform trials grouped by expertise

4.3 Path Patterns

Figure 13 and Figure 14 show plots of the paths travelled by a participant during the VPTs and the HPTs respectively. It is clear that in the last three VPTs, the participants took a more or less direct path towards the visible platform.

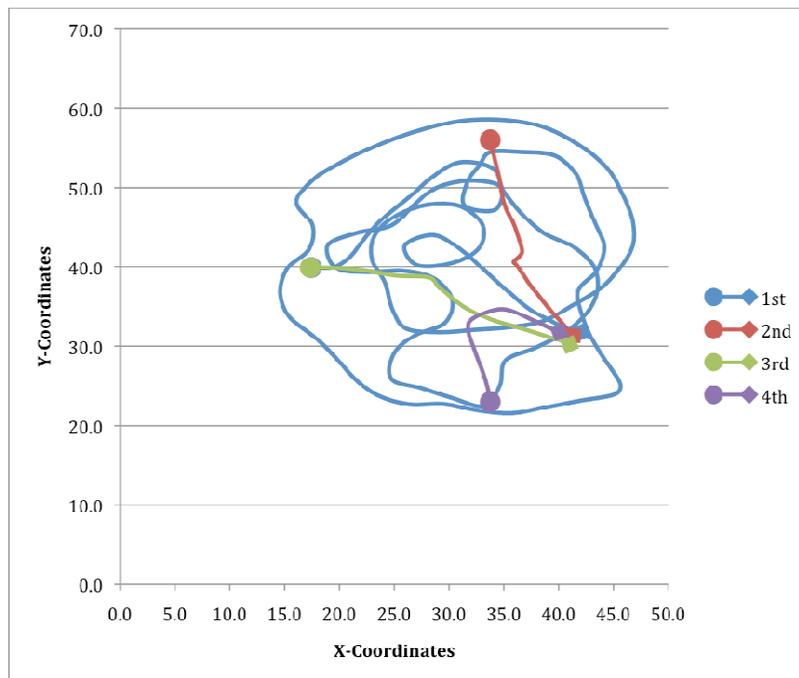


Figure 13. Plotted paths travelled during the visible platform trials

By contrast, the paths that the participants travelled when the platform was hidden (Figure 14) were more complex than the paths that they travelled when the platform was visible.

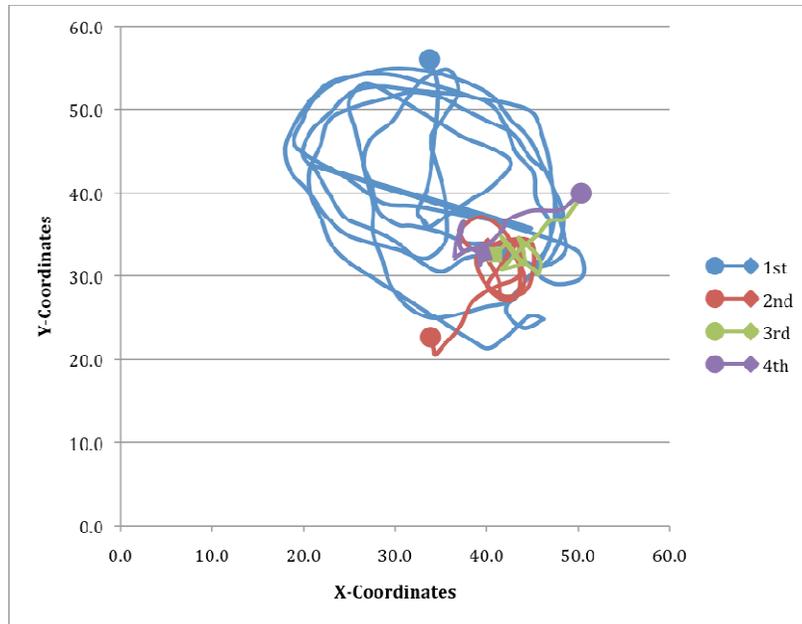


Figure 14. Plotted paths travelled during the hidden platform trials

Table 3 shows the frequency of the occurrence of three search strategies: thigmotaxis, circling, and visual scan. Examination of the thigmotaxis and circling search strategies show that the differences between males and females were small, and so were the differences between novices and experts.

Table 3: Frequency of Search Strategies During the Hidden Platform Trials

	Thigmotaxis	Circling	Visual Scan
All	21	23	53
Males	11	13	10
Females	10	10	43
Novices	9	12	35
Experts	12	11	18
Male Novices	4	7	6
Male Experts	7	6	4
Female Novices	5	5	29
Female Experts	5	5	14

Figure 15 shows that participants used the visual scan strategy frequently. Females and novices relied on this strategy more so than males. Novice females in particular were more likely to rely on the visual scan strategy. As shown, this strategy was used across all trials but decreased in the last trial.

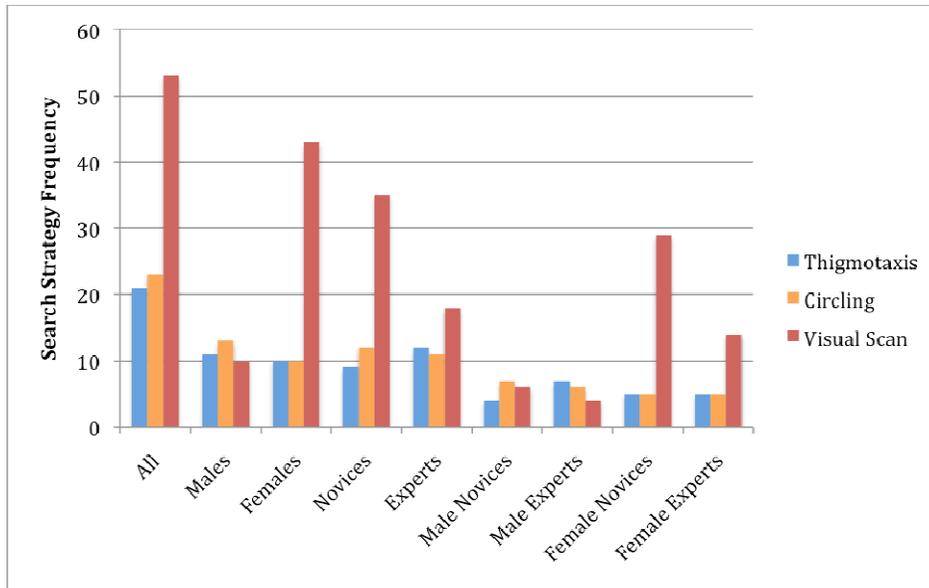


Figure 15. Frequency of search strategies

Figure 16 shows the mean path length associated with *enfilading* on the last 3 trials. Males relied on this strategy less frequently than females, while novices and experts differed little in its use.

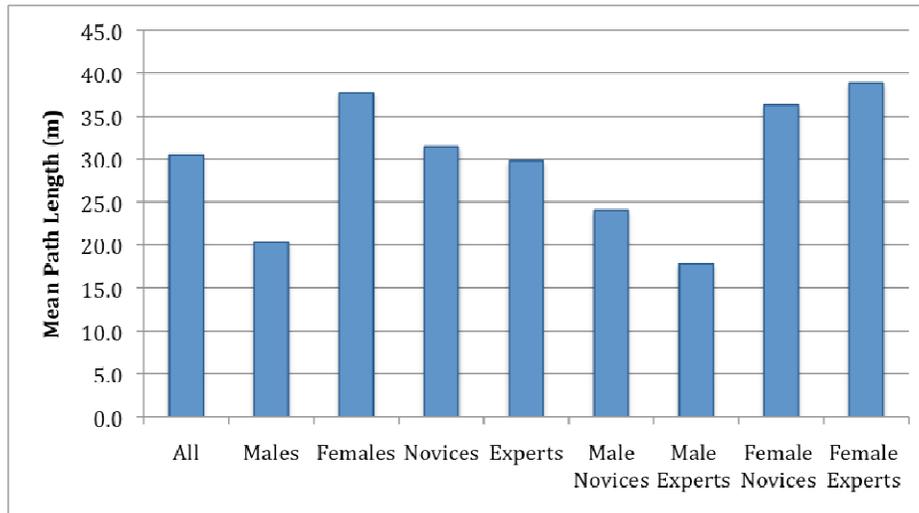


Figure 16. Mean path length associated with the enfilading search strategy on the last three hidden platform trials

The frequency of use of the enfilading strategies on the last three HPTs trials is shown on Figure 17 and Figure 18 . As participants did not know the location of the platform in the first trial, we plotted this trial at 0. The results show that the use of enfilading declined in the last trial regardless of sex or expertise.

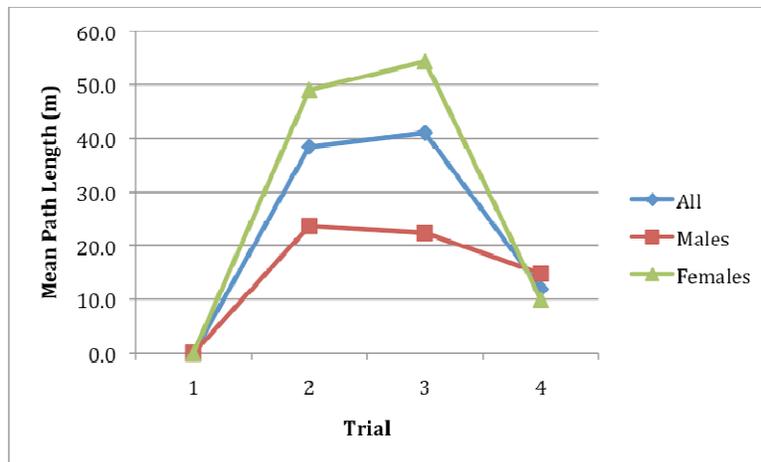


Figure 17. Mean path length of enfilading across 4 hidden platform trial grouped by sex

On the second and third trials, males relied on enfilading more so than females.

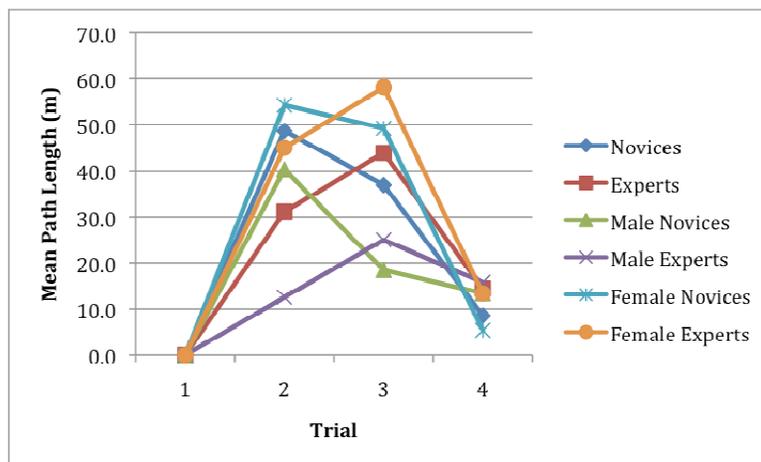


Figure 18. Mean Path length associated of enfilading across 4 hidden platform trials grouped by expertise

Experts and novices showed variability in the use of enfilading across the trials, but eventually the use of this strategy decreased, likely because participants took a more direct route to the platform on the last trial.

5. Discussion

In this pilot study, we examined the relationship between video game experience and spatial learning in males and females. Although our samples were too small to conduct tests of significance, the descriptive statistics yielded some revealing trends. As expected, the differences between groups in the VPTs were relatively small, indicating the following:

- Participants understood the task and did not have difficulties completing it.
- Participants were equally capable of using the keyboard to navigate the environment.
- Participants did not suffer any major sensory-motor or cognitive deficits that impeded their ability to complete the task.

- Participants did not lack motivation to complete the task as they purposefully moved towards the visible platform.
- Participants were not adversely affected by the virtual nature of the task in spite of the absence of kinesthetic and proprioceptive information.

In the HPTs, participants' path lengths decreased steadily, indicating that they learned the location of the platform and took a more direct path with each successive trial. When the data were grouped by sex, the results showed that males' mean path length was shorter than that of females. This difference appeared by the second trial and decreased over the course of the next trials but did not entirely disappear. So while both sexes learned the location of the platform, males travelled more direct paths towards the platform than females. While we do not know whether these differences are significant, they are in alignment with studies that have found sex differences in performance (e.g., Astur, Ortiz, & Sutherland, 1998; Mueller et al., 2008; Sandstrom, Kaufman, & Huettel, 1998).

While biological and cognitive factors in navigation have been investigated in prior research, little work has been conducted to determine the role of (spatial) experience in spatial learning and memory. Given the variety of experience over the lifetime of an individual, it is difficult to isolate any given variable to determine its effect on spatial learning. The present work focused on video game experience, which has been shown to be associated with various aspects of perception and cognition. The results of this experiment showed that video game experts navigated shorter paths than novices. While we cannot make inferences about a causal relationship between video game experience and VMWM performance, these results suggest a positive correlation between the two. Interestingly, females appear to have benefited from prior video game experience more so than males, and this finding is consistent with past research (Feng et al., 2007).

Analysis of the search strategies showed that *thigmotaxis* and *circling* were mainly used in the early trials, and differences between groups were relatively small. Differences between males and females and between experts and novices were pronounced in the use of *visual scanning* with reliance on this strategy decreasing on the last trial. This finding suggests that once participants learned the location of the platform, they moved swiftly towards it without the need to pause and carefully scan their surroundings. Males relied on the *enfilading* strategy to a lesser degree than females, and the differences in enfilading between novices and experts were small. The use of this strategy also lessened with increased awareness of the platform location. Of the four strategies, visual scanning and enfilading appear to be the best predictors of performance in a VMWM though a more thorough treatment of this subject is required.

The results of this study indicate that there is value in assessing adolescents' spatial cognition using a VMWM. This research paradigm can help us better understand how spatial experiences, like video game playing, affect cognitive abilities. In turn, these abilities can predict future educational and vocational success. Questions remain regarding how users employ perceptual (e.g., visual attention) and cognitive (e.g., mental rotation) mechanisms when interacting with virtual worlds. How does the design of the virtual environment itself aid or hinder spatial learning? Which metrics, besides the ones reported in this article, are useful in understanding performance? Future research into these questions could further take advantage of psychometric tools like eye-tracking technology (see Mueller et al., 2008), which have become less costly and easier to use. Moreover, some of the limitations of desktop VMWM (e.g., lack of stereoscopic cues) may be overcome by newer virtual technologies like Oculus Rift (2015) and Microsoft HoloLens (2015). The present study was limited in the number of participants that were tested, as well as in the number of trials administered, so we could not determine if the differences

between males and females or between video game novices and experts were statistically significant. Yet, the results suggest that it is possible to use the VMWM to assess the differences in spatial cognition between groups. These results also give us a more precise understanding of how spatial experience affects cognition. This understanding can help us design tools for the purposes of assessment and training of spatial abilities.

Acknowledgements

We would like to thank Elaan Bauder and her students, David Harris Smith, Milena Droumeva, and John Murray for their invaluable contributions. This research was supported by the U.S. Air Force Research Laboratory under contract FA8650-10-C-7009, by the GRAND NCE, and by The Social Sciences and Humanities Research Council of Canada.

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