Title
Learning and Memory in Minecraft: Objects and Object-Location Associations in a Virtual Open-Field Environment

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Learning and Memory in Minecraft: Objects and Object-Location Associations in a Virtual Open-Field Environment

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ABSTRACT OF THE THESIS

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by

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Master of Arts, Graduate Program in Education
University of California, Riverside, September 2024
Dr. Kinnari Atit, Chairperson

This study investigates the potential impact of passive learning for retaining spatial memory using an open-field Minecraft environment. The goal was to understand the extent to which memory of object locations can be retained when learned from watching a video. We wanted to understand how perspective-taking skills and the development of spatial memory contribute to the consolidation of memories from this passive learning experience. We examined how 59 participants learned a path and objects located throughout an environment from viewing a video featuring an avatar navigating the path to 12 specific objects. After watching the video, participants were given a paper-based object recognition test to gauge immediate object memory. Following this, they navigated the Minecraft environment to recreate the path and locate the objects. Their accuracy was measured through Euclidean distances calculated with recorded coordinates. Participants subsequently were tested on how closely they could replace the found objects back in original locations. Our findings reveal moderate correlations between our spatial memory and perspective-taking measures. Location memory accuracy and perspective-taking ability were predictive of accurate object-location associations. This indicates that better memory for the locations where objects should be found and visualization for those locations from different perspectives aid in consolidating the association between specific objects and their locations. We also found object-location associations to be marginally significant as a predictor for path recreation accuracy. This indicates that strong associations encoded for objects and their locations are useful for navigating a related path. Our findings point towards which specific forms of spatial memory and skills best bolster strategies for navigating through open-field environments.

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Introduction

The world is a spatial thing. Everything takes up space. People need to go on journeys, big or small, and learn to move through the three dimensions of space that make up our reality. Interacting with the many screens of modern technology—understanding both the 2D and 3D objects that can be displayed and manipulated—requires understanding the spatial properties assigned to those digital objects. To arrange objects to fit within the spaces designated for them, the objects, their spatial properties, and the properties of the location must all be considered. All these ways of interacting with the spatial aspects of the world require people to develop their spatial skills. The everyday usage of spatial skills, both in terms of the skills themselves and the optimal usage of tools that depend on understanding spatial properties, will persist no matter how the world or its people continue to change.

Spatial Skills

It is important to understand what spatial skills are, and how they are developed and enhanced. Spatial skills refer to a category of cognitive abilities related to holding in mind and utilizing the understanding of spatial properties within and between entities (Uttal et al., 2013). They are important cognitive abilities that can be broadly categorized into small-scale and large-scale spatial skills (Yuan et al, 2019; Wang et al., 2014). Small-scale spatial skills involve the manipulation of objects in a limited space, such as mental rotation where an object is visualized from different points of view (Shepard & Metzler, 1971; Hegarty & Waller, 2004). Large-scale spatial skills take place within a large environment and involve the abilities required to navigate and orientate oneself, including navigation, perspective-taking, and wayfinding (Maguire et al., 1998; Carbonell-Carrera & Hess Medler, 2017; Lawton, 1994).

Navigation is a key spatial skill that governs the ability to move through environments and determine one's location relative to other entities. This is a process that requires the collective use of related spatial skills, such as object memory, object-location association memory, and wayfinding or path learning (Simon et al., 2022; Burgess et al., 2002). Wayfinding is the ability to orientate oneself based on environmental cues, allowing for the planning and execution of routes to follow. With object-location association, specific objects are linked to specific places within the environment and retained together (Hannula & Ranganath, 2008). Once associations are established, navigating to objects in an environment involves the use of wayfinding to determine a route and follow it to reach a target location. Throughout the process, there is a need to accurately orientate oneself relative to the environment, and perspective-taking is utilized to achieve this accurate spatial orientation (Hegarty & Waller, 2004; Carbonell-Carrera & Hess Medler, 2017). Perspective-taking is the ability to visualize how something looks from a different point of view (Goldhagen et al., 2023; Carbonell-Carrera & Hess Medler, 2017; Hegarty & Waller, 2004). This in turn requires an understanding of the spatial arrangement of entities within an environment, accurately gauging the spacing between object-locations. Effective use of perspective-taking leads to accurate expectations of how specific spaces will look from different angles and distances.

The Spatial Brain

The hippocampus is the part of the brain that plays a crucial role in spatial memory and skills. It helps to encode and retrieve information about object-location associations relative to one another, assisting in the allocentric processing of the spatial environment and supporting episodic memory (Burgess et al., 2002). The hippocampus is also attributed as the location where cognitive maps—the mental representations of spatial environments—are developed (Tolman, 1948; O'Keefe & Nadel, 1978). This gives the hippocampus a central role in encoding the memory that is referenced when utilizing large-scale spatial skills. This is further evidenced when, upon utilizing spatial strategies, increased activity in the right hippocampus has been observed via fMRI imaging (Iaria et al., 2003). Studies have also shown that damage to the hippocampus is proportionally correlated with poorer performance at spatial tasks (Burgess et al., 2002). Given the everyday importance of spatial skills, extensive activity in the hippocampus as part of the utilization of these skills is to be expected.

Minecraft as the Medium

Virtual environments (VEs) have long been used in the determination and analysis of spatial skills in past studies. Virtual reality studies have shown promise in the neurorehabilitation of spatial skills for people with spatial memory disorders; navigation tasks conducted in both immersive (e.g. VR headset) and nonimmersive (e.g. Laptop screen) VEs have been used for transferable improvements to spatial memory (Montana et al., 2019). VEs are also used to gauge participants' spatial abilities. Seeing aspects of visual cues in a VE result in recognizable spatial memory and navigation that can be picked up via fMRI (Ekstrom et al., 2003). The use of a VE also offers the benefits of an experimentally consistent space that can be perfectly duplicated and redeployed for each participant. The size, lighting, and starting coordinates of the environment can remain the same regardless of the time and location that a test is administered within the VE. The immersive elements that help VEs appear like real physical environments is also an important aspect to determine an effective VE.

Minecraft is a video game that centers around the exploration of an open environment constructed by an enormous variety of differently textured and realistically placed cubic blocks. It was released in 2009 by Mojang Studios, and its rights were purchased by Microsoft in 2014. It is an ecologically viable method to present participants with an open-field environment, which mimics natural environments, that they can move through in realistic manners (Simon et al., 2022; Clemenson et al., 2019). The blocks that make up a Minecraft world represent the building blocks of natural environments, such as soil or sand, and include immersive sensory elements. For instance, walking on a sand block with an avatar in Minecraft generates footstep noises that sound distinctly like walking on sand in a real environment. Minecraft world creation is also coded to generate natural environments like people would find in nature, including distinct biomes such as mountains, deserts, and forests. It therefore becomes easier to create an immersive, open-field VE by building within Minecraft. The usage of plugins within the Minecraft world also allows for the alteration of its game rules to align with experimental conditions while also recording avatar movement in the form of coordinates.

Simon et al. (2022) developed an effective Minecraft VE with corresponding plugins as part of their Minecraft Memory and Navigation (MMN) task. This task helped to find how spatial memory and navigation were disassociated, so we found it to be an ideal VE to adapt for our own study to further examine the relationship between these spatial skills. We modified Simon et al. (2022)'s MMN task to suit the conditions of this study.

Prior Research

Postma and De Haan (1996) posit, in experiments on object location memory, that two distinct processes are involved: the encoding of positions and the assignment of objects to the encoded positions (i.e. object-location associations). In their first experiment, participants studied a square containing objects in different locations. The object sets varied between identical objects (position-only focus), letters (easily verbalized objects), and nonsense characters (difficult to verbally label). Increasing the load on object-to-position assignments did not affect the encoding of the positions themselves. This indicates that position encoding is separate from object-location associations. Their similar second and third experiments altered how the squares were presented and whether the participants did or did not need to remember the positions in the squares. These experiments help to affirm their findings of how the processes for position encoding and object-location associations were separate components for object location memory.

In a virtual environment exploration study by Gaunet, Vidal, Kemeny, and Berthoz (2001), the differences between active, passive and snapshot exploration were investigated. In the context of their study, *active* involved giving instructions to participants while they controlled the virtual avatar, *passive* was when a computer controlled the avatar's exploration, and *snapshot* involved presenting a series of 47 static images. They utilized a driving simulator virtual environment analogous to a city with obstructive walls. Navigation in this environment was only within the bounds of roads and footpaths. After experiencing the different exploratory modes, the study administered three tasks: remembering whether snapshots were or were not part of the experienced exploration, orientating towards the beginning of the path from the end of the path, and drawing the shape of the path experienced in the exploration on a piece of paper. Gaunet et al. (2001) found that the drawn paths were affected by the mode of explorations, with greater errors following snapshot exploration but no significant difference between active and passive explorations.

Current Study

The current study builds upon the prior research conducted by Simon, Clemenson, and Zhang (2022) with the goal of improving our understanding of how perspective-taking skills and spatial memory contribute to our learning of open-field environments. Simon et al. (2022) utilized an open-field Minecraft environment to explore spatial memory accuracy and navigation in relation to sleep, reporting findings of how sleep enhances spatial memory for objects and where they are in the environment. Their study found a difference in relationship to sleep by spatial memory and navigation, helping to disassociate them as separate spatial skills. We seek to extend this work with an examination of object-location associations and navigation as retained in memory after passive video learning. By administering Guay's Visualization of Views (VOV) test (Guay, 1977) beforehand to assess perspective-taking skills, we can also measure how perspective-taking skills correlate with spatial memory retained through viewing the video. Our plan is to investigate how path learning fits as a component to object-location associations and navigation. By introducing a path that needs to be learned from the passive video learning and recreated in the open-field environment, we can measure participants' path learning. We can then further examine the relationship between object-location associations and path memory when both are learned through the same passive learning medium. The memory of watching the passive instruction video must be encoded as referenceable directions for recreating the path that the participant has not yet taken for the first time. Participants must recognize when they are seeing familiar viewpoints—following the path—or when they are seeing new viewpoints and deviating from the path.

Questions and Hypotheses

We think there will be some notable relationships between perspective-taking, spatial memory, and path learning. To investigate this, we ask the following research questions. First, what are the relations between perspective-taking skills and aspects of memory important for navigation (i.e., object memory, location memory, memory for object-location associations, and path learning)? To investigate this question, we will run correlational analyses to compare our measures for these variables. Next, accounting for participants' gender and Minecraft experience, if and how do perspective-taking skills, and memory for objects and locations, contribute to memory of object-location associations in open-field environments? To answer this, we will use a regression model to examine the contributions of the Visualization of Views test, object memory score, and location memory score in predicting the results of our measure for object-location associations memory. Finally, accounting for participants' gender and Minecraft experience, if and how do perspective-taking skills and the components of spatial memory (i.e., object memory, location memory, and object-location association memory) contribute to passive path learning in open-field environments? We will use another regression model to answer this question, this time measuring the contributions of our predictors towards predicting the outcome of our path learning measure.

Prior studies have shown gender differences in spatial skills (Yuan et al., 2019; Lawton, 1994). The review by Yuan et al. (2019) shows a difference in behavior performance between males and females in both small-scale and large-scale spatial ability, with the difference in large-scale spatial ability being more pronounced. The study by Lawton (1994) showed a difference in preferred wayfinding strategies based on gender. Lawton (1994) also found higher reports of anxiety about environmental navigation from woman than men. Thus, we included gender in our analyses as we wanted to account for these potential gender-based variations in spatial skill measures.

The popularity of Minecraft as a game meant we expected a notable portion of our participants to have heard about or played the game. We also expect that among the participants who have played Minecraft, the amount of their overall experience would differ. Since the open-field environment is contained within Minecraft and is navigated with the game's controls, performance may vary based on individual levels of expertise.

We surveyed all participants for Minecraft experience and accounted for potential variance tied to it in our research.

Based on prior research on the relationship between object memory and path memory, we know that the aspects of spatial memory operate via distinct neural circuits as related but separate processes (Postma et al., 2008; Postma & Haan, 1996). We hypothesize that the relationships between perspective-taking, navigation, and aspects of spatial memory will be related to different degrees because of their interconnected usages in spatial tasks. We expect perspective-taking skills to be related to path learning and navigating to object locations in open-field environments. Perspective-taking involves understanding how the same scene appears from different viewpoints, and people naturally move through different viewpoints when they move across an environment as part of wayfinding (Hegarty et al., 2005). Successful navigation, particularly with path recreation, requires anticipating and recognizing viewpoints that should be seen from along the path (Shelton & McNamara, 2004). It also requires recognizing views of importance, such as the location where a big turn should be taken as part of the path. In the case of object-location associations, this is recognizing where an object should be found based on what the view of its location should look like. Given the constant necessity of recognizing key views with perspective-taking throughout the entire path in the environment, high perspective-taking skill scores should positively correlate with high path learning performance and accurate object-location association.

Methods

Participants

Seventy-two (26 male, 42 female, 1 nonbinary, 3 not reported) undergraduate education students were recruited from the University of California, Riverside (UCR) to participate in this study. Of those participants, usable data was collected from fifty-nine (23 male, 32 female, 1 nonbinary, 3 not reported) students and analyzed for this study. Data from thirteen participants were excluded due to experiment administration errors, incompletion of the Paper Object Test, or incompletion of the In-Vivo Environment Test. Most of these participants had experience playing video games and were familiar with Minecraft. We requested that participants report on their level of expertise in Minecraft.

Table 1. Participant Data.

Gender	*n*	% total
Male	23	38.98
Female	32	54.24
Nonbinary	1	1.69
Not Reported	3	5.08
Plays Video Games for Leisure		
Yes	47	79.66
No	10	16.95
Not Reported	2	3.39
Prior Minecraft Experience		
Yes	46	77.97
No	11	18.64
Not Reported	2	3.39
Reported Minecraft Expertise		
Not Applicable	8	13.56
Novice	18	30.51
Intermediate	15	25.42
Advanced	8	13.56
Expert	5	8.47
Not Reported	3	5.08

Survey Items

The Demographics and Video Game Questionnaire features 13 items: 7 on demographic information and 6 on video game experiences. The video game experience items probed about participants' video game playing experience and behavior. The questionnaire asked for the favorite genres of games played, whether games were played for leisure, and overall experience with Minecraft.

Guay's Visualization of Views

The Visualization of Views (VOV) test is a psychometric measure used to assess perspective-taking skills in participants (Goldhagen et al. 2023; Guay, 1977). It is a 24-item test that features 3D objects viewed from different positions. Participants are asked to correctly identify the angle from which a 3D object is being viewed. Each correct answer on an item awards 1 point, while each incorrect answer is penalized by 1/6ths of a point. This means that the minimum score on this test is -4 while the maximum score is 24. When measuring the internal consistency of the test items using Cronbach's *α,* the internal reliability for the measure was good ($\alpha = 0.89$).

Open-Field Minecraft Environments

The VE used in this study was adapted from Environment 2 of the Minecraft Memory and Navigation (MMN) task (Simon et al., 2022). This is a mostly flat plains landscape with two major bodies of water, a forest, a swamp, a hill, a mountain, and some minor manmade structures. Most of this environment was preserved, with the biggest changes being the addition of some grassy flower fields, the removal of some climbable features, and a bridge over one of the major bodies of water. The plugins were modified to place objects in the environment without an indicator to make the objects easier to find and to introduce one nearby distractor object near each of the twelve objects meant to be located. One plugin recorded each participants' interaction with objects categorized by task. Another plugin recorded the steps each participant took in the environment as detailed coordinates.

A practice environment, with completely different features and objects, was prepared to present participants with a tutorial of how to move through Minecraft and interact with objects.

Passive Instruction Video

The Passive Instruction Video is a 9 minute and 13 second video that features an avatar following a complex path through the open-field Minecraft environment. While along this path, the avatar stumbles upon 12 chests, and each chest contains one object. A narrator speaks throughout the video, delivering an introduction about Minecraft, describing the steps being taken while navigating, and naming each object found. The video lingers on each object as the narrator provides a brief fun fact related to it. The fun fact is unrelated to the location of the object.

Test 1: Paper Object Recognition

The first test conducted after the Passive Instruction Video was the Paper-Based Object Recognition test, which was designed to gauge each participant's immediate short-term memory of the 12 objects observed in the video. This test is a single paper sheet given to participants. It contains 24 Minecraft objects, 12 being from the video and 12 being distractor objects that could also be found in the environment. Participants were asked to identify as many objects as they could remember from the video. The number of objects identified was recorded as the participant's Object Recognition score.

Test 2A: In-Vivo Object Location and Path Accuracy

The second test is conducted immediately after the Paper-Based Object Recognition Task. In the first part of the In-Vivo Environment Test, participants are given control of an avatar in the same Minecraft virtual environment as was shown in the Passive Instruction Video. They have 10 minutes to recreate the same path as seen in the video and find the same 12 objects in the environment. The participants are also not informed of or given any instruction about the 12 additional distractor objects in the environment.

Each correct object and its corresponding distractor object are considered a node. When a participant navigates their avatar to one of the twelve nodes, regardless of whether they find the correct object, they are given a point for their Object Location Accuracy score if that is their first encounter with the node. This score accounts for the number of object locations that the participant navigates to.

Our measure for path recreation accuracy compares the movement coordinates of the participant with the coordinates of the Passive Learning Video's original path. The percentage of a participant's path that falls within a 5-unit radius of the original path is the participants 5-Radius Path Overlap score.

Test 2B: In-Vivo Object Replacement

After the path recreation portion of Test 2, the participants were administered the second part of the test: each participant was given one of the 12 correct objects at random and asked to place the object as close to its correct location as possible. This is our measure for object-location associations. Once an object is placed, the next object will be given until all objects have been placed. The coordinates of where the participants placed each object was recorded in a log file.

The Euclidean distance between where each object was placed by the participant and the correct location was calculated. Given $X_{1,}$ $Y_{1,\text{ and}}$ Z_1 are the coordinates of the participants' object placement and $X_{2,}$ $Y_{2,\text{ and}}$ Z_2 were the correct coordinates, the following equation was used:

$$\text{Distance} = \sqrt{(X_1 - X_2)^2 + (Y_1 - Y_2)^2 + (Z_1 - Z_2)^2}$$

Once this distance was calculated for each object placed by each participant, the distances were summated and then divided by the number of objects placed by the participant to get the average. This became each participant's Average Euclidean Distance score.

Procedure

This study comprised of two sessions. The first session was the remote session where participants are asked to fill out the Demographics and Video Game Questionnaire on Qualtrics and a Visualization of Views test. Next was the in-person session with the Passive Instruction Video and all subsequent paper and environment tasks. In the in-person session, the participants were first given control of an avatar in the Minecraft practice environment. Minecraft controls were introduced and explained to participants to ensure they met the minimum required familiarity with the rules of the virtual environment and how to navigate it. Participants were told what buttons to press to move forward, backwards, left, right, and jump. They were told how to look around by moving the mouse, followed by how to open chests and place objects by pressing the right mouse button. To confirm that the participants understood how to control the avatar, they needed to successfully move through the practice environment and interact with objects. Before participants could advance, they had to complete practice tasks. The practice tasks used the same mechanics as the two-part In-Vivo Environment Task to confirm that the participants knew all necessary controls to interact with objects.

After completing the practice environment tutorial and tasks, we presented the participants with the Passive Instruction Video and read off the script instructing them to pay attention to the path they would later replicate and objects they would later find. Participants were also instructed not to pause the video and to watch it in its entirety. Once the video ended, we administered the Paper-Based Object Recognition Task. After the participants identified the objects they recognized, we administered the In-Vivo Environment Task. Participants were given control of a Minecraft avatar in the same environment as the Passive Instruction Video and given ten minutes to recreate the path and find the same twelve objects. Once the time limit ran out, or when the participants finished the In-Vivo Object Location Accuracy portion of the task, the In-Vivo Object

Replacement portion of the task was administered. The in-person session ended once the In-Vivo Environment Task was fully completed.

Results

Tools of Analysis

RStudio, using R version 3.5.3, was the primary software used for the calculation of variables and overall analysis of the data (RStudio Team, 2020; R Core Team, 2019).

Table 2. Descriptives

Descriptive Statistics

Measure	*M*	*SD*
Paper Object Recognition	9.76	1.72
In-Vivo Location Accuracy	7.34	2.55
In-Vivo Euclidean Distance	84.07	30.34
In-Vivo 5-Radius Path Overlap	0.53	0.11
Visualization of Views	10.87	6.98

Note. *M* indicates the mean. *SD* indicates the standard deviation.

The performance of participants across our spatial memory and skills measures were assessed and summarized in Table 2. Paper Object Recognition showed relatively high accuracy, based on the maximum score being 12, with moderate variability (*M* = 9.76, *SD* = 1.72). In-Vivo Location Accuracy, also with a maximum possible score of 12, showed lower accuracy and higher variability (*M* = 7.32, *SD* = 2.55). In-Vivo Euclidean Distance (*M* = 84.07, *SD* = 30.34) and Visualization of Views (*M* = 10.87, *SD* = 6.98) both show considerable variability. In-Vivo 5-Radius Path Overlap, with a maximum possible score of 1, indicates moderate accuracy and variability (*M* = 0.53, *SD* = 0.11).

Research Question 1

Our first research question asked about the relations between perspective-taking skills and aspects of memory important for navigation (i.e., object memory, location memory, memory for object-location associations, and path learning). We ran correlational analyses to compare our measures for these variables. The results are arranged in the correlation matrix of Table 3.

Table 3. Correlation Table

Correlation Table

	1.	2.	3.	4.
1. Paper Object Recognition				
2. In-Vivo Location Accuracy	0.36			
3. In-Vivo Euclidean Distance	-0.38	-0.59		
4. In-Vivo 5-Radius Path Overlap	0.34	0.47	-0.55	
5. Visualization of Views	0.39	0.44	-0.48	0.42

Note. All correlations are significant at $p < 0.05$. Boxes around numbers indicate $r > 0.4$. Bolded boxes indicate $r > 0.5$.

All variables had at least moderate correlational relationships with all other variables. This indicates an underlying interconnectedness between these spatial memory variables. Paper Object Recognition was our object memory measure and has the lowest overall correlation with all other variables. In-Vivo Location Accuracy is our location memory measure, and it has a stronger relationship with our Euclidean Distance variable ($r = -0.59$, $p < 0.001$). The In-Vivo Euclidean Distance variable is our object-location associations measure, which has stronger correlations with our path learning measure (r = -0.55, $p < 0.001$), the In-Vivo 5-Radius Path Overlap variable. Finally, we have the perspective-taking measure based on the score from Guay's Visualization of Views test being moderately correlated with all other variables and showing stronger correlations with the In-Vivo variables.

Research Question 2

Our second research question was about how perspective-taking skills, and memory for objects and locations, contribute to memory of object-location associations in open-field environments. We conducted a multiple linear regression to investigate the impact of gender, Minecraft experience, object memory, location memory, and perspective-taking on our object-location associations measure: the Euclidean distance scores from the In-Vivo Object Replacement test. All predictor variables were standardized for the analysis of each variable's relative contribution. This regression model is significant ($F(5, 46) = 8.515$, $p < 0.001$), and 48.07% ($R^2 = 0.4807$) of the variance in our object-location associations measure is explained by the predictors in our model.

Table 4. Regression Model 1

Coefficient	b(SE)	B	p
Intercept			0.45
Gender	-7.00(7.88)	-0.12	0.38
Minecraft Expertise	-4.00(3.53)	-0.16	0.26
Object Recognition	-0.81(2.50)	-0.05	0.75
IV Location Accuracy	-5.44(1.58)	-0.46	0.001**
VOV	-1.14(0.56)	-0.26	0.048*
R^2		0.48	

Note. Regression Model 1 includes the unstandardized betas (b) with standard error, standardized betas (B), and the associated p-values. * = $p < 0.05$, ** = $p < 0.01$.

Lower In-Vivo Euclidean Distance scores indicate a shorter distance between where participants remember objects were located versus those objects' true original location in the In-Vivo Object Replacement test, indicating higher object-location association accuracy. In-Vivo Location Accuracy is a significant predictor for object-location association ($B = -0.46$, $p = 0.001$). Higher accuracy in participants' ability to remember and navigate to the location of objects in the open-field Minecraft environment is associated with higher object-location association accuracy. The VOV score, with higher scores indicating greater perspective-taking ability, is also significantly predictive of object-location association accuracy ($B = -0.26$, $p = 0.048$). Object memory is not a significant variable in this study ($B = -0.05$, $p = 0.75$).

Table 5. Model 1 Interaction

	Model 1			Model 1 Interaction		
Coefficient	*b*(SE)	*B*	*p*	*b(SE)*	*B*	*p*
Intercept			0.45			0.76
Gender	-7.00(7.88)	-0.12	0.38	-6.55(7.95)	-0.11	0.41
Minecraft Exp	-4.00(3.53)	-0.16	0.26	-4.17(3.57)	-0.16	0.25
Object Recog	-0.81(2.50)	-0.05	0.75	-1.18(2.57)	-0.07	0.65
IVLocAcc	-5.44(1.58)	-0.46	0.001**	-3.57(3.31)	-0.44	0.003**
VOV	-1.14(0.56)	-0.26	0.048*	0.07(1.97)	-0.24	0.09 +
IVLocAcc:VOV				-0.15(0.23)	-0.09	0.52
R^2		0.48			0.49	

Note. + = $p < 0.1$, * = $p < 0.05$, ** = $p < 0.01$

Upon seeing the significance of our location memory and perspective taking measures as predictors for object-location associations, we ran analyses for interaction effects between these variables. However, we found no significant interaction effects between the variables. The lack of interaction effects between location accuracy and VOV (B = -0.09, p = 0.52) indicates that location memory and perspective-taking skills contribute independently to object-location associations. This indicates that even if perspective-taking skills are used to visualize a location in the environment from a different angle, it is not significantly related to the spatial memory of those locations.

Research Question 3

Our last research question was looking into how perspective-taking skills and the components of spatial memory (i.e., object memory, location memory, and object-location association memory) contribute to passive path learning in open-field environments. We conducted a second multiple linear regression to investigate the impact on our path learning measure, the 5-Radius Path Overlap variable. Our predictors for this model were gender, Minecraft expertise, object memory, location memory, perspective-taking skill, and object-location association accuracy. Like our first regression model, all predictor variables were standardized for analysis in this second model. This regression model is significant ($F(6, 45) = 5.063$, $p < 0.001$), and 40.30% ($R^2 = 0.403$) of the variance in our path learning measure, the 5-Radius Path Overlap, is explained by the predictors in our model.

Table 6. Regression Model 2

Coefficient	*b*(SE)	*B*	*p*
Intercept			0.010
Gender	0.031(0.03)	0.15	0.35
Minecraft Expertise	0.01(0.01)	0.10	0.53
Object Recognition	0.01(0.01)	0.20	0.21
IV Location Accuracy	0.01(0.01)	0.18	0.30
VOV	0.002(0.002)	0.15	0.32
IV Euclidean Dis	-0.001(0.001)	-0.33	0.052 +
R^2		0.40	

Note. Regression Model 2 includes the unstandardized betas (*b*) with standard error, standardized betas (*B*), and the associated *p*-values. + = $p < 0.1$.

Though the overall model was significant, only the In-Vivo Euclidean Distance variable showed marginal significance (B= -0.33, $p = 0.052$). Based on how object memory (B= 0.20, $p = 0.21$) and location memory (B= 0.18, $p = 0.30$) were not significant predictors, there is something about remembering object-location associations specifically that aids in path learning. This model does not support our hypothesis of perspective-taking skills being predictive of passive path learning, because VOV was not a significant predictor for our path learning measure ($B= 0.15$, $p = 0.32$).

Discussion

This study's goal was to extend the prior research by Simon et al. (2022), investigating perspective-taking skills and spatial memory based on passive video learning in open-field environments. We accomplished this with an examination of path learning through a virtual Minecraft environment, using features of the digital environment to keep a precise record of how participants navigated a controlled avatar. By analyzing these records, we can better explain what components of spatial cognition contribute to building object-location associations and path learning. We found that there are moderate correlational relationships between perspective-taking skills, object memory, location memory, object-location associations, and path learning. In our open-field environment, perspective-taking skills and location memory contribute significantly to object-location associations. For path learning, only object-location association is marginally significant as a predictor for path recreation accuracy. The following sections dive deeper into these key findings.

Spatial Skill Relationships

Out of all our interconnected variables for spatial memory and perspective-taking, object memory had the weakest correlational relationships while object-location association had the strongest. The stronger relationship between our location memory measure and object-location associations measure, compared to object memory with object-location associations, seems to indicate the greater importance of affirming where an object is located over what the identity of an object is when making accurate object-location associations. The stronger correlation between the path learning measure and object-location associations indicates that greater path learning accuracy is indicative of also remembering object-location associations related to the path more accurately.

Contributions to Object-Location Associations

We asked how perspective-taking skills, and memory for objects and locations, contribute to memory of object-location associations in open-field environments. In Model 1 (Table 4), we found that both the scores for the Visualization of Views test and object memory are predictive of object-location association accuracy. This result supports our hypothesis of perspective-taking skills being supportive of object-location associations. Location memory, being what we expect as one of the core components of object-location associations, is the more significant predictor. We also expected object memory to be a core component of object-location associations, but object memory turned out to be insignificant as a predictor. This aligns with the work by Postma and De Haan (1996) on how memory for positions, in addition to being separate from object-location associations, were more reliably encoded across different studies. The lower correlations between object recognition and all other variables in our correlation table also help to support this finding. Remembering the identity of what objects were seen in the video, even when the objects were introduced at the locations they should be mentally assigned to, is not predictive of accurately remembering those object-location associations.

Perspective-taking ability and location memory from our model showed no interaction effect in Table 5. This indicates that they contribute independently to object-location association accuracy. Participants could be utilizing their location memory to build their object-location associations, and they could be separately using their perspective-taking skills as part of navigating through other parts of the environment. Unlike in path recreation, participants were not instructed to recreate any prior experience in the In-Vivo Object Replacement test. They were given an object that was previously seen in the environment and asked to replace it as close to its associated location as possible. This required navigating directly to an object location, so perspective-taking skills could come into play in terms of recognizing those object locations from unfamiliar angles of approach.

Contributions to Path Learning

For our last research question, we asked how perspective-taking skills, and the components of spatial memory, contribute to passive path learning. In Model 2 (Table 6), only object-location associations were marginally significant as a predictor of the degree of overlap between the original path and participants' recreated path. We suspect this relationship is based on how the object-locations were points along the learned path. However, this does not paint the whole picture, because the location memory score was insignificant. Why specifically is the memory of object-location associations marginally significant when all other variables are insignificant?

To better understand the differences between variables, we compared both of our models. A high 5-Radius Path Overlap score depends on closely following a familiar path to familiar locations. Not deviating from the path when recreating it would mean a higher overlap score. The participant would only see locations from different perspectives if they navigated off the intended course. This helps to explain why perspective-taking skills would not contribute to path learning, because there is less need to visualize from different perspectives when the goal is orientated towards recognizing a single perspective. A low Euclidean Distance score, indicating high object-location association accuracy, requires navigating directly to the locations where objects were originally found. It could be that high perspective-taking ability allows participants to understand and encode locations more effectively by being able to visualize it from more angles. Encoding location memory as a space that can be visualized from multiple angles would allow the location to be recognized more easily in exploratory navigation. We did find that perspective-taking skills contributed to object-location associations alongside location memory. This potentially indicates that higher accuracy in object-location association requires encoding the spatial memory in a way that is more useful for utilizing navigational strategies.

This finding is better situated in the context of prior literature on wayfinding strategies by Hegarty et al. (2023). They describe individual differences in strategies like taking well-learned routes versus new paths based on knowledge of the environment. Individuals, when given a goal location in a familiar environment with no instructions on which specific strategies to utilize, will default to three methods: retracing a path learned through repetition (response strategy), take a shortcut based on environment knowledge (place strategy), or a mix of both. Hegarty et al. (2023) discuss how the uses of these strategies have different preferences based on individual differences and depend on the availability of associated environmental knowledge. A learned route through the environment is what our study imparted on participants through the learning video, and the path recreation task measured how well that route was imparted with a single passive exposure. This essentially tested all participants in their ability to utilize a response strategy. The object replacement task encouraged the formation of shortcuts leading to the location where objects were found. Higher accuracy for object-location associations is tied to how well participants utilized place strategy. What we see in Model 2 is that a greater effectiveness in finding new routes to object locations is also tied to greater effectiveness in following a briefly learned route. Our finding shows potential for using place strategy effectiveness to predict effectiveness in using the response strategy.

Limitations

We want to acknowledge several limitations in our study that may be improved upon in future research.

Our measure for object memory was not done in-vivo like our measures for location memory and object-location association. Object memory was assessed with a paper test after passive video learning, whereas location memory and object-location associations were assessed inside the digital environment based on coordinate analysis. There is a potential for different results if object memory was also designed to be assessed when the participants were engaged within the Minecraft environment. There is already research on applications of Minecraft in education, and its principal benefits are its degrees of modifiability and connections it can make with the physical world (Nebel et al., 2016). An ecologically viable virtual environment mimics the more complex environment akin to the natural world, so measures recorded within it better represent how participants would perform in real-world scenarios. Given the variety of ways to build within Minecraft environments, a trackable method of assessing object memory could be designed and programmed within. Future studies involving these digital environments could focus on fully utilizing its features within the environment.

The path recreation portion of the study was an opportunity for participants to reinforce spatial memory. During the test to recreate the remembered path from the video, participants interacted with the digital environment and found at least a partial group of the objects they were meant to remember. This took place before the test used to assess their object-location associations, so there is an active component of reinforcing object-location associations based on participants' effectiveness at path recreation. Due to the presence of distractor objects within the environment, not all objects found could contribute to reinforcing the memory of correct objects. Nonetheless, steps could be taken to more independently assess object-location associations versus path learning.

There is a gender imbalance in our sample of participants that we made efforts to correct. Partway through participant recruitment, most participants were female. Of the first 50 out of 72 recruited undergraduate education students, only 9 were male. Due to the gender difference in spatial ability found from prior studies, it was important to ensure a balanced sample of participants. We noticed the gender imbalance in our sample and, to ensure a lesser degree of imbalance, purposefully focused on recruiting mostly male students for our remaining participants, adding 17 male students as part of the remaining 22.

Our study lacked a method to measure the neural component of participant experiences in the virtual environment. We know from prior studies on male pigmented rats that the hippocampus, perirhinal, and medial prefrontal cortices are involved in a network that contributes to object-location associations (Barker & Warburton, 2015; Barker & Warburton, 2020). We also know that the involvement of the hippocampus in the human brain differs based on the topological scale of detail when learning object positions (Robin & Moscovitch, 2017) and the strategy used during learning or navigation (Iaria et al., 2003; Hegarty et al., 2023). Our findings highlight the connections between perspective-taking, location memory, and object-location associations, but further research is needed to explore the neural mechanisms that support these cognitive processes and their relationships.

Conclusions

We set out to better understand the relationships between aspects of spatial memory and cognitive skills. Our analyses show some of the ways in which our measures for these factors interrelate. A passive learning experience of spatial information in an open-field environment, containing a path to navigate and 12 objects, can be retained and encoded into knowledge usable in related tasks. The identities of the objects were the most accurately remembered, but knowledge of those object identities was the least effective form of spatial memory to predict for the other variables. Perspective-taking ability and location memory are the most effective for encoding accurate object-location associations. Object-location associations, in turn, are marginally predictive of accurate path learning. These findings help to establish what contributes to strong object-location associations and how those associations contribute to better navigate through open-field environments. Future studies can focus on the assessment of these factors, how they can explain differences in navigating large scale environments, and how to design effective training for spatial ability. All of which remains important for helping people to continue living in this spatial world.

References

Azevedo, R. (2015). Defining and Measuring Engagement and Learning in Science: Conceptual, Theoretical, Methodological, and Analytical Issues. *Educational Psychologist*, *50*(1), 84–94. https://doi.org/10.1080/00461520.2015.1004069

Barker, G. R., & Warburton, E. C. (2015). Object-in-place associative recognition memory depends on glutamate receptor neurotransmission within two defined hippocampal-cortical circuits: a critical role for AMPA and NMDA receptors in the hippocampus, perirhinal, and prefrontal cortices. *Cerebral cortex (New York, N.Y. : 1991)*, *25*(2), 472–481. https://doi.org/10.1093/cercor/bht245

Barker, G. R. I., & Warburton, E. C. (2020). Putting objects in context: A prefrontal–hippocampal–perirhinal cortex network. *Brain and Neuroscience Advances*, *4*, 2398212820937621. https://doi.org/10.1177/2398212820937621

Burgess, N., Maguire, E. A., & O'Keefe, J. (2002). The human hippocampus and spatial and episodic memory. *Neuron*, *35*(4), 625–641. https://doi.org/10.1016/s0896-6273(02)00830-9

Carassa, A., Geminiani, G., Morganti, F., & Varotto, D. (2002). Active and passive spatial learning in a complex virtual environment: The effect of efficient exploration. *Cognitive processing, 3*(4), 65-81.

Carbonell-Carrera, C., & Hess Medler, S. (2017). Spatial Orientation Skill Improvement with Geospatial Applications: Report of a Multi-Year Study. *ISPRS International Journal of Geo-Information*, *6*(9). https://doi.org/10.3390/ijgi6090278

Chi, M. T. H., & Wylie, R. (2014). The ICAP framework: Linking cognitive engagement to active learning outcomes. *Educational Psychologist*, *49*(4), 219-243. https://doi.org/10.1080/00461520.2014.965823

Chrastil, E. R., & Warren, W. H. (2012). Active and passive contributions to spatial learning. *Psychonomic Bulletin & Review*, *19*(1), 1–23. https://doi.org/10.3758/s13423-011-0182-x

Clemenson, G.D., Henningfield, C.M., & Stark, C.E.L. (2019). Improving Hippocampal Memory Through the Experience of a Rich Minecraft Environment. *Frontiers in Behavioral Neuroscience*, *13*, Article 57. https://doi.org/10.3389/fnbeh.2019.00057

Deslauriers, L., Schelew, E., & Wieman, C. (2011). Improved Learning in a Large-Enrollment Physics Class. *Science*, *332*(6031), 862–864. https://doi.org/10.1126/science.1201783

Donato, F., Alberini, C. M., Amso, D., Dragoi, G., Dranovsky, A., & Newcombe, N. S. (2021). The Ontogeny of Hippocampus-Dependent Memories. *The Journal of Neuroscience: the official journal of the Society for Neuroscience*, *41*(5), 920–926. https://doi.org/10.1523/JNEUROSCI.1651-20.2020

Egenfeldt-Nielsen, S., Smith, J.H., & Tosca, S.P. (2019). Understanding Video Games: The Essential Introduction (4th ed.). Routledge. https://doi.org/10.4324/9780429431791

Ekstrom, A. D., Kahana, M. J., Caplan, J. B., Fields, T. A., Isham, E. A., Newman, E. L., & Fried, I. (2003). Cellular networks underlying human spatial navigation. *Nature*, *425*(6954), 184–188. https://doi.org/10.1038/nature01964

Ekstrom, A. D., Spiers, H. J., Bohbot, V. D., & Rosenbaum, R. S. (2018). *Human spatial navigation*. Princeton University Press.

Gaunet, F., Vidal, M., Kemeny, A., & Berthoz, A. (2001). Active, passive and snapshot exploration in a virtual environment: influence on scene memory, reorientation and path memory. *Brain research. Cognitive brain research*, *11*(3), 409–420. https://doi.org/10.1016/s0926-6410(01)00013-1

Goldhagen, G., Ford, H., & Atit, K. (2023). Examining perspective-taking skills in introductory geoscience students. *Journal of Geoscience Education*, *72*(2), 159–169. https://doi.org/10.1080/10899995.2023.2251818

Guay, R. B., & McDaniel, E. D. (1977). The relationship between mathematics achievement and spatial abilities among elementary school children. Journal for Research in Mathematics Education, 8(3), 211-215.

Hannula, D. E., & Ranganath, C. (2008). Medial temporal lobe activity predicts successful relational memory binding. *The Journal of neuroscience: the official journal of the Society for Neuroscience*, *28*(1), 116–124. https://doi.org/10.1523/JNEUROSCI.3086-07.2008

Hegarty, M., & Waller, D. (2004). A dissociation between mental rotation and perspective-taking spatial abilities. *Intelligence*, *32*(2), 175–191. https://doi.org/10.1016/j.intell.2003.12.001

Hegarty, M., Montello, D. R., Richardson, A. E., Ishikawa, T., & Lovelace, K. (2006). Spatial abilities at different scales: Individual differences in aptitude-test performance and spatial-layout learning. *Intelligence*, *34*(2), 151–176. https://doi.org/10.1016/j.intell.2005.09.005

Hegarty, M., He, C., Boone, A. P., Yu, S., Jacobs, E. G., & Chrastil, E. R. (2023). Understanding Differences in Wayfinding Strategies. *Topics in cognitive science*, *15*(1), 102–119. https://doi.org/10.1111/tops.12592

Iaria, G., Petrides, M., Dagher, A., Pike, B., & Bohbot, V. D. (2003). Cognitive strategies dependent on the hippocampus and caudate nucleus in human navigation: variability and change with practice. *The Journal of neuroscience: the official journal of the Society for Neuroscience*, *23*(13), 5945–5952. https://doi.org/10.1523/JNEUROSCI.23-13-05945.2003

Kessels, R. P., de Haan, E. H., Kappelle, L. J., & Postma, A. (2001). Varieties of human spatial memory: a meta-analysis on the effects of hippocampal lesions. *Brain research. Brain research reviews*, *35*(3), 295–303. https://doi.org/10.1016/s0165-0173(01)00058-3

Labate, E., Pazzaglia, F., & Hegarty, M. (2014). What working memory subcomponents are needed in the acquisition of survey knowledge? Evidence from direction estimation and shortcut tasks. *Journal of Environmental Psychology*, *37*, 73–79. https://doi.org/10.1016/j.jenvp.2013.11.007

Lawton, C. A. (1994). Gender differences in way-finding strategies: Relationship to spatial ability and spatial anxiety. *Sex Roles*, *30*(11), 765–779. https://doi.org/10.1007/BF01544230

Linn, M. C., & Petersen, A. C. (1985). Emergence and Characterization of Sex Differences in Spatial Ability: A Meta-Analysis. *Child Development*, *56*(6), 1479–1498. https://doi.org/10.1111/j.1467-8624.1985.tb00213.x

Maguire, E. A., Burgess, N., Donnett, J. G., Frackowiak, R. S., Frith, C. D., & O'Keefe, J. (1998). Knowing where and getting there: a human navigation network. *Science (New York, N.Y.)*, *280*(5365), 921–924. https://doi.org/10.1126/science.280.5365.921

Montana, J. I., Tuena, C., Serino, S., Cipresso, P., & Riva, G. (2019). Neurorehabilitation of Spatial Memory Using Virtual Environments: A Systematic Review. *Journal of Clinical Medicine*, *8*(10), 1516. https://doi.org/10.3390/jcm8101516

Muller, R. U., Bostock, E., Taube, J. S., & Kubie, J. L. (1994). On the directional firing properties of hippocampal place cells. *The Journal of neuroscience: the official journal of the Society for Neuroscience*, *14*(12), 7235–7251. https://doi.org/10.1523/JNEUROSCI.14-12-07235.1994

Newcombe, N.S., Balcomb, F., Ferrara, K., Hansen, M., & Koski, J. (2014), Two rooms, two representations? Episodic-like memory in toddlers and preschoolers. *Developmental Science*, *17*, 743-756. https://doi.org/10.1111/desc.12162

Nebel, S., Schneider, S., & Rey Günter, D. (2016), Mining Learning and Crafting Scientific Experiments: A Literature Review on the Use of Minecraft in Education and Research. *Journal of Educational Technology & Society*, *19*(2), 355–366. http://www.jstor.org/stable/jeductechsoci.19.2.355

O'Keefe, J., & Nadel, L. (1978). *The hippocampus as a cognitive map*. Oxford, United Kingdom: Clarendon Press.

O'Keefe, J., & Dostrovsky, J. (1971). The hippocampus as a spatial map. Preliminary evidence from unit activity in the freely-moving rat. *Brain research*, *34*(1), 171–175. https://doi.org/10.1016/0006-8993(71)90358-1

Postma, A., & De Haan, E. H. (1996). What was where? Memory for object locations. *The Quarterly journal of experimental psychology. A, Human experimental psychology*, *49*(1), 178–199. https://doi.org/10.1080/713755605

Postma, A., Kessels, R. P., & van Asselen, M. (2008). How the brain remembers and forgets where things are: the neurocognition of object-location memory. *Neuroscience and biobehavioral reviews*, *32*(8), 1339–1345. https://doi.org/10.1016/j.neubiorev.2008.05.001

R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.m

Robin, J., & Moscovitch, M. (2017). Details, gist and schema: Hippocampal–neocortical interactions underlying recent and remote episodic and spatial memory. *Current Opinion in Behavioral Sciences*, *17*, 114–123. https://doi.org/10.1016/j.cobeha.2017.07.016

Rolls, E. T., & O'Mara, S. M. (1995). View-responsive neurons in the primate hippocampal complex. *Hippocampus*, *5*(5), 409–424. https://doi.org/10.1002/hipo.450050504

RStudio Team (2020). RStudio: Integrated Development for R. RStudio, Inc., Boston, MA URL http://www.rstudio.com/.

Shelton, A. L., & McNamara, T. P. (2004). Spatial memory and perspective taking. *Memory & Cognition*, *32*(3), 416–426. https://doi.org/10.3758/BF03195835

Shepard, R. N., & Metzler, J. (1971). Mental Rotation of Three-Dimensional Objects. *Science, 171*(3972), 701–703. https://doi.org/10.1126/science.171.3972.701

Simon, K.C., Clemenson, G.D., & Zhang, J. (2022), Sleep facilitates spatial memory but not navigation using the Minecraft Memory and Navigation task. *Proceedings of the National Academy of Sciences, 119*(43), Article e2202394119. https://doi.org/10.1073/pnas.2202394119

Tolman, E. C. (1948). Cognitive maps in rats and men. *Psychological Review, 55*(4), 189–208. https://doi.org/10.1037/h0061626

Tuena, C., Mancuso, V., Stramba-Badiale, C., Pedroli, E., Stramba-Badiale, M., Riva, G., & Repetto, C. (2021), Egocentric and Allocentric Spatial Memory in Mild Cognitive Impairment with Real-World and Virtual Navigation Tasks: A Systematic Review. *Journal of Alzheimer's Disease*, *79*(1), 95-116. https://doi.org/10.3233/JAD-201017

Uttal, D. H., Meadow, N. G., Tipton, E., Hand, L. L., Alden, A. R., Warren, C., & Newcombe, N. S. (2013). The malleability of spatial skills: a meta-analysis of training studies. Psychological bulletin, 139(2), 352–402. https://doi.org/10.1037/a0028446

Wai, J., Lubinski, D., & Benbow, C. P. (2009). Spatial ability for STEM domains: Aligning over 50 years of cumulative psychological knowledge solidifies its importance. *Journal of Educational Psychology, 101*(4), 817–835. https://doi.org/10.1037/a0016127

Wang, L., Cohen, A. S., & Carr, M. (2014). Spatial ability at two scales of representation: A meta-analysis. *Learning and Individual Differences, 36*, 140-144. https://doi.org/10.1016/j.lindif.2014.10.006

Xie, Y., Fang, M., & Shauman, K. (2015). STEM Education. In *Annual Review of Sociology* (Vol. 41, Issue Volume 41, 2015, pp. 331–357). Annual Reviews. https://doi.org/10.1146/annurev-soc-071312-145659

Yamamoto, N., & Shelton, A. L. (2009). Sequential versus simultaneous viewing of an environment: Effects of focal attention to individual object locations on visual spatial learning. *Visual Cognition, 17*(4), 457–483. https://doi.org/10.1080/13506280701653644

Yuan, L., Kong, F., Luo, Y., Zeng, S., Lan, J., & You, X. (2019). Gender Differences in Large-Scale and Small-Scale Spatial Ability: A Systematic Review Based on Behavioral and Neuroimaging Research. *Frontiers in behavioral neuroscience, 13*, 128. https://doi.org/10.3389/fnbeh.2019.00128