How Cognitive Load Difficulty Affects Cognitive Mapping and Individual Differences in Navigation

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Abstract

In order to study the effects of varying the levels of cognitive load and individual differences upon cognitive mapping, forty-eight young adults participated in this virtual navigation study. To compare different levels of cognitive load, half of the participants trained in an Abstract Virtual Environment (low cognitive load) while the other half trained in a Realistic Virtual Environment (high cognitive load). After the training, participants were exposed to a series of navigational and pointing tasks to analyze the effects of the training environments – the different levels of cognitive load. It was observed that Abstraction was beneficial to participants in the training phase for the pointing task. In addition, in the testing phase, there was a noticeable trend of Abstraction also being beneficial for some of the pointing and navigational tasks. However, in one of the navigational tasks in the testing phase, Abstraction was shown to be more beneficial to those with a high spatial working memory. Thus, a lower cognitive load via Abstraction can be beneficial to navigation and creating a cognitive map. Further research should be conducted in which varying levels of Abstraction (cognitive load) is combined with other visual design elements, such as Translucency, in order to analyze if a conjunction of other variables alongside with cognitive load could potentially increase spatial abilities in individuals.

Introduction

When navigating through an unfamiliar environment, some individuals create a cognitive map (Weisberg & Newcombe, 2018), a configural representation of the spatial environment. People utilize various types of spatial information to create a metrical representation of the environment when creating a cognitive map. Such information could include landmark association to take note of important locations, metric information to determine how far certain locations are from each other, etc. (van Asselen, Fritschy, & Postma, 2006). These various types of spatial information aid in creating a route and survey representation of the environment (Siegel & White, 1975). The effort undertaken by the spatial working memory to remember these individual details of spatial information to create the cognitive map is known as cognitive load (Weisberg, Schinazi, Newcombe, Shipley, & Epstein, 2014). The more spatial information one must remember, the higher the cognitive load the spatial working memory must assume.

Little research has been conducted to understand the underlying effects of spatial information and visual design of an environment upon spatial working memory (Lokka, Çöltekin, Wiener, Fabrikant, & Röcke, 2018; Meilinger, Knauff, & Bülthoff, 2008) . These studies used various mediums of virtual reality environments to investigate these effects because the use of virtual environments is functional to answering research questions about navigation that cannot be investigated in the real-world due to the limitations of being able to manipulate features of a real-world environment (Lokka et al., 2018). Lokka et al. conducted a study to investigate the effects of visual design of virtual environments upon successful navigation to a goal location. By manipulating the graphics of these environments through varying levels of realism and location of landmarks, this study conveyed how a Mixed Virtual Environment, representative of the real world with abstract elements, aided in route collection and also "support[ed] [navigational] learning beyond short-term memorization" for both younger and older adults (Lokka et al.). By emphasizing the saliency of an environment's features that are important to navigating and decreasing the cognitive load through the concealing of less important features, the study highlighted how both an inadequate and excessive amount of spatial information serve as an impediment to spatial working memory and thus, cognitive mapping.

These studies have provided important insights to what visual elements of virtual reality are advantageous to process spatial information in order to a create cognitive map. However, there are some severe limitations. For example, having the same training and the testing environments makes it impossible to examine whether the lower cognitive load improves cognitive map formation in the real word or whether training in a more simplistic virtual environment could benefit real-world navigation (Lokka et al., 2018). There is the possibility that a specific type of environment could help increase spatial abilities for certain individuals. In addition, these studies and others (Evans & Pezdek, 1980; Liverence & Scholl, 2015; Meneghetti et al., 2016) do not incorporate the importance of individual differences. Previous research has found that men and women use different mechanisms for cognitive mapping. O'Laughlin and Brubaker (1998) found that men and women were both able to excel in cognitive mapping using different techniques. Women utilize landmark and location association to aid in navigation while men employ spatial abilities. Parush and Berman (2004) observed that women thrived in spatial navigation when immersed in a virtual environment with landmarks, while these landmarks appeared to have an inhibitory effect to navigation for men. These results suggest that men use the structural aspect of an environment as their own mechanism of creating landmarks to remember an environment. Thus, it appears as if additional landmarks in an environment serve as a more difficult cognitive load for cognitive mapping for the men but not for women.

This current study aims to research the effects of varying the levels of cognitive load difficultly upon cognitive mapping. The individual differences in spatial navigation and cognitive mapping will also be analyzed to pinpoint any significant effects of cognitive load. There will be various training environments but only one testing environment, the Realistic Virtual Environment, in order to research the applied implications of cognitive load reduction in spatial learning facilitation. Additionally, this current study will measure individuals' spatial working memory capacity (Unsworth, Heitz, Schrock, & Engle, 2005) to investigate whether the manipulation of cognitive load affects people with different spatial working capacity differently (e.g., people with a lower spatial working memory benefit more from the Abstract Virtual Environment than people with larger capacity). Researching relationship between cognitive load and cognitive mapping is vital to understanding what factors aid in route memorization and what facets of spatial information serve as inhibitors to spatial memory mapping. This research could potentially reveal techniques to help improve spatial knowledge acquisition which could also lead to the development of a tool to increase wayfinding abilities. Currently, when one is not cognizant of how to get to another location, the person will utilize some sort of navigation system, such as a GPS. A GPS, however, harms the acquisition of knowledge (Ishikawa, Fujiwara, Imai, & Okabe, 2008). Thus, conducting research that investigates the effects of spatial knowledge acquisition can result in understanding on how to develop spatial abilities.

Literature Review

When navigating through an environment, multiple types of information are encoded, such as visual, verbal, and spatial information. Various cognitive mechanisms are engaged with each other to process these difference categories of information in order to create a functional representation of the environment (Weisberg et al., 2014). This mental representation of the environment created from navigation is known as a cognitive map. The effort taken upon the spatial working memory to remember every aspect of the spatial information gained via navigation is referred to here as cognitive load. The more information that must be encoded results in the working memory taking on a higher cognitive load. Understanding the relationship between spatial navigation and cognitive functionality, such as cognitive load, is important because navigation is essential to our daily lives. Research on this relationship could reveal how information overload upon the spatial working memory can either encourage or obstruct cognitive mapping and navigation. Virtual environments serve as a versatile platform that allow for such research. These environments allow for the manipulation of environments that emulate both conditions similar and not similar of the real-world to allow for such implications. (Lokka et al., 2018).

Research conducted by Weisberg et al. indicated that investigation of this relationship could also potentially reveal if individuals who contain strong navigational skills will enter into an academic field that utilizes this spatial intelligence, such as Mathematics, Science, Technology, and Engineering (2014). Wai et al. found results that indicated spatial ability has a profound effect upon learning STEM skills (2009). Research on spatial abilities could potentially allow for recruitment of students who could excel in STEM fields. Hence, there are many advantages to researching spatial navigation and spatial abilities. However, there is minimal research inquiring about the relationship between spatial navigation and cognitive load, thus stressing the need for more investigation into this topic. Some studies have only identified a correlational relationship between these two variables (Weisberg et al., 2014), and other studies that have tried to establish a causal relationship experienced the obstacles of confounding variables, resulting in inapplicable real-world implications (Lokka et al., 2018).

Blacker et al. conducted a study to investigate the claim of the spatial working memory being divided into two separate components: locations spatial information and relations spatial information (2017). This claim was tested through a desktop virtual environment that was interpreted as a large-scaled 3-D space. The creation of this environment was based upon previous research that indicated that the environmental design promoted the display of individual differences during spatial navigation. The data from this experiment found that the participants with superior working memory for both spatial relations and spatial locations were the best navigators. Individual differences in spatial navigation were highlighted when the cognitive load in the virtual environment was high. This study provided valuable information and stronger implications of how spatial working memory plays a role in spatial navigation in the real-world because it investigated the different sectors of working-memory in a large-scale virtual environment unlike previous studies.

There is limited research that investigates the effects of the visual design of a virtual environment upon spatial working memory. Lokka et al. (2018) analyzed the effects of the realism presented in a virtual environment through the manipulation of visual textures. Participants who navigated through the Mixed Virtual Environment (the environment that contained both realistic and abstract elements) were more able to successfully navigate to the goal location. As a result, this study emphasized the importance of cognitive load upon spatial memory. By emphasizing the features of an environment that are important to navigating and decreasing the cognitive load through the concealing of less important features, the participants were able to increase their memory skills and saliency. Thus, this environment enabled participants to not only memorize the route for the duration of this study but rather learn beyond short-term route memorization. Due to the researchers conjunctively testing the effects of manipulated levels of realism and specific landmarks relevancy, they were not able to discern which of these variables had more impact upon increasing the spatial working memory for navigation. Also, there is the limitation of having the same the training and testing environments for a participant. This methodological flaw results in a weaker real-world application of the causal relationship between cognitive mechanisms and spatial navigation. There is the possibility that a participant trained in a more simplistic virtual environment (Abstract

Environment) could outperform a participant who trained in an environment similar to real-world conditions when tested in a realistic environment. The opposite could also hold true. However, due to both the testing and training environments being identical, we cannot discern the impact of such training. Thus, our study will evaluate the impact of different training conditions by analyzing how training in either an abstract environment or realistic environment will affect navigation and goal-finding in a realistic environment. In other words, there will be multiple training environments but only one testing environment.

Liverence and Scholl researched the effects of visual design upon spatial navigation through the medium of object persistence (2015). By using cues from smartphone interfaces to create the virtual environments, the researchers aimed to understand the effects of persisting object representations upon navigation and long-term memory. The object representations were conveyed through the use of landmarks within the environment. The observations from this study showed that the object persistence prompts of sliding transitions, which were similar to real-world environments, allowed for participants to navigate to the target faster. The object persistence of the landmarks enhanced spatial navigation and learning in comparison to the results found from the object-disruption animations – fading animations. Extra experimentation was performed to account for the confounding variables of object visibility, object moment, and environment memorization in order to ensure that the participants' ability to navigate quicker and create better representations of the virtual environment was due solely to the object persistence animations. Thus, with high confidence, this study was able to implicate that the creation of spatial representations and navigation rely on object persistence in real-world and virtual environments.

A study by van Asselen et al. explored the impact of intentional learning and incidental learning upon spatial knowledge (2006). Because their data depicted no statistically significant difference between the incidental and intentional learning group for landmark recognition and ordering the landmarks in the building environment, the researchers were able to conclude that automatic processes rather than effortful processes are enough for landmark spatial knowledge. Further implications were that the spatial knowledge for remembering and ordering landmarks is easily encoded regardless of the fact that people may not actively pay attention to them. The data from this study also showed that when individuals need to have a specific mental map in which they must be cognizant of every location, landmark, and direction, more effortful learning processes must be employed.

Steck and Mallot performed a study to analyze the role that global and local landmarks serve in the navigation of a virtual environment (2000). Global landmarks refer to the landmarks that one can always refer to throughout navigation in such that the frame of reference never changes as the person continuously moves in the environment, or in other words, a visual compass. Local landmarks differ in such that they are only visible to the person at a short distance from the current point of location of the person. A landmark can be deemed to either be local or global at any occurrence in the journey, depending upon the current perspective of the person. This study intended the analyze the individual and independent functionality of each type of landmark. In one experiment, the local landmarks were shifted around to create cue conflict. Participants utilized both types of landmarks in the decision process when finding another location; however, the participants did not make an equal use of these landmarks. Thus, these observations implied that the method in which participants decide which type of landmarks to use is contingent upon the saliency and functionality of the landmark at a certain location. In addition, in another experiment where one type of landmark was removed in the experimental environment, there were no effects. As a result, the researchers were also able to form the implication of both the local and global landmarks were saved to the spatial memory during the training session; there is no preference to what type of landmark is retained in memory. These implications derived from this study are applicable to real-world environments due to the environment containing a high degree of realism.

O'Laughlin et al aimed to investigate the individual differences in cognitive mapping by analyzing the gender differences in creating a map of a house environment with furnishing and no furnishing (1998). Furnishing was representative of landmarks. The results of this study found that both men and women performed equally as well when drawing a map of the furnished house. These findings supported previous research landmarks are functional in an unknown environment (Evans, Marrero, & Butler, 1981). O'Laughlin et al. suggest that although women utilize location memory to navigate through environments while men utilize Euclidian type spatial skills, both genders have the same results in navigational tasks. However, this study had the limitation of using a video of a house tour rather than a physical tour. This medium resulted in the potential prohibited visual access necessary for some participants to get a better understanding and mapping of the environment. Also, the video medium could have been too complicated for individuals who were not familiar with floor plans. Even with these limitations, this study highlighted the difference mechanisms used by males and females during cognitive mapping and emphasized the importance of analyzing individual differences in navigation.

Parush and Berman investigated how participants acquire spatial cognition in a virtual environment (2004). More specifically, the researchers focused on the impact of navigational aids and landmarks by testing how a map or route list may affect how the environment knowledge is gained and the route is acquired alongside the presence or absence of landmarks. Findings of this study highlighted individual differences in navigation. The landmarks in the virtual environment appeared to have an inhibitory effect when it came to navigating for males, while females thrived in spatial navigation when landmarks were present. These observations indicate that men use the structural aspect of the environment as their own mechanism of creating landmarks to remember an environment. Thus, the results give the impression that additional landmarks serve as a more difficult cognitive load for cognitive mapping for males and furthermore suggest that too difficult of a cognitive load can be detrimental to cognitive mapping and navigation. Females use landmarks as a strategy for building a cognitive map and aiding in navigation. Further research can be performed to analyze if a more difficult load would be more beneficial for women while being inhibitory for men in this present study.

As mentioned earlier, this present study will utilize multiple training environments and one testing environment to investigate how training in either an abstract environment or realistic environment will affect goal-finding and individual differences in navigation in an environment similar to real world conditions. The abstract environment represents low cognitive load. The realistic environment that will contain many other buildings in addition to the goal buildings will serve as the high cognitive load condition. This study could provide vital research on how to improve spatial knowledge acquisition. In addition, we also predict that an individual’s spatial working memory capacity could affect our results, as it is possible that an individual with lower spatial working memory capacity would benefit more from the abstract environment. By understanding how to enhance spatial abilities, the development of an instrument that could increase wayfinding abilities is possible. While utilizing a GPS is functional to navigating through an unfamiliar environment, this tool is harmful to spatial knowledge acquisition

(Ishikawa et al., 2008). Because spatial abilities have a substantial effect upon developing STEM skills (Wai et al., 2009), the understanding of the individual differences in spatial abilities, spatial navigation, and cognitive mapping is essential. By enhancing spatial knowledge acquisition, there is the additional benefit of increasing the aptitude for STEM fields.

Methods

Participants

Forty-eight participants from the Georgia Institute of Technology participated in this research project for course credits. Of these participants, 19 were female and 29 were male with a mean age of 19.542. The participants were randomly assigned to either the Opaque Abstract or Opaque Realistic training condition.

Pre-Experiment Measures

- *Santa Barbara Sense of Direction Scale (SBSOD)*

  The Santa Barbara Sense of Direction Scale (SBSOD) is a self-report measure of environmental spatial ability (Hegarty, Richardson, Montello, Lovelace, & Subbiah, 2002). While this survey appears more subjective in measuring one's navigational skills, this self-report provides a correlation to objective measures of performance in environmental spatial cognition tasks (e.g. pointing tasks, environmental learning tasks, etc.) (Hegarty et al., 2002). Also, previous research has found that participants are for the most part, honest and accurate when reporting their spatial skills (Hegarty et al., 2002). By understanding the participants' current spatial abilities, we would be able to understand the effects of our training environments upon the navigation through the testing environment.

This scale consists of fifteen statements in which participants must rate the accuracy of said statements from a scale of one (strong agree) to seven (strongly disagree). The score for sense of direction is calculated adding up the scores for each question and dividing by fifteen – in essence, taking the average. Reversing scoring should be applied for all positively stated items (Questions 1, 3,4,5,7,9,14). The higher the score, the better sense of direction the participant has (Hegarty et al., 2002).

- *Questionnaire on Spatial Representation (QSR)*

  The Questionnaire on Spatial Representation (QSR) is an eleven question survey that measures how individuals represent their environment (De Beni, 2001). This report focuses on two types of spatial representation – survey representation and landmark-centered representations (2001). Studies have found that individuals employ different processing spatial information methods when using either the survey or landmark-centered representation of the environment (2001). Thus, our study aims to take note of what method of spatial represent participants tend to use to understand what techniques they may utilize when creating a cognitive map of the virtual environments they navigate through.

Procedure and Measures

There were four tasks that were used for this study.

1. *Advanced Symmetry Span Test*

   The purpose of the Advanced Symmetry Test is to measure the spatial working memory. The test consists of participants remembering the order of highlighted cells in a 4 x 4 grid. In order to prevent rehearsal of the cells positions, the ordering task would be interrupted with a symmetry task. The symmetry task involved participants discerning whether or not a figure in a n 8 x 8 grid was vertically symmetrical. The dependent variable of this test would be the memory score for the highlighted cells (Draheim, Harrison, Embretson, & Engle, 2018). This test was administered in three blocks of trials in order to have a stabilizing effect of performance.

2. *Practice Environment*

   The Practice Environment was a virtual environment created in Unity to allow the participants to gain familiarity with this type of environment. In this environment, participants were shown how to navigate using the left-right-up-down or a-s-w-d keys and change their orientation by rotating the mouse at a comfortable speed to them. Also, participants were shown how to find a target location. The participant would have to locate the goal location and then officially find it by walking right into the location itself. Once participants were shown to be comfortable in this environment, they were ready to move on to the training phase.

3. *Training*

   There were two training environments – Opaque Abstract and Opaque Realistic, both of which were programmed in Unity. Participants were randomly assigned to either of these training environments.

   - *Opaque Abstract*

     The Opaque Abstract virtual environment consisted of the target building being highlighted in green. All other buildings that were not relevant (i.e. not target buildings) were made abstract – a cube with no textures, just a white canvas.

- *Opaque Realistic*

  Like the Opaque Abstract environment, the target buildings were surrounded by a green outline. Other than the green outline, the Opaque Realistic environment was more similar to the environment in the real-world. Target buildings were dispersed amongst other textured buildings.

In their respective virtual environment, participants were to locate nine target buildings presented to them on a checklist showing the name and the visual representation. These buildings can be found in any order the participants prefer. Within this navigational task, participants were exposed to a pointing task.

- *Pointing Task*

  For the pointing task, participants were to determine the location and distance of one of the target buildings from one of the target buildings on the list. Participants were to use the mouse to change orientation and the scroll feature of the mouse to extend or reduce the distance. Participants could not change the position from where they were placed. This pointing task was automatically administered intermittently as participants navigated through the environment.

Participants were required to be in the training phase for at least twelve minutes. If participants were to complete the training early, they were encouraged to use the remaining time to navigate through the environment in order to familiarize themselves better with the environment and better memorize the location of the buildings.

4. *Testing*

   The testing phase was the same type of environment for all participants, regardless of what training group they were in. The testing environment was Opaque Realistic – the same environment as the Training Opaque Realistic. In this testing environment, the goal locations were not surrounding by the green glow. The locations of all target buildings were probed equally. For this testing phase, participants alternated between navigating through the environment and performing the pointing task. The same nine target buildings were to be located as in the training phase; however, the participants had to find these buildings in the order presented to them on the screen (Wayfinding task. e.g., Participants were first required to go to Burger City and when they reached that place, they were then required to go to Fashion Bookstore, etc.). Participants were encouraged to finish this task in the shortest path and quickest time possible.

Post-Procedure Measures

When participants had finished the testing phase, they were presented with one final questionnaire created by the researchers of this present study. This questionnaire was to take note of what aspects of the virtual environments might have served as an aid for the creation of the cognitive map. This questionnaire can be referenced on page 35 of this paper.

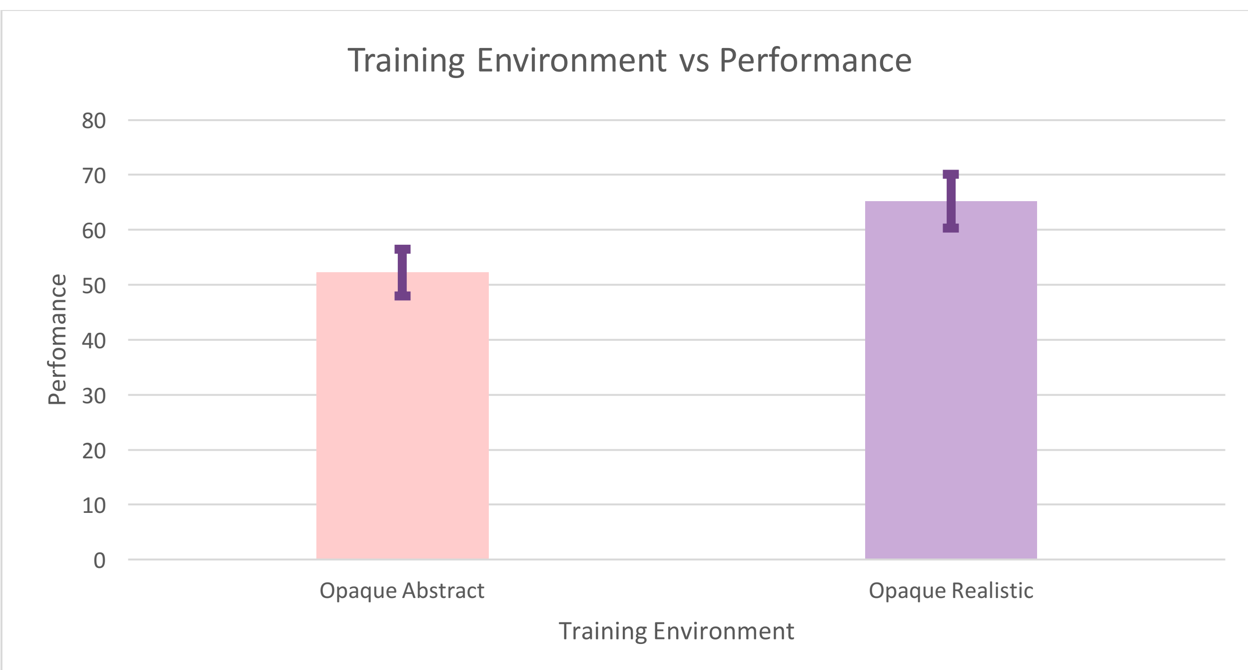
Results

The testing phase of this study consisted of the participants navigating through the Opaque Realistic environment to find target buildings as well as completing the pointing tasks. This phase involved switching between the navigation and pointing tasks. In addition, this section will examine the data found in the training phase of this study.

Training Phase

Pointing Task 1

In the training phase, Pointing Task 1 consisted of 18 trials of participants taking part in the Pointing Task (as described in the Methods Section) in their respective training environment – Opaque Abstract or Opaque Realistic. The dependent variable measured from this task was Performance in terms of position error. Position error is defined as the Euclidean distance between the target building's location and the participant's position to which he/she points to as the estimate. This position error calculation also takes into the account of the accuracy of the angle of the participant's attempt. Since the Euclidean distance is being calculated, the unit of measure is meters. Using an Analysis of Variance (ANOVA) test, a statically significant difference was found in the performance of the Pointing task between the training environment the participants were randomly assigned to ($p = 0.041$). To determine which group of participants had the better performance, the average performances needed to be graphically represented (Figure 1). As shown in Figure 1, participants who completed the training phase in the Opaque Abstract environment had a better level of performance in the pointing task. In addition, a statistically significant difference was found between participants with high and low spatial working memory ($p = .011$). In Figure 2, the data shows that participants with a high spatial working memory had a better performance than those with a low spatial working memory. There was no statistical difference ($p > 0.05$) noticed between participants with high and low sense of direction.



Figure`1: Participants who were randomly assigned to the Opaque Abstract training performed better in Pointing Task 1 than those who were assigned to the Opaque Realistic Environment. Performance was determined via the calculation of position error (measured in meters). The farther the participant's estimated distance from the true distance of the target building, the worse the performance. Thus, a better performance is represented by a lower performance value on the y-axis. A higher performance value indicated a worse performance.

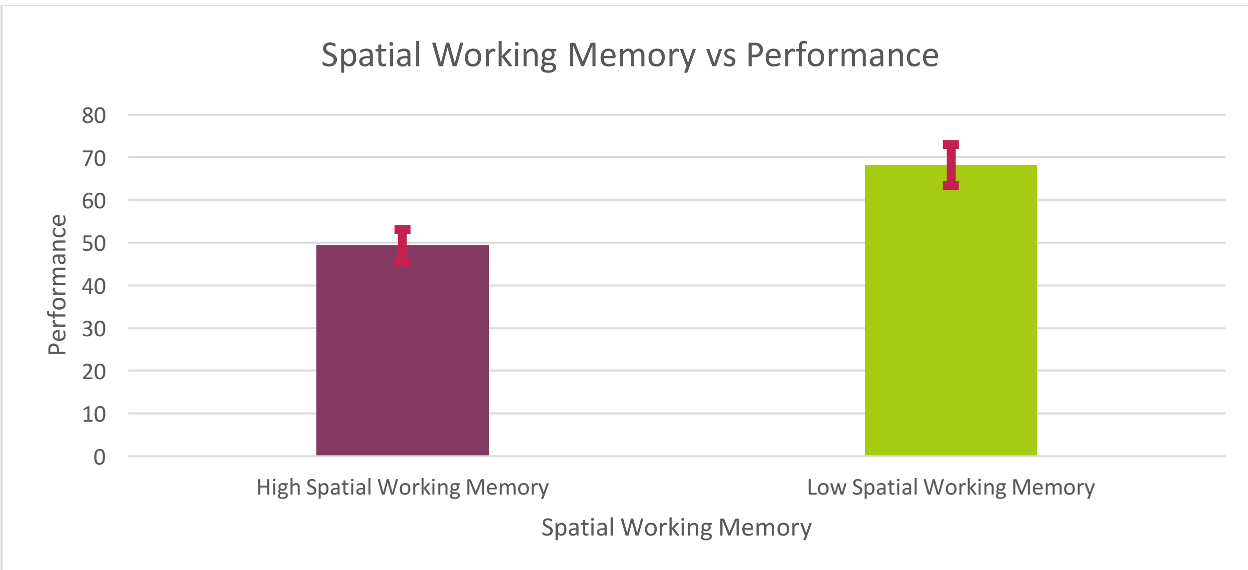


Figure 2: From the Pointing Task 1, it can be seen that the participants with a high spatial working memory had a significantly better performance than those with low spatial working memory. Performance was determined via the calculation of position error (measured in meters). The farther the participant's estimated distance from the true distance of the target building, the worse the performance. Thus, a better performance is represented by a lower performance value on the y-axis. A higher performance value indicated a worse performance.

<u>*Testing Phase*</u>

Navigation Task 1

Navigation Task 1 consisted of the first nine trials of the participants navigating through the environment and locating target building locations. The dependent variable measured from this task was Performance. Performance was represented in the form of a ratio calculated with the formula: distance_traveled – optimal_distance)/optimal_distance. The variable distance_traveled was defined as the distance the participant traveled to get to the target location. The other variable optimal_distance is Position error was defined as the shortest distance possible to reach the target location. Since this value is a ratio, there is not units for the dependent variable. Using an ANOVA test, it was determined that there was no statistical difference ($p > 0.05$) between the Opaque Abstract Environment and the Opaque Realistic Environment – the training environments the participants were placed in for the Training Phase. In addition, there was no statistical difference ($p > 0.05$) identified between both participants with high and low sense of direction nor between participants with high and low spatial working memory. However, there was a significant interaction between Sense of Direction and Spatial Working Memory ($p = .023$). Looking further into this interaction (Figure 3), it was discovered that among participants with high sense of direction, those with low spatial working memory performed worse than those with a high spatial working memory ($p = .018$). This pattern was not observed among participants with low sense of direction ($p > .05$).

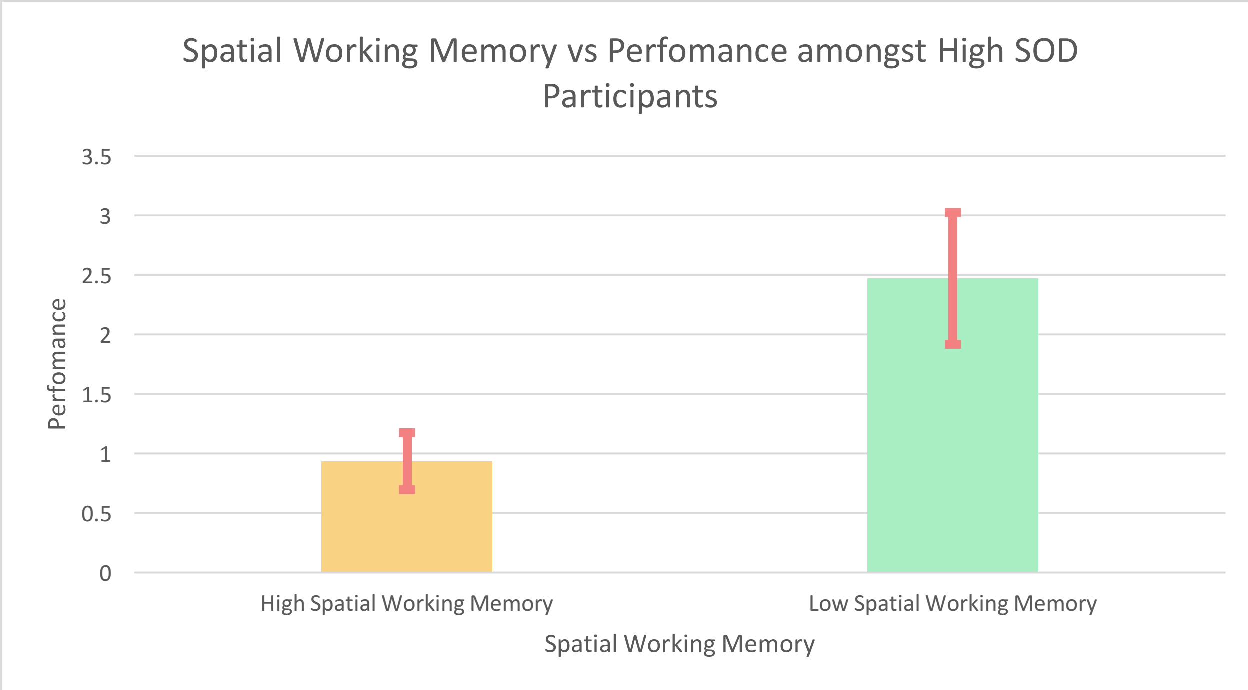


Figure 3: From Navigation Task 1, it can be seen that among the participants with a high sense of direction, those with a high spatial working memory had a significantly better performance than those with low spatial working memory. Performance was determined via the calculation of the ratio of the distance the participant traveled to the optimal distance to reach the target building location. The higher the distance the participant traveled (compared to the optimal distance), the worse the performance. A better performance is represented by a lower value on the y-axis. A higher performance value indicated a worse performance.

Navigation Task 2

Navigation Task 2 consisted of the second set of nine trials of the participants navigating through the environment and locating target building locations. The dependent variable measured from this task was the ratio value derived using the same formula from Navigation Task 1. The ANOVA determined there was marginally statistical difference ($p = 0.069$) between the training environments of Opaque Abstract Environment and Opaque Realistic. In addition, there was no statistical difference ($p > 0.05$) identified between both participants with high and low sense of direction nor between participants with high and low spatial working memory. Similar to Navigation Task 1, there was a statistically significant interaction between Sense of Direction and Spatial Working Memory ($p = .030$). Continuing with the similarities from Navigation Task 1, among the participants with high sense of direction, those with a low spatial working memory performed worse than those with a high spatial working memory ($p = .007$) (Figure 4). This pattern was not observed among participants with low sense of direction ($p > .05$).

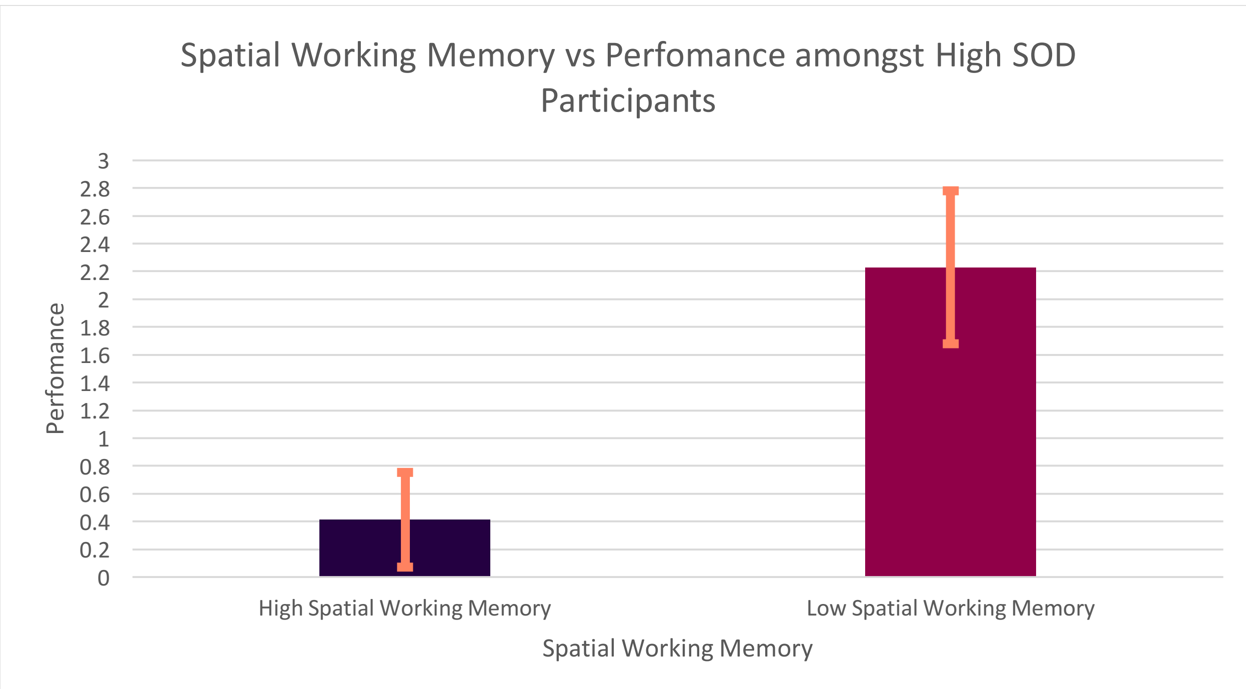


Figure 4: From Navigation Task 2, it can be seen that among the participants with a high sense of direction, those with a high spatial working memory had a significantly better performance than those with low spatial working memory. Performance was determined via the calculation of the ratio of the distance the participant traveled to the optimal distance to reach the target building location. The higher the distance the participant traveled (compared to the optimal

distance), the worse the performance. A better performance is represented by a lower value on the y-axis. A higher performance value indicated a worse performance.

Navigation 3

Navigation Task 3 consisted of the third and last set of nine trials of the participants navigating through the environment and locating target building locations. The dependent variable measured from this task was the ratio value derived using the same formula from Navigation Task 1. The ANOVA did not reveal any statistically significant differences between the two types of training environments nor between the participants with high and low working spatial working memory nor the participants with high and low sense of direction ($p > .05$). The ANOVA did however show a statically significant interaction between the Abstraction of the Environment and Spatial Working Memory ($p = 0.038$). From the participants who completed the training phase in the Opaque Abstract Environment, those with a low spatial working memory performed worse than those with a higher spatial working memory ($p = 0.045$) (Figure 5). This trend was not observed among participants who were randomly assigned the Opaque Realistic Environment for the training phase ($p > 0.05$).

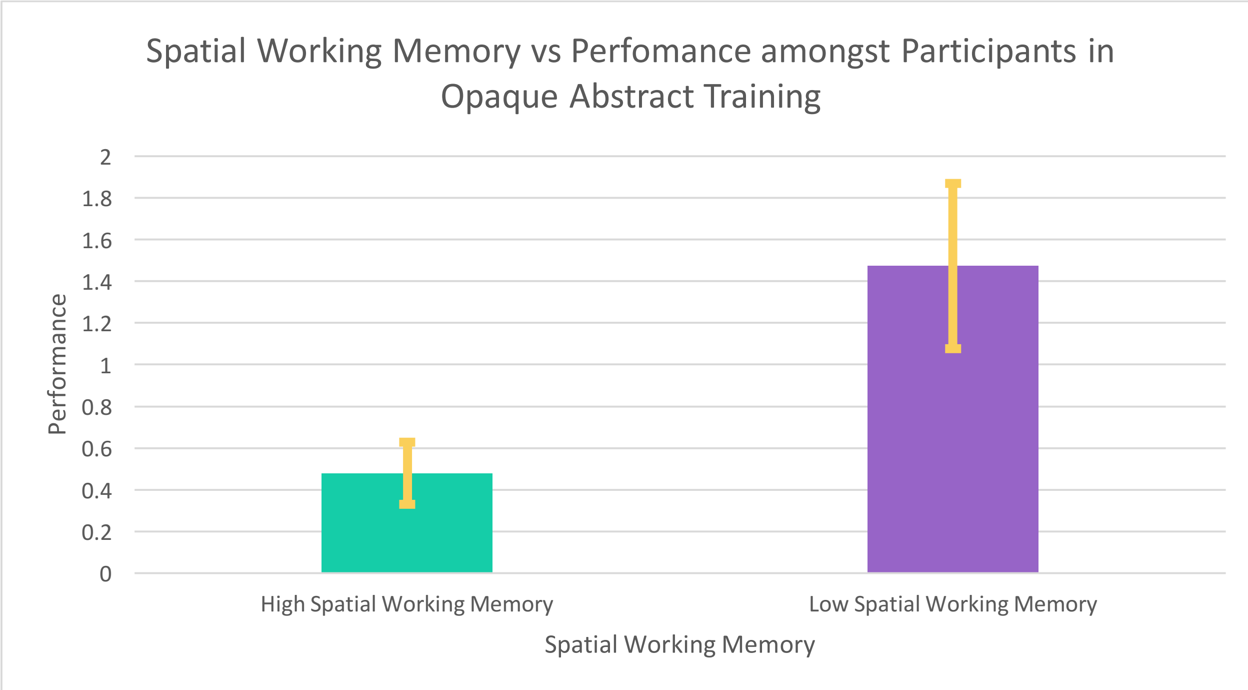


Figure 5: From Navigation Task 3, it can be seen that among the participants completed the training phase in the Opaque Abstract Environment, those with a high spatial working memory had a significantly better performance than those with low spatial working memory. Performance was determined via the calculation of the ratio of the distance the participant traveled to the optimal distance to reach the target building location. The higher the distance the participant traveled (compared to the optimal distance), the worse the performance. A better performance is represented by a lower value on the y-axis. A higher performance value indicated a worse performance.

Pointing Task 2

Pointing Task 2 consisted of the first 18 trials of participants taking part in the Pointing Task in the testing phase. The dependent variable measured from this task was Performance in terms of position error which was calculated using the same formula from Pointing Task 1.

Using an ANOVA, it was determined that there was a marginally statistical difference ($p = 0.058$) based upon the type of training environments the participants were subjected to. In addition, there was no statistical difference ($p > 0.05$) identified between participants with high and low sense of direction. There was a statistical difference established between participants with high and low spatial working memory ($p = .014$). In order to discern which group of participants had the better performance, the average performances needed to be graphically represented (Figure 6). As shown in Figure 6, participants with a higher spatial working memory performed better in the pointing task. There was also a statistically significant interaction between Sense of Direction and Spatial Working Memory ($p = .049$). Among participants with high sense of direction, those with low spatial working memory performed worse than those with a high spatial working memory ($p = .001$) (Figure 7). This pattern was not observed among participants with low sense of direction ($p > .05$).

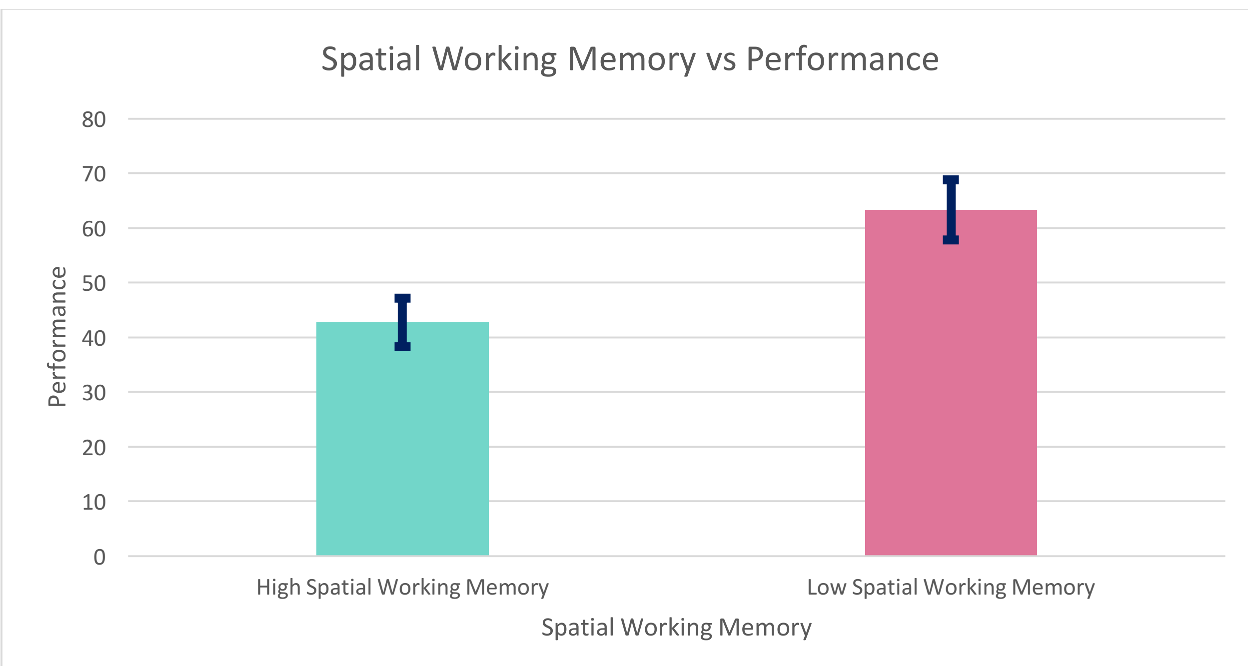


Figure 6: From the Pointing Task 2, it can be seen that the participants with a high spatial working memory had a significantly better performance than those with low spatial working

memory. Performance was determined via the calculation of position error (measured in meters). The farther the participant's estimated distance from the true distance of the target building, the worse the performance. Thus, a better performance is represented by a lower performance value on the y-axis. A higher performance value indicated a worse performance.

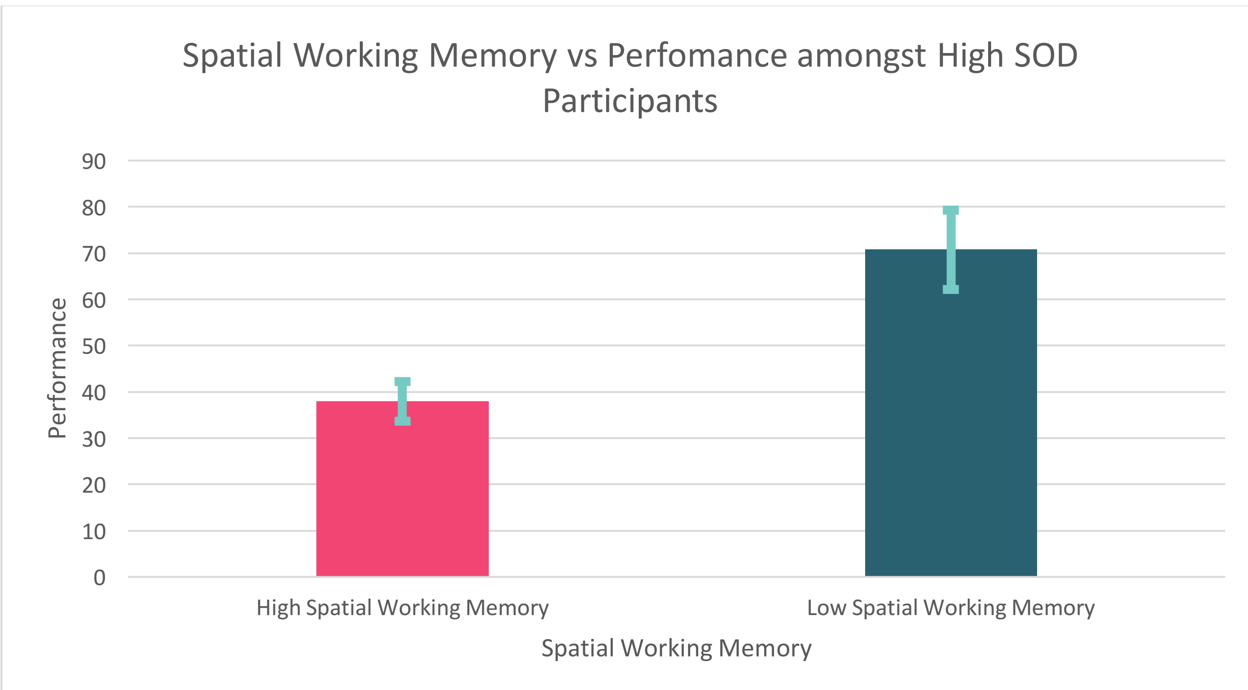


Figure 7: From the Pointing Task 2, it can be seen that among the participants with a high sense of direction, those with a high spatial working memory had a significantly better performance than those with low spatial working memory. Performance was determined via the calculation of position error (measured in meters). The farther the participant's estimated distance from the true distance of the target building, the worse the performance. Thus, a better performance is represented by a lower performance value on the y-axis. A higher performance value indicated a worse performance.

Pointing Task 3

Pointing Task 3 consisted of the second and last set of eighteen trials of the participants partaking in the Pointing Task. The dependent variable measured from this task was Performance in terms of position error which was calculated using the same formula from Pointing Task 1. The ANOVA did not calculate a statistically significant difference between the two types of training environments nor between the participants with high and low working spatial working memory nor the participants with high and low sense of direction ($p > .05$). There were no statistically significant results for the interaction between variables as shown in Pointing Task 2 – Sense of Direction and Spatial Working Memory. With these results being said, there was a marginally significant result of $p = .060$ for the performance between the participants with high and low spatial working memory, with the participants with the higher spatial working memory performing better at the Pointing Task. In addition, the interaction between Sense of Direction and Spatial Working Memory also had a marginally significant difference of $p = .084$. Further analysis revealed that among participants with high sense of direction, those with low spatial working memory performed worse than those with a high spatial working memory ($p = .009$) (Figure 8). This pattern was not observed among participants with low sense of direction ($p > .05$). If one were to consider these slightly significant results mentioned, then one could deem that this Pointing Task 3 had the similar results to those of Pointing Task 2.

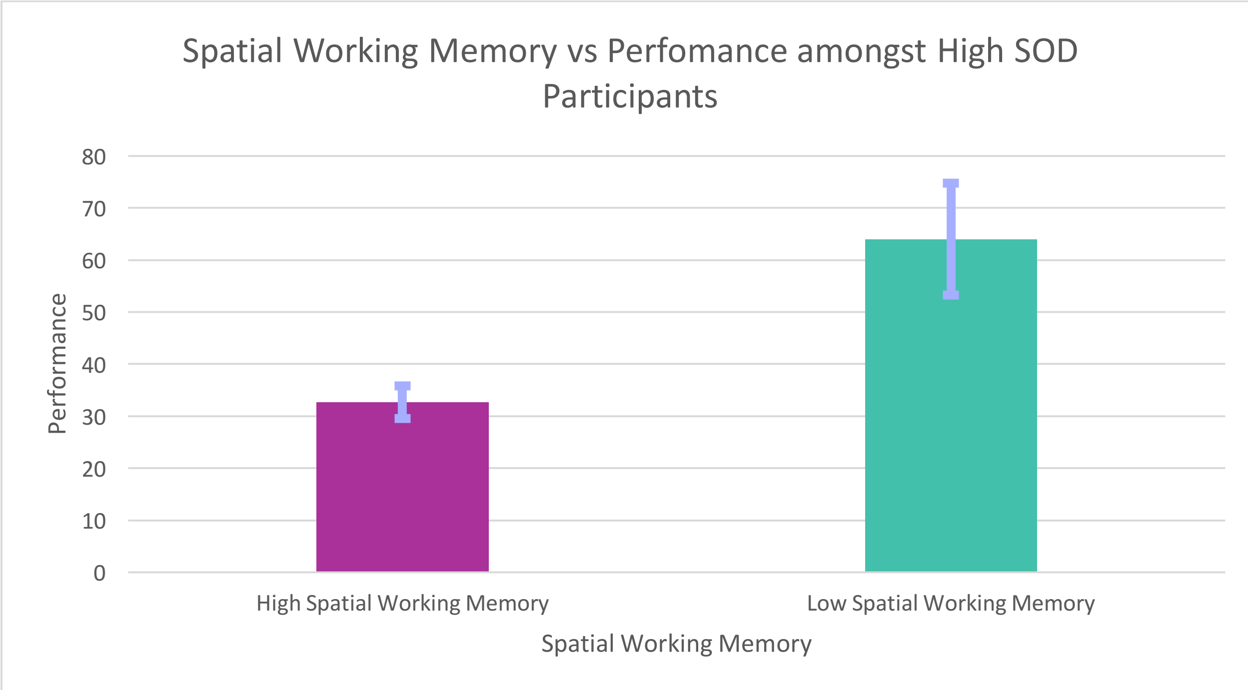


Figure 8: From the Pointing Task 3, it can be seen that among the participants with a high sense of direction, those with a high spatial working memory had a significantly better performance than those with low spatial working memory. Performance was determined via the calculation of position error (measured in meters). The farther the participant's estimated distance from the true distance of the target building, the worse the performance. Thus, a better performance is represented by a lower performance value on the y-axis. A higher performance value indicated a worse performance.

Discussion

The results from this study suggests that the Abstraction of the virtual environment does play a significant role upon navigation. A bigger sample size would be needed to better support this conclusion; however, the current data does provide a strong indication that Abstraction has an effect upon navigation and cognitive mapping.

From Pointing Task 1 completed during the Training Phase, the data depicts how participants in the Opaque Abstract environment performed better than those in the Opaque Realistic environment. Navigation Task 2 and Pointing Task 2 also had marginally significant results that show that the Opaque Abstract environment was more beneficial to performance. Thus, the reduction of cognitive load aided participants in being able to determine the positioning of the target buildings from a certain point of reference. This result is supported by the study conducted by Lokka et al in 2018. The emphasis upon the target buildings aided in the participants in being able to create a cognitive map. As a result, the participants in this condition were better able to reference buildings from any point in space in the virtual environment. By making all the other buildings in the environment abstract through white cubes, cognitive load was decreased. Furthermore, the excessive amount of spatial information that could serve as an impediment to cognitive mapping was removed through this cognitive load reduction. Thus, it can be inferred that a less cognitive load can indeed be beneficial to creating a cognitive map as long as an adequate amount of spatial information is present.

The results from Navigation 3 from the Testing Phase also supports the claim that Abstraction – a lesser cognitive load – is a beneficial to navigation and cognitive mapping. In the testing phase, from the participants who trained in the Opaque Abstract environment, those with a high spatial working memory performed better than those with a low spatial working memory in the navigation task. There are two potential reasons for this result.

Reason 1

Previous research has found that individuals with a high working memory are able to learn more cognitive training than those with low working memory (Foster et al., 2017). A reasoning to why this relationship may be the case is still unknown. There is one hypothesis that participants gain certain strategies in order to help them succeed at such cognitive tasks. Another hypothesis is that participants might reallocate time and/or effort towards certain mini-tasks within the cognitive task. For example, in the case of the Advanced Symmetry Span Test, some participants may have noticed that they needed to spend more time trying to remember the order of the highlighted squares rather than spending more time to check the symmetry of the figures shown intermittently. Regardless of which hypothesis supports why cognitive training is less beneficial to people with low memory capacity compared to those with high memory capacity, this reasoning would support the other results found in this study. In Pointing Task 1 and 2, participants with a high spatial working memory had a better performance than the participants with a low spatial working memory. In Navigation 1, Navigation 2, and Pointing Task 2, among the participants with a high sense of direction, those with a high spatial working memory had a superior performance. From these results mentioned, a pattern can be noticed. Those with a high spatial working memory excelled in the cognitive training, and this trend does not take into account the type of training environment the participants were exposed to. Thus, these results are in conjunction with the research conducted by Foster et al. – people with a high working memory are better able to learn from cognitive tasks such as the ones presented in this study.

Reason 2

Another potential reason for these results can be based of research conducted by Lokka et al in 2018. This study emphasized the importance of how both an insufficient and excessive amount of spatial information can obstruct the spatial working memory and cognitive mapping. While the Opaque Abstract environment was shown to be beneficial for the Pointing 1 Task in the training phase, it may have become an impediment for the testing phase. The training phase was less intense than the testing phase. The training only required participants to find the nine target buildings once and do one set of pointing tasks (18 trials). The testing phase, however, had the participants navigate through the nine buildings three times while also doing two sets of pointing tasks (36 trials total). Thus, the Abstraction may have been beneficial for the training phase where there were not as many tasks to do. The participants only had to remember the cognitive map for a short period of time to be successful in these cognitive tasks. However, the testing phase consisted of more tasks which would have required a longer duration of remembering the environment. Furthermore, the Abstraction may have not provided enough spatial information for participants with a low spatial working memory. The Abstraction would not have allowed for those participants to use any other buildings as landmarks because these said buildings would be white cubes in this training condition. Those with a high spatial working memory would not have been affected significantly because their memory is high enough to create a map to remember the buildings regardless of the Abstraction. Following with the logic from the research from Lokka et al, the Abstraction would have obstructed the spatial working memory and thus, cognitive mapping for participants with low spatial working memory due to the inadequate amount of spatial information – too low of a cognitive load.

Abstraction – creating a lower cognitive load – can be beneficial to aiding with navigation and creating a cognitive map in some situations. Further investigation should be conducted to understand how Abstraction is beneficial to certain situations. In some occurrences, Abstraction may become an impediment while in others, it may serve as an aid. Perhaps, varying the levels of Abstraction in an environment could prove to be beneficial. Most importantly, the study has found a visual design factor that can prove to help individuals increase their spatial abilities.

Perhaps combined with other visual design factors such as Translucency, where an individual can see through buildings, can lead to more profound results.

Limitations

A main focus of this study was to highlight the individual differences among the participants in order to derive applicable results about navigation to all kinds of people in the world. This study succeeded in this area by dividing people into subgroups of low and high spatial working memory and low and high sense of direction. However, this study did not focus on the individual difference of gender.

Gender is a very important individual difference in navigation. Previous research by O'Laughlin found that men and women utilize different strategies when navigating. Men use spatial abilities while women use landmark and location association (1998). Parush and Berman found that landmarks were inhibitory for men when navigating (2004). However, women were very successful when placed in an environment with many landmarks (2004).

This current study could not focus on sex as an individual difference because a majority of the female participants who attempted to partake in this study became physically ill when navigating through the virtual environment. Thus, a majority of the participants were male. Furthermore, a comparison between the results of males and females would not be accurate due to not enough of each gender to make a concrete conclusion about the results. A possible reason for female participants not being able to complete this navigational study is perhaps the graphics of the virtual environment. Further investigation into this matter should be conducted.

Conclusion

From this study, it was found that Abstraction can be beneficial to navigation and building a cognitive map. In certain situations, abstraction allows for individuals to visualize their environment more easily without obstruction of other extraneous spatial information. However, in other scenarios, Abstraction may be inhibitory to those with a lower spatial memory capacity. This occurrence could be due to the lack of spatial information (Lokka et al., 2018) to utilize over a longer period of time. Another explanation could be cognitive training tasks are less beneficial to individuals with a lower memory capacity (Foster et al., 2017). Nevertheless, the observations from this study indicates the Abstraction within an environment does have an effect on navigation. The observations can be used to help understand how Abstraction can be used in conjunction with other visual design elements to help increase spatial abilities within all types of individuals. With more research, virtual environments can be created to boost spatial abilities of individuals in order for people to be less dependent upon technological devices, such as a GPS, which ultimate harms the acquisition of knowledge (Ishikawa et al., 2008) In addition, if environments can be created to help increase spatial abilities, then STEM abilities can be developed in students (Wai et al., 2009). Thus, it is important to continue research in this area. With more studies analyzing the effects of visual design and varying levels of cognitive load, there is the possibility of creating environments that could be beneficial to understanding the environment one navigates through and how to build a long term cognitive map of said environment.

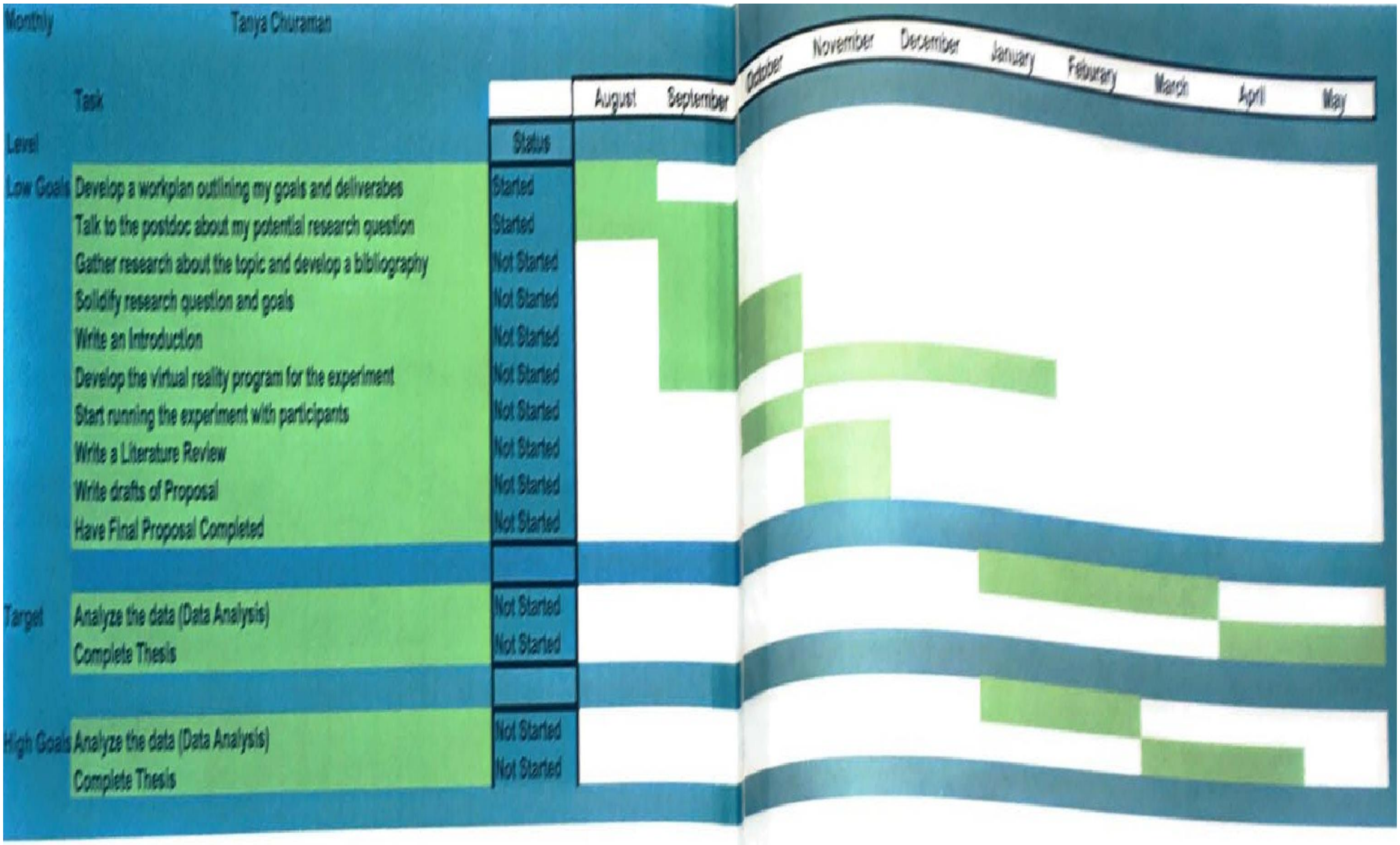
Recommendations

Further research should be conducted about varying the levels of Abstraction in virtual environments. The observations of this study have indicated that Abstraction is a visual design factor of virtual environments that can aid individuals in increasing their spatial abilities. Future studies can mix other design factors, such as Translucency, to see if there are other variables that need to be combined with Abstraction to have more successful observations. Also, a bigger sample size should be gathered in order to have more confidence in the conclusions.

In addition, more research should be conducted to find a medium to create a virtual reality environment that is friendly to all types of people. This study experiments the challenge of the virtual environment causing some female participants to become physical ill. Researchers should further examine why such programs have such an adverse effect and what can be done to rectify this issue. It is important that the navigational implications found in future studies can be applied to all types of individuals. With more research, there is a high probability that individuals can gain stronger spatial abilities.

Lastly, the current study presented the virtual environments via the medium of a desktop computer. Future studies should also take in account the usage of different platforms to display the virtual environment, such as a full immersive virtual reality headset. These different platforms could potentially yield different results.

Work Plan



Thackery Brown, Asst. Prof

Post-Procedure Measures

1. How helpful the concaved corner was in the wayfinding task?

   1 (not helpful at all)   2   3   4   5 (very helpful)

2. How helpful the concaved corner was in the pointing task?

   1 (not helpful at all)   2   3   4   5 (very helpful)

3. How helpful the enclosure was in the wayfinding task?

   1 (not helpful at all)   2   3   4   5 (very helpful)

4. How helpful the enclosure was in the pointing task?

   1 (not helpful at all)   2   3   4   5 (very helpful)

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