The Impact of Spatial Involvement on Training Mental Rotation with Minecraft

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Dedications

I dedicate this project to present and future players, and those who have yet to see how games can be a truly empowering and inspiring medium.

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Table of Contents

List of Tables

List of Figures

Abstract

The Impact of Spatial Involvement on Training Mental Rotation with Minecraft

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Previous research on understanding the effects of computer gameplay showed a shift from negative behavioral consequences to positive cognitive development across multiple age groups. A positive correlation exists between spatial skills and indications of success in science, technology, engineering, and mathematics fields. Game-based regimens explored training cognition and focus on spatial abilities as many post-secondary students with poor spatial skills can be place at a disadvantage in introductory courses. While the results of game-based studies suggested the potential of games, there were limitations to the studies conducted. Research examining effects from gameplay often compared across different genres, levels of graphical fidelity, input methods, and other variables. Which aspects of gameplay have an impact on the positive consequences is an open question. We focused on the role of spatial involvement, expressed as different control schemes, and its impact on training mental rotation by implementing a training regimen through *Minecraft*. Our project utilized *Minecraft* and its modification capabilities to recreate a proven engaging experience for players, making training mental rotation more accessible. We varied the different levels of spatial involvement in our interventions—full control *Minecraft*, partial control *Minecraft*, and a control condition—and designed an experiment to compare the effect of the experience's impact. Further, our work extended game training endeavors in psychology using digital media. A target outcome was a method to improve our understanding of what aspects of digital games are relevant for successful training applications. Results of a pilot study demonstrated the viability of the approach for relating spatial involvement, the sense of inhabiting the virtual space, to training effect in mental rotation and wider spatial skills. Additionally, the developed game-based training regimen is more accessible as there is a lower skill floor than games that have previously been shown to improve cognition.

Chapter 1: INTRODUCTION

Playing computer games is now a global pastime. From a report by the Entertainment Software Association [2015], we can conclude that player demographics are diversifying. Today's gaming audience has expanded to include more gender orientations and ages [Adachi and Willoughby 2012]. The current age range extends from age 8 to over 50, with the average being 35, and with 27 percent of gamers being 50 years or older. Further, women over the age of 18 are beginning to represent a greater portion of the game-playing population. The explosive growth gaming culture has experienced in the past few years alone provided an opportunity for games to establish themselves as more than mere pieces of entertainment.

We are interested in how games can achieve effects in the real world. Scholarly research on computer games has been greatly stimulated by the sharp increase in the number of players over a short time [Adachi and Willoughby 2012; Olson 2010; Pryzbylski et al. 2010]. Initially, researched trends examined the negative aspects of computer playing, such as: increased acts of aggression and violence; increased gender stereotyping; and computer game play addiction [Pryzbylski et al. 2010]. By contrast, recent computer game research has shifted towards identifying and promoting positive effects that result from playing computer games.

We aimed to contribute to understanding the potential benefits of computer games by focusing our exploration on which formal gameplay elements can be influential. Game-based training is an area that exemplifies the benefits a player can receive from engaging in digitally mediated play. Several studies have investigated the correlation between action games and game-based training outcomes; however, action games can be either inaccessible or undesirable to some populations. For example, such populations may find that action games have too much violent content or have undesirably high skill floors that are required to master the rules of the game. Furthermore, it is unclear as to whether or why action video games are better at game-based training than other genres as there is no basis for a direct comparison.

Game-based training regimens have been used to target cognition and have focused on spatial abilities. Research have established a positive correlation between spatial skills and indication of success in science, technology, engineering, and mathematics (STEM) fields. Students in STEM fields have a high level of three-dimensional (3D) spatial skills when compared to their non-STEM peers. Incoming post-secondary students with poor spatial skills can be placed at a disadvantage in introductory courses and developing the skill is often unaddressed by the curriculum [Sorby and Baartmans 2000; Spence and Feng 2010]. When training for spatial abilities, successful training outcomes highlighted one of three domains within spatial abilities over the others. We focused on mental rotation (MR), which can be defined as the ability to mentally rotate two-dimensional (2D) or 3D figures a number of degrees around a specified axis [Lisi and Wolford 2002]. While seemingly simple, MR is a complex spatial task involving the following steps: (1) rapid allocation, (2) disengagement, and (3) reallocation of multiple features of the stimuli [Spence and Feng 2010]. Several studies supported that MR is easier to train than other spatial skills [Sorby and Baartmans 2000; Terlecki and Newcombe 2005]. Pre- and post-test experimental design across several studies suggested a statistically significant divide in measurements of MR performance between males and females at all ages [Cherney 2008; Geiser et al. 2008; Jaušovec and Jaušovec 2012; Neubauer et al. 2010]. However, the divide can be minimized through training.

Despite improvements in MR performance, some training regimens used games that have a higher barrier to entry for self-identified non-gamers. The steep learning curve established an issue of accessibility and a need for providing more engaging spatial experiences. Traditionally, spatial skills have been developed in children through play with physical objects such as building blocks, but the style of play needed to improve spatial skills is more positively reinforced in boys than girls [Brosnan 2014; Casey et al. 2008; Verenikina 2014]. Researchers have begun creating digital training regimens to address the lack of spatial skill improving activities while incorporating the gravitation towards more mediated experiences observed in adolescents [Martin-Dorta et al. 2013; Rafi and Samsudin 2009; Verenikina 2014].

We based our work in *Minecraft*, a sandbox computer game where players break and place blocks to build structures that protect them from nocturnal creatures, and modify it to be a vehicle for computer game-based training designed to improve MR. The approach addressed the limitations of research on action computer games by extending a previous non-digital training intervention by Casey et al. [2008]. By basing the training content on previous successful research, we focused on the issue of distinguishing the aspects of immersion that can have an impact on the training results. Immersion in games can be expressed in many ways. We used Calleja [2011]'s Player Involvement Model (PIM) to understand how immersion is constructed. The approach used focuses on the dimension of spatial involvement which is how players engage with the virtual environment in terms of spatial control, navigation, and exploration [Calleja 2011]. We varied the level of involvement by modifying the control scheme and compare the effect on training impact. Different spatial involvement was achieved primarily through the use of different control schemes: default interaction with the game compared to a restricted one.

Minecraft has already achieved success as an educational tool and has been marketed as a platform for education[1]. *Minecraft* has delivered content using methods commonly seen in educational games [Scarlett 2015]. However, these experiences, such as modifications to *Minecraft*, have only demonstrated a growth of content knowledge and have not shown a growth in cognitive abilities or ways in which students solve problems. In addition, there was an opportunity to explore games without inducing the strong placebo effect Boot et al. [2011] describes. We modified *Minecraft* to affect game play rather than content. By varying how the game is played, without drastically changing the environment in which the interaction is occurring, the our research has the potential to make training spatial visualization more accessible and unobtrusive.

The remainder of this document describes the rationale, design, and execution of the research. In Chapter 2, we provided literature that reflect the state of the art in game-based training regimens. In Chapter 3, we posed our research question and subsidiary questions. In Chapter 4, we explained the key components of our approach and design decisions. In Chapter 5, we detailed the development of the digital training regimen and the differentiation between the control schemes based on *Minecraft*.

[1] By TeacherGaming LLC, as MinecraftEdu, `http://minecraftedu.com/`

In Chapter 6, we reported on the results of the pilot study testing the viability of the approach. In Chapter 7, we synthesized and made conclusions about the results and discussed the drawbacks and future directions of our work.

Chapter 2: GAME-BASED TRAINING

Several studies suggested that computer games provide opportunities to achieve positive, real-world effects. We began with an examination of games and game studies by exploring qualities of games that make them unparalleled to traditional methods of achieving certain tasks, such as disseminating content knowledge or training. In understanding how games can affect their players, researchers have investigated improving cognitive abilities through game-based training regimens. We discussed MR, an ability addressed in previous research, in detail and establish a foundational understanding of how MR has been trained. Finally, we focused on the immersive quality of games and the impact on training MR. Using Calleja [2011]'s PIM, we explored avenues to increase or decrease immersion without changing the game itself by altering different game elements.

2.1 Exploring Games as an Opportunity

Games have been explored as an unprecedented opportunity to achieve real-world effects, extending models of traditional learning and training regimens [Adachi and Willoughby 2012; Gee 2003; Pryzbylski et al. 2010]. Research commonly observed repeated patterns on how games affect behavioral patterns. Our literature review focused on positive consequences of game playing.

Research conducted within the last decade positions games as a positive influence on development. Across several lenses in psychology, computer games created meaningful learning experiences through well-executed design. Despite the theoretical framework, the motivation behind choosing to play games was highlighted as a driving force. Olson [2010] suggested that computer game playing has an effect on youth development. She dissected and categorized various types of motivations and how they manifest in as behaviors in adolescents. The study concluded that computer games have an expansive appeal and serve several needs, suggesting that computer game experiences can shape development [Olson 2010]. Adachi and Willoughby [2012] also explored how computer games promote youth development using a pre-existing framework by Larson on fostering initiative from organized activities. The design inherent to computer games positioned engagement in this type of medium to foster initiative in youth. Games are designed to be intrinsically motivating. Players responded to rules and procedures by continuing to play. Games required concentration and cognitive effort for players to be able to execute the core mechanic properly. Efforts towards meeting the objective of the game resulted in goal attainment. Adachi and Willoughby [2012] suggested that games do foster initiative and, ultimately, positive youth development despite being an unorganized activity.

Studies have suggested the potential good of computer games and gave advice on methods to minimize the harmful effects of massively consuming this medium. In pursuing a different route than behavioral considerations of computer game play, research has investigated how games can be applied to skill-based learning through training. Studies have been designed to examine how different game environments affect the training outcome by experimenting with variables such as genres and input methods. Several researchers have created training regimens for MR, notably [Sorby and Baartmans 2000]—[Terlecki and Newcombe 2005]. In first-person shooting (FPS) games, the core mechanic is shooting at a target while moving in first-person point of view through a virtual environment packed with stimuli. Experiments involving FPS games have suggested that there are performance improvements when testing with various measurements of cognition [Gentile 2011; Granic et al. 2014; Oei and Patterson 2013; Subrahmanyam and Greenfield 1994]. As a result, FPS games have received attention from scholars. A limitation of studies using FPS games was the high barrier to entry for non-gamers. Lack of confidence in executing the controls deterred the motivation to continue playing.

Scholars have approached training cognition with computer games by using games across various genres in empirical research. Gee [2003] has stated that games test the boundaries for existing theory in learning and education. Similarly, games can provide solutions to training cognitive abilities. Researchers utilized opportunities for immersion and challenge that games provide to examine the effects of training cognition. Various studies have noted larger improvements on spatial cognitive tasks for amounts of time, varying from one to two hours to several weeks, after being exposed to games that simulate the concepts presented in the tests [Baniqued et al. 2014; Feng et al. 2007; Oei and Patterson 2013; Okagaki and Frensch 1994; Sorby and Baartmans 2000].

2.2 Mental Rotation as Content

Researchers have identified a desire to train cognitive abilities as related skills are important to higher level thinking. An aspect of cognition is the ability to think spatially. Spatial abilities are a collection of processes that can be broken down into three domains [Sorby and Baartmans 2000]:

1. Spatial relations: the ability to rapidly transform objects in the mind, such as mentally rotation an object about its center
2. Spatial visualization: the ability to imagine the relative movements of internal parts of an image, such as folding and unfolding flat patterns
3. Perceptual speed: the ability to rapid encoding and compare visual forms

Throughout the literature, the three domains have been called a multitude of names. For example, Okagaki and Frensch [1994] framed the abilities as MR, spatial visualization, and spatial perception respectively. We followed Okagaki and Frensch [1994]'s example and used MR.

The study of MR has a long tradition in the field of psychology. MR can be described as imagining the 2D or 3D objects after the figure has been turned around a specified axis a given number of degrees [Lisi and Wolford 2002]. While the description sounds fairly simple, MR is a complex spatial task involving the following steps: rapid allocation, disengagement, and reallocation of multiple features of the stimuli [Spence and Feng 2010]. Despite the complexity of experiencing MR, studies have established how to influence and observe changes in MR performance. A large body of instruments to measure performance exists for MR. The tests have been constantly verified and improved. Several research papers, notably [Sorby and Baartmans 2000] – [Terlecki and Newcombe 2005], reported that MR is quantifiable along two axis: speed and accuracy. MR has the additional benefit of being easily trainable compared to the other two domains of spatial abilities.

Researchers have looked to train MR due its characteristics for a couple of reasons: STEM fields have gained traction in the modern world, and higher level thinking has been established as a prerequisite for success in STEM fields. Unfortunately, not all students entering STEM fields in post-secondary education have well-developed spatial skills. Previous research studies have attempted to train MR through digital interfaces. Rafi and Samsudin [2009] created modules with exercises to train MR that were disseminated through an online learning platform. The intervention they designed was effective in increasing MR performance. Researchers have considered the potential to make learning interfaces more engaging and borrow game elements to do so. Martin-Dorta et al. [2013] designed a mobile application that trained MR for engineering students at the University of La Laguna and examined the effects of training using a pre- and post-test design. In the application, players placed blocks on a grid to match the blueprints presented to them. The grid was three units wide, three units deep, and three units tall. The intervention required students to complete a problem every day for a week. Results suggested that the training was successful and participants reported positive feedback on using the application. As training interventions were being proved as effective means for training MR, researchers looked to improve the pedagogical aspects while making the experience more engaging for students.

2.3 Immersion and Player Involvement

Computer games are designed to be immersive, challenging, and engaging and can be examined as complex systems with interconnected elements. Literature have observed how participants respond to challenge in computer games and their motivations behind play. Few studies have examined how the experience of playing affects participants. Calleja [2011] approached games and immersion analytically through PIM. The PIM described the methods and degree in which a player inhabited a virtual environment. The model was broken down into six axes: kinesthetic involvement, spatial involvement, shared involvement, narrative involvement, affective involvement, and ludic involvement [Calleja 2011]. Spatial involvement was the dimension that "concerned players' engagement with the spatial qualities of a virtual environment in terms of spatial control, navigation, and exploration" [Calleja 2011]. The qualities of spatial involvement related to the design of training regimen found in previous literature. For example, Martin-Dorta et al. [2013] created an application with limited spatial involvement because there was little control, navigation, and exploration of the virtual environment where participants completed the activities. Understanding what events happened when playing a certain type of game over others can allow training regimens to produce stronger training outcomes.

Chapter 3: THESIS STATEMENT

We established games as a viable platform for training. Several studies have noted overall performance improvements to spatial skills while highlighting the greater improvement in MR. We focused our exploration on a gameplay element, spatial involvement, using the lens of Calleja [2011]'s PIM. Below is a synthesis of the research presented in the form of a question and subsidiary issues that are related to developing a viable approach. The next chapter will describe pre- and post-test experimental approach designed to answer this question.

Please refer to Appendix A for concise explanations of the main terminology used in this thesis.

3.1 Research Question

How does a player's spatial involvement within *Minecraft*, which varies by the navigational controls a player has, affect the training effect (in terms of speed and accuracy) of mental rotation performance in young adults?

3.2 Subsidiary Questions

In order to address the question above, the first step to develop a viable approach for collecting relevant data in experimental settings. As part of this effort, we also considered if that approach can serve to answer further related questions.

1. Will spatial involvement increase speed and/or accuracy when testing for MR performance?
2. How will other aspects of immersion, specifically narrative and affective, manifest in tandem with the story context provided by the conditions?
3. Which experiment condition will produce the greater change?

Chapter 4: APPROACH

We devised a pre- and post-test experimental design to assess the impact of spatial involvement on training mental rotation. Using *Minecraft* and its modification capabilities, we designed three interventions that vary by spatial involvement: full control *Minecraft* (FCM), partial control *Minecraft* (PCM), and a control. Three components influenced the design of our approach: (1) a research paper titled "The development of spatial skills through block building interventions" authored by Casey et al. [2008]; (2) a battery of traditional psychological assessment; and (3) the game-based training regimen. In this chapter, we reported on the re-mediation of the content from Casey et al. [2008]'s lesson plan in *Minecraft*, a virtual environment. We extended the work of Casey et al. [2008] as results from their study suggested block building interventions completed with physical blocks improved MR. Our design decisions involved in adapting the original design to better suit the *Minecraft* environment were informed by similar game-based training environments, covered in the previous chapter, and the PIM.

4.1 Developing Spatial Skills through Block Building

Before games, block building was investigated as a method to improving spatial skills in early childhood. A team of researchers were interested in structured block building activities and the effects on developing spatial skills. Additionally, they wanted to observe if using narrative was a successful strategy to teaching spatial concepts to young children [Casey et al. 2008]. As a result, Casey et al. [2008] designed non-block spatial activities and block building activities to develop spatial and mathematical skills in kindergartners. The story and activities were packaged as book titled *Sneeze builds a castle* for teachers to use in their classroom. In the fantastical narrative, Sneeze, a friendly time-traveling sneezing dragon, brings the children to Middle Land. There, the children engaged in a series of activities, culminating in an activity to rebuild the castle that Sneeze accidentally sneezed down. There were two intervention conditions—block building with story and block building without story—and one control condition where participants engaged in free play with the blocks. In the block building with story intervention, *Sneeze builds a castle* was used to guide the interventions. The two intervention conditions described the orientation of the structures using spatial cues, such as "above" and "around". In all conditions, kindergartners built structures with building blocks: castle tower, a moat, a bridge, and walls with a gate. They used a pre- and post-test quasi-experimental design to assess the effectiveness of their interventions. Two weeks prior and after the intervention, students completed three tests assessing block-building skills, spatial visualization, and mental rotation. In the block-building assessment, children were instructed to build a series of structures. A point value was assigned to the level of complexity achieved in each structure. Casey et al. [2008] used the Block Design subtest from the Wechsler Child Intelligence Scale to measure spatial visualization. A higher score was awarded when completing a test item with less time. The researchers devised a modified version of the Shepard-Metzler test (mSMT) to measure mental rotation. The mSMT was used in place of an existing test that measures MR to make the task more accessible to kindergartners. In the mSMT, students were presented with a pair of identical figures, constructed out of multi-link cubes, that are at a different orientation from each other. The kindergartners were tasked with rotating the figure on the right to match the orientation of the figure on the left. The mSMT shares the same scoring mechanism as the Block Design subtest. The study concluded that the block building with story intervention was most effective in improving spatial skills.

4.2 Psychological Assessment

Similar to Casey et al. [2008], we used an array of psychological assessments to measure improvements in MR and wider spatial skills in our experimental design. The goal was to extend the work of Casey et al. [2008], and therefore, the mSMT and the Block Design subtest were used as part of the cognitive battery. Finally, we added an electronic version of the original Shepard-Metzler test (eSMT) and the electronic Guilford-Zimmerman Spatial Orientation test (eGZSOT) to observe possible transference effects.

4.2.1 Modified Version of Shepard-Metzler Test

The difference between the mSMT devised by Casey et al. [2008] and the original SMT is that the original SMT was conducted using 2D representations of 3D objects presented on paper or screen. Participants were tasked with identifying whether the two figures were the same or mirrors of each other. Compared to the original SMT, the presentation of stimuli differed while the objective remains the same. In mSMT, participants were presented, in reality, a series of identical figures constructed out of multi-link cubes. The pre-test and post-test figure set differed by the post-test figure being a variant of the corresponding figure in the pre-test in one of the following ways: having one less block, being mirrored, or having a chain of blocks in another section.

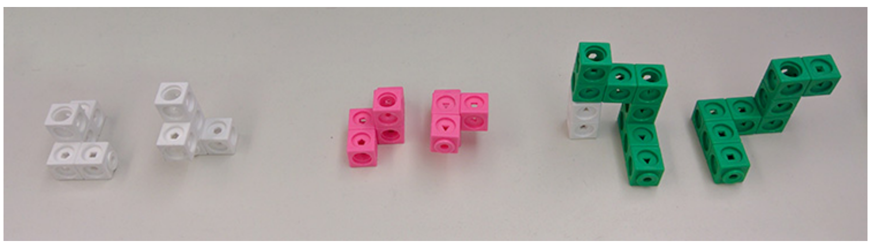

Figure 4.1: The first three items of the mSMT pre-test

The test consisted of ten figure pairs and one pair as a the sample item. Each figure pair was presented with a different orientation. Participants were then given ten seconds to rotate the figure on the right to match the figure on the left. Testing ended prematurely if participants made three consecutive errors. Completing the rotation with less time resulted in a higher score for the respective item. Each correct item was awarded one point regardless of time spent on the item.

In using this assessment for our study, adjustments were made to address the limitations of the source material and to suit the changes in participant demographics, from kindergartners to first or second year college students. While Casey et al. [2008] provided a description and rationale of the mSMT, there were no references as to what the figures looked like and at what orientation the figures were for the pre- and post-test. We knew that the problems increased in difficulty level by increasing the complexity of the figures through adding more cubes to the core block structure and by increasing the number of directions the cubes extended from the core [Casey et al. 2008]. With this information, we found a library of figures used for the SMT and created an order for the figures that reflected the rules governing difficulty.

4.2.2 Electronic Shepard-Metzler Test

The SMT is a long-established test measuring mental rotation performance developed by Roger N. Shepard and Jacqueline Metzler. In the original version of the test, participants were presented with twenty pairs of 2D representations of 3D figures. Participants indicated whether the figures were identical or mirrored to each other. We used the eSMT in addition to the mSMT to observe possible effects resulting from task transference. Casey et al. [2008] designed the mSMT to mirror activities from the lesson plan. Since we were using *Minecraft* as our testing environment, we looked to use an electronic version of the SMT to mirror activities from the intervention. The word "electronic" describes administration of the SMT using a computer. In this electronic version, we are able to configure the test to include more figures. Participants observe the figures on a computer monitor and use the keyboard to input their answer. The source of the test can be found at the Hanover College Psychology Department website [Krantz n.d.]. Participants solved a total of eighty problems with ten problems for eight levels of rotation. The speed and accuracy of MR performance was assessed by performing a mathematical operation on the speed on each level of rotation. The highest value a level of rotation can receive for accuracy was 1.0.

4.2.3 Electronic Guilford-Zimmerman Spatial Orientation Test

We introduced a test measuring wider spatial abilities to examine if the training regimen has broader effects. The Guilford-Zimmerman Spatial Orientation Test (GZSOT) is an instrument that examines the test-takers spatial orientation ability. The participant is presented with a pair of two images that, together, describe the movement of a boat. We employed the electronic version of the instrument, eGZSOT, created by Kyritsis and Gulliver [2009]. The interface of the electronic version differed from the paper-based original. The first image, positioned on top in the paper version of the GZSOT or on the left in the electronic version, represented the initial state of the boat's prow. The second image, positioned below the first in the paper version of the GZSOT or on the right in the electronic version, represented the location of the boat's prow after movement has occurred. The participant was tasked with choosing the sequence best representing the prow's movement. For the electronic version of the GZSOT, choosing the sequence involved entering a combination of up to three directions: forward, backward, left, right, rotate clockwise, and rotate counter clockwise. After the participant finished reading the instructions and the eight sample problems from the original GZSOT, they have fifty-nine items to complete for the eGZSOT in seven minutes. The score was calculated by subtracting the total amount of wrong answers divided by four from the total amount of correct answers.

4.2.4 Block Design subtest of Wechsler Adult Intelligence Scale

We used the Block Design subtest of the Wechsler Adult Intelligence Scale (WAIS) in lieu of the subtest with the same name from the Wechsler Intelligence Scale for Children, which Casey et al. [2008] uses in their study. The Block Design subtest measured spatial reasoning and spatial visualization skills [Casey et al. 2008]. In the subtest, participants were shown images of red and white 2D patterns. They were tasked to assemble small cubes so that the top surfaces of the blocks match the images. Some sides of the cubes were all red, all white, or diagonally half-red and half-white. There were a total of one sample item and ten test items, presented in increasing difficulty. The test stopped if the participant failed two items in a row. For the first four items, participants received a maximum of four points for solving the puzzle under the time-limit. For the remaining items, participants received a maximum of seven points based on the time spent on each puzzle. The participant received zero points for an item if they do not finish on time. The raw score was calculated by adding the points up.

4.3 Game-based Training Regimen

We designed a digital game-based implementation of the lesson planned by Casey et al. [2008] suitable for participants aged 18-21 who can read English and assessed the effectiveness using a pre- and post-test training regimen. We mirrored the narrative arc and adapted the friendly dragon character, Sneeze, from Casey et al. [2008] into a non-player character. Similar to Casey et al. [2008], the objective of the experience is to build five structures: a moat, a bridge, a castle tower, walls, and a gate. In extending Casey et al. [2008]'s work, several details of the lesson plan provided to the teachers must change to suit the chosen medium—games. The block-building mechanic in *Minecraft* replaced the tactile interactions with traditional physical building blocks. There are three interventions that a participant can be randomly assigned to: (1) full control *Minecraft* (FCM), which has the strongest spatial involvement; (2) partial control *Minecraft* (PCM), which has less spatial involvement than FCM; and (3) a control condition, which had minimal spatial involvement. We decrease spatial involvement by restricting the level of control, navigation, and exploration using *Minecraft*'s modification capabilities.

A major difference between Casey et al. [2008]'s work and the study presented was the participant demographic. Casey et al. [2008] focused on observing kindergartners. We focus our recruitment effort on first or second year university students. The change in demographics required alterations to the study timeline. Casey et al. [2008] observed long-term effects, requiring about a month of participating with two weeks of waiting after the pre-test and before the post-test. We decreased the length of our study to two days and focused our investigation on short-term effects. Participants began the intervention after taking the pre-test. Approximately twenty-four hours after finishing the first half of the intervention, they completed the remaining half of the intervention and took the post-test immediately after.

The overall lesson plan framework presented in Casey et al. [2008] remained but was scaled down to better address the time constraints of the researchers and participants. We included a narrative arc in our implementation as Casey et al. [2008]'s results suggest more pronounced performance with a story context but adapted the execution to suit games. Casey et al. [2008] had access to classrooms where teachers would verbally guide students through the lesson plan. In the story and block building intervention, teachers would role play as Sneeze, the friendly dragon that sets the tone of the students' medieval adventure. Since our investigation lasted two days and was completed without much intervention from the researcher, we shortened the lesson plan to only include an introduction to the world and the context in which the participants will complete the study tasks. Our narrative was told primarily through game elements. For example, Sneeze appeared as a dragon that participants can interact with in *Minecraft*. When in dialogue with Sneeze, participants were presented with various pre-determined phrases to respond with. We retained the description of structures and how Casey et al. [2008] spatially related each part of the castle. However, we created several lines of dialogue to help build the narrative arc and Sneeze's character. These lines were not present in the lesson plan and relied on the teacher's proficiency at storytelling.

4.3.1 Conditions

For this study, there were three interventions that participants could be randomly assigned to. These conditions were designed in a manner where differences were minimized to spatial involvement. All participants used the keyboard and mouse as input devices. Regardless of the intervention, the same narrative was conveyed through interactions with Sneeze. In the FCM and PCM intervention, participants had the ability to choose the order of the structure construction.

Full Control *Minecraft*

Of the three interventions, FCM has the strongest spatial involvement. Participants have free range of character and camera movement and block building capabilities. By pressing the "W", "A", "S", and "D" keys, participants can move forward, backwards, left, and right. Moving the mouse moved the first-person camera. Participants built structures using the default control scheme for *Minecraft*. They can press the left mouse button to destroy blocks and the right mouse button to place blocks. The materials used for building appear in the in-game tool bar located at the bottom of the window.

Partial Control *Minecraft*

Compared to FCM and the control condition, PCM has a level of spatial involvement that is in between. We restricted methods of movement and control by modifying the existing control scheme through *Minecraft*'s modification capabilities. Movement was confined to forward and backward on a visible rail system. Participants pressed "W" to move forward in the direction they are facing along the track. Camera movement was not restricted to give players the ability to go backwards and observe objects at higher levels of elevation.

Figure 4.2: In-game screenshot of PCM at the beginning of the experience

Rather than building structures block by block with the right mouse button, as found in FCM, PCM has an interface of buttons that allows players to place larger pre-defined structures at designated places. Participants sifted through the options by pressing the button labeled "Forward" or the button labeled "Backward". Larger structures were broken down into multiple chunks. The moat had four chunks that are all parallel to the ground. The tower had three vertical chunks. The walls have a total of twenty-four chunks. There were eight chunks parallel to the ground and three vertical chunks for each. For the bridge, castle tower, and walls and gate, there were three different placements possible and two styles for participants to choose from. Therefore, there were a total of six options that the participants could to choose from. We implemented these options so that the time spent playing *Minecraft* in the PCM intervention would be closer to the time spent in the FCM intervention.

Control

The control had minimal spatial involvement. Participants experienced the narrative and block building through still images by pressing the down arrow on the keyboard. The images were taken from a walk-through of the PCM condition. In this condition, participants were unable to decide the build order. The order was set to building the structures in this order: the tower, the moat, the bridge, and the walls and gate.

4.3.2 Quest and Objectives

All interventions have the same quest progression and quests objectives. The quests were given to the participant by Sneeze. Participants received the first quest, "Meet Sneeze," when engaged in dialogue with Sneeze for the first time. The objective was to get to know Sneeze. The resulting conversation established the introduction of the story. There was no reward. At the end of the quest, Sneeze took the participant on a "bumpy" flight. The participant was then teleported to the next area where they primarily spent their time. The second quest, "Adventures of Middle Land," consisted of building the following structures. Each was expressed as a sub-quest: a moat, a bridge, a gate, and a tower. The objective of each sub-quest was to complete the structure before the respective maximum time limit. Participants were given the opportunity to complete the sub-quests in any order. At the end of each sub-quest, participants returned to Sneeze to accept one of the remaining sub-quests until there were no more. Once all four sub-quests are finished, participants returned to Sneeze. When "Adventures of Middle Land" was completed, the training regimen ended.

4.3.3 Procedure

We recruited seven undergraduate students between the ages of 18 and 21 for our Internal Review Board-approved study using flyers, advertisements through e-mail lists, and class visits. Students were screened by an online questionnaire to verify that they were between the ages of 18 and 21 and could read English. The training regimen required a total of two days of participation. On the first day, participants completed the four assessments in this order: mSMT, eSMT, eGZSOT, and the Block Design subtest of the WAIS. In the same session, participants were taught how to play *Minecraft* by the researchers and then went to complete two of the structures. The second session took place twenty-four hours after the first. In this session, the participant finishes the remaining two structures. Then, they completed the assessments in the same order as the first session. Afterwards, participants filled out a questionnaire about previous gameplaying experiences and their demographics. Either session may last up to two hours depending on the speed of completing the tests.

Chapter 5: DEVELOPMENT

In this chapter, we explain the process of how the scenarios were created in *Minecraft*. *Minecraft* offers tools native to the game that allow players to implement sequential execution of logical operations. The tools are collectively known as the redstone system. To extend the modification abilities offered by *Minecraft*, we also used MC Edit, a third-party map editing software, to build our environment quickly. MC Edit boasted functionality such as massively filling areas with blocks and copying and pasting blocks. The screenshots presented in this chapter come from either *Minecraft* or MC Edit.

We began development by planning the spaces where the participants would encounter Sneeze, the friendly dragon. Based on the narrative provided by *Sneeze builds a castle* from Casey et al. [2008], we understood that the setting was medieval. We replicated the playful tone and atmosphere by introducing the participant to the world in a small, forest area. Compared to the second area where participants would spend a majority of their time, the forest area was smaller and has less stimuli to overwhelm participants.

Figure 5.1: An aerial view of the beginning area in MC Edit

Fig. 5.1 shows the area where the start of the first quest, titled "Meet Sneeze," was located. The objective of "Meet Sneeze" was to meet Sneeze. Here, the participants received the exposition of the narrative. We utilized the barrier block featured in *Minecraft*, version 1.8, to create boundaries for the participant. The barrier blocks appeared as invisible, impassible blocks in game. To add more visual clarity in the boundaries of the space that the participants inhabited, we placed trees around the perimeter of the space created by the barrier blocks.

While we shaped the map using MC Edit, we adapted the dialogue from *Sneeze builds a castle* and implemented interactions with Sneeze using the Custom NPCs modification (mod). The mod allowed dialogue with Sneeze in an overlay that appears over the in-game screen. Participant initiated interactions with Sneeze by pressing the right mouse button.

Figure 5.2: In-game screenshot of dialogue with Sneeze

Underneath the horizontal line in fig. 5.2, participants were able to pick the line they want to respond with using the left mouse button. In the first quest, there was no branching dialogue. We wanted participants to quickly be oriented to the world and begin the building activities as soon as possible due to the time constraints on their participation.

Our development efforts were focused on the second portion of experience where participants would be spending most of their time. After participants completed "Meet Sneeze," they were teleported to another area resembling a town. They were introduced to the town and the area where they would build the structures.

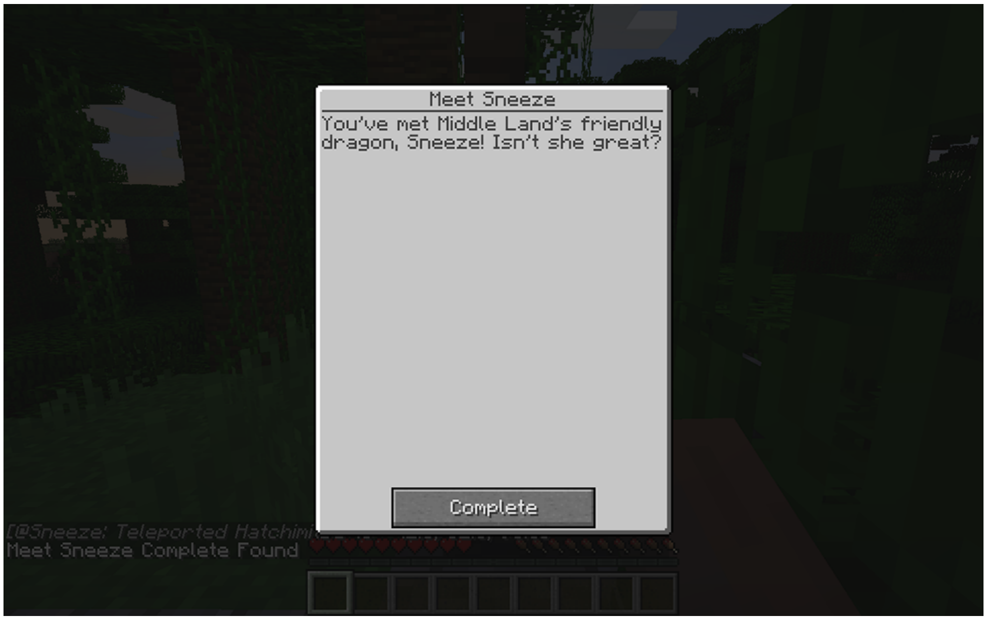

Figure 5.3: In-game screenshot of completing the first quest

The second area was called Middle Land. In Casey et al. [2008], the medieval world the children get brought to was called Middle Land. We made slight adaptations and designated the name to the town.

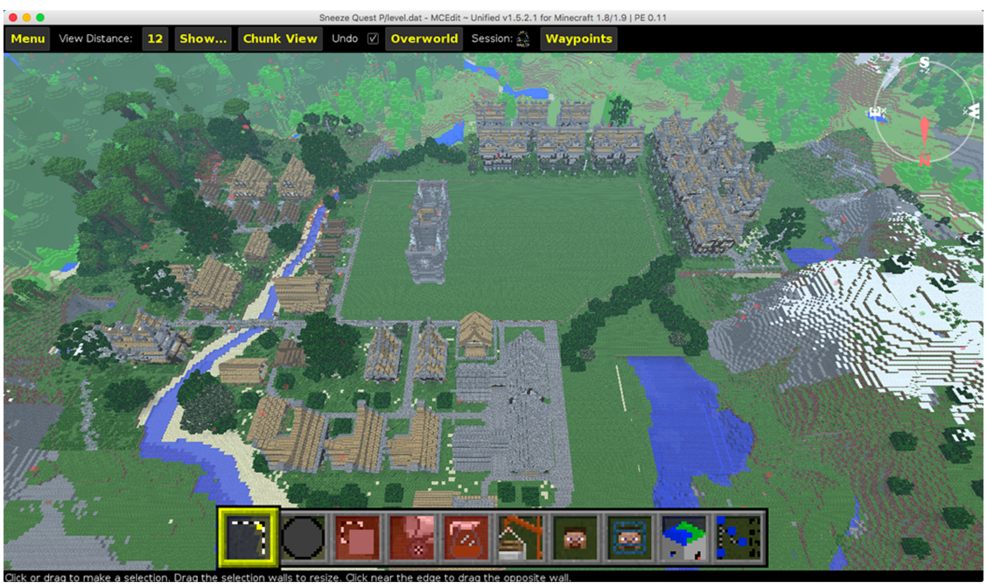

Figure 5.4: An aerial view of the town where Sneeze brings the player to see the castle

Fig. 5.4 shows the town in MC Edit, surrounded by rivers. The rivers served as visual cues for participants to stay within the town area and traverse past the rivers. The open area in the middle of fig. 5.4 was where participants engaged in building the structures. Additional visual cues placed to establish boundaries to the environment were the trees on the corners of the open area.

We designed the path the participants would follow once in the town to simulate the feeling that Sneeze was taking them on a tour. Participants were encouraged to interact with Sneeze. Rather than engage in dialogue through an overlay, Sneeze's dialogue appeared overhead.

Figure 5.5: In-game screenshot of dialogue with Sneeze while touring the town

In some scenarios, we used a combination of blocks in *Minecraft* to recreate events from the book. In *Sneeze builds a castle*, Sneeze sneezed down the existing castle, prompting the children to engage in block-building activities. We recreated the event in *Minecraft* by using the TNT block and a chain of commands to trigger their explosion. After the explosion, another command cleared the remaining blocks. Fig. 5.6 and fig. 5.7 demonstrates how the event panned out.

Figure 5.6: In-game screenshot of the existing tower

Figure 5.7: In-game screenshot of the existing tower disappearing into a poof of smoke

PCM required the most development time, out of the three interventions. The condition needed to be implemented manually using the redstone system in *Minecraft* due to our design. Our approach in reducing spatial involvement required that block building be abstracted through an interface. Compared to placing blocks one by one, we designed the interface to visualize larger pre-defined chunks of structures. We wanted participants to be able to press a "Forward" and "Backward" button to shift through their options and then press a "Set" button to finalize their selection and move onto the next chunk. Early experimentation is displayed in Fig. 5.8 and fig. 5.9.

Figure 5.8: Testing a singular line of commands

Figure 5.9: Testing several commands triggered by the initial redstone block placement

We developed a system where we tracked which structure placement and style the participant was currently seeing underground, directly below the open area where participants were building.

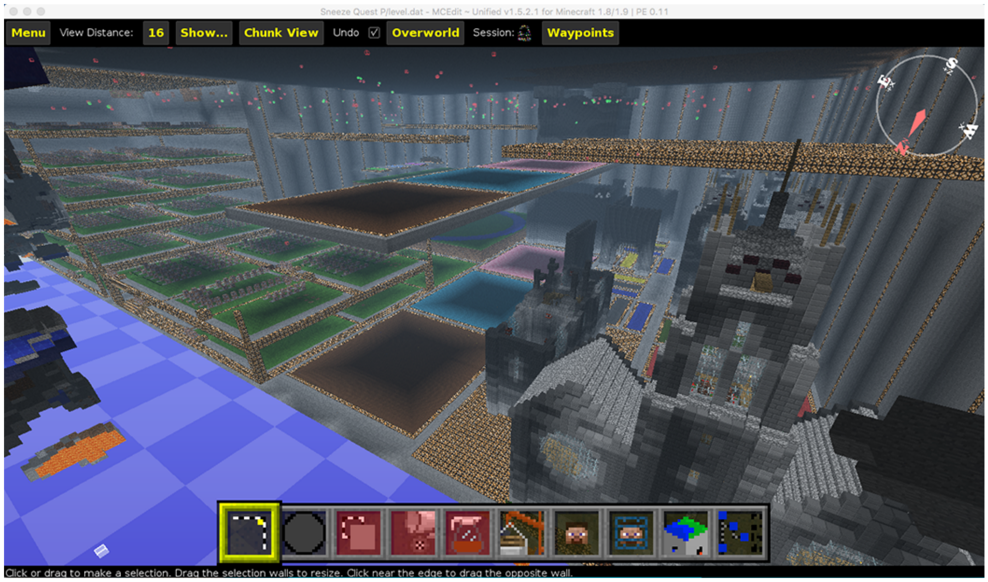

Figure 5.10: Underground space for command chains

A chain of command blocks using the clone and setblock command that would set-up the interface, "save" the area where the participants were building their structures, and begin the tracker.

Figure 5.11: In-game screenshot of participant approaching interface from behind

Whenever the participant pressed the forward button, a series of commands ran in the following order:

1. Test to see where the tracker block is using the comparator block in Minecraft

2. Save the working area again as safety by cloning the working area to the underground space

3. Display the current selection by cloning the pre-existing structure underground to the working area

4. Move the tracker block to the next selection by destroying the previous tracker block and setting a new one at the next placement.

Figure 5.12: In-game screenshot of participant pressing the button

Figure 5.13: In-game screenshot of the pre-defined tower chunk placed

These chain of commands were created for as many options there were for the participant to choose from. For example, the tower had three vertical slices with three placement options and two styles each. The configuration for the tower resulted in placing 24 individual chains, grouped by threes to represent the vertical slices.

Chapter 6: RESULTS

There was little experimental data on the effects of changing the context in which a game is played. Our approach focused on a valid method for establishing short-term effects on MR performance and wider spatial skills. We conducted a pilot study to demonstrate the viability of the approach with seven subjects in the targeted age bracket between 18 and 21. There were three participants for the FCM conditions and two each for the PCM and control conditions. In the following, the quantitative data from the measures are presented first. We examined the effects of the different interventions using the four instruments: (1) the mSMT, (2) the eSMT, (3) the eGZSOT, and (4) the Block Design subtest of the WAIS. Then, we explored a qualitative analysis of previous game-playing experience to supplement our understanding of the activities that occurred during the interventions.

6.1 Quantitative Analysis of Psychological Assessments

For each condition, we collected data on participants performance for four instruments before and after the experience. The order that the assessments was presented to participants was:

1. mSMT—used to measure mental rotation by rotating figures
2. eSMT—used to measure mental rotation and observe any transference effects by indicating whether a pair of figures were the same or mirrored
3. eGZSOT—used to measure spatial orientation by combining a sequence of directions to describe the motion of a boat's prow
4. Block Design subtest—used to measure wider spatial skills by assembling cubes to match a prescribed pattern.

During the pre-test, participants were given instructions on how to complete the assessment tasks. In the post-test, we delivered a shorthand version of the instructions.

Each instrument had different times during the procedure where the data were collected. The mSMT and Block Design subtest shared the same procedure while the eSMT and eGZSOT shared a different procedure. During the mSMT, we used a stopwatch to time spent working on each pair of figures. Afterwards, we assigned a point value based on the time spent and calculated the total raw score. The Block Design subtest followed a similar method of obtaining the final raw score. The results of the eSMT were given to us through the Java applet. Based on the configuration of the test, we received speed and accuracy values for the each level of rotation. The eGZSOT also gave us a final score through the source website.

6.1.1 Preliminary Analysis

We examined the relationships between the pre-test and post-test scores for the two interventions and the control. For tests scored using a single point value, we calculated the mean for each condition. From the Java applet for the electronic SMT, we received four measurements: (1) the time spent rotating identical or same figures; (2) the accuracy of rotating same figures; (3) the time spent rotating mirrored figures; and (4) the accuracy of rotating mirrored figures. We compared the average of scores for the pre-test and post-test for each series of values.

Table 6.1: Pre- and Post-test Scores for the Three Spatial Measures

Source	Condition (n)	Pretest Mean	Posttest Mean
Modified Shepard-Metzler Test	FCM (2)	35	43
	PCM (2)	49	48
	Control (1)	43	45
Electronic Guilford-Zimmerman Spatial Orientation Test	FCM (2)	27.92	34.5
	PCM (2)	40.75	47
	Control (1)	23	28.5
Block Design subtest	FCM (2)	63	63
	PCM (2)	62	62
	Control (1)	42	52

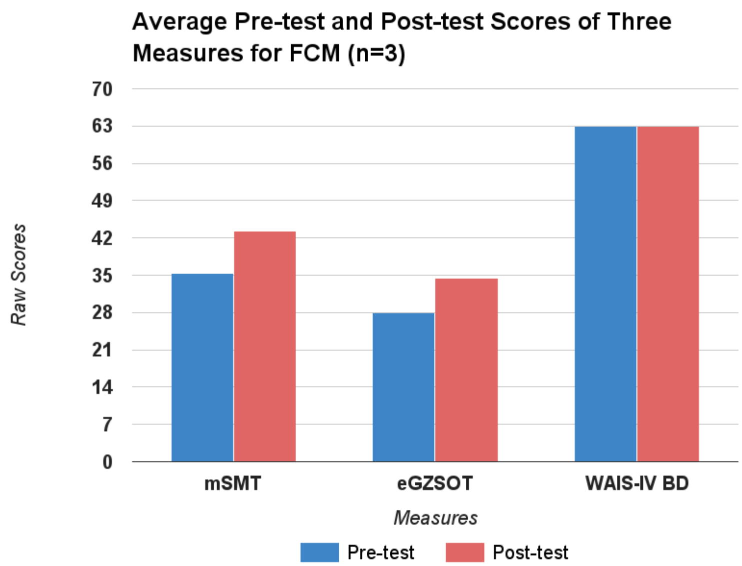

Figure 6.1: Average Pre-test and Post-test Scores of Three Measures for Full Control Minecraft

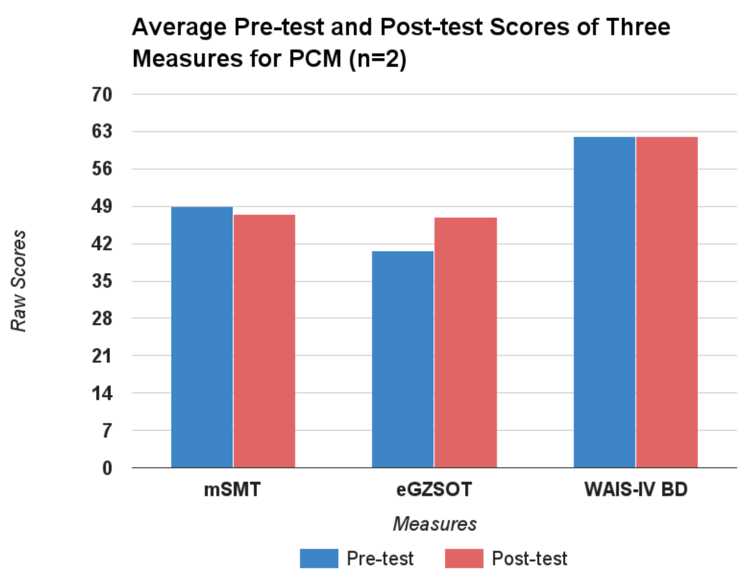

Figure 6.2: Average Pre-test and Post-test Scores of Three Measures for Partial Control Minecraft

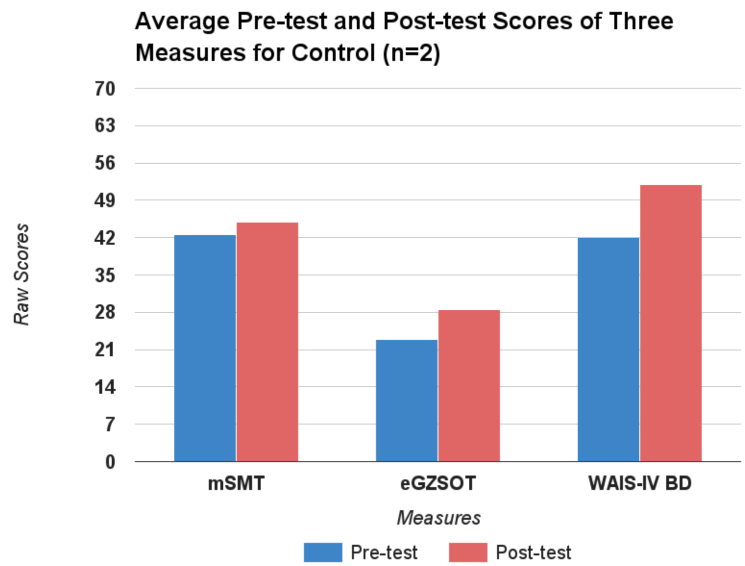

Figure 6.3: Average Pre-test and Post-test Scores of Three Measures for Control

We observed a small increase in performance for the mSMT; a moderate increase in performance for the eGZSOT, and minimal increase in performance for the Block Design subtest. Participants assigned to the FCM condition demonstrated the greatest improvements.

The eSMT assessed the speed and accuracy of mental rotation performance. There were eight levels of rotation for the configuration used in the pilot study. We observed the averaged pre-test and post-test scores for rotating the same and mirrored figures across the three conditions.

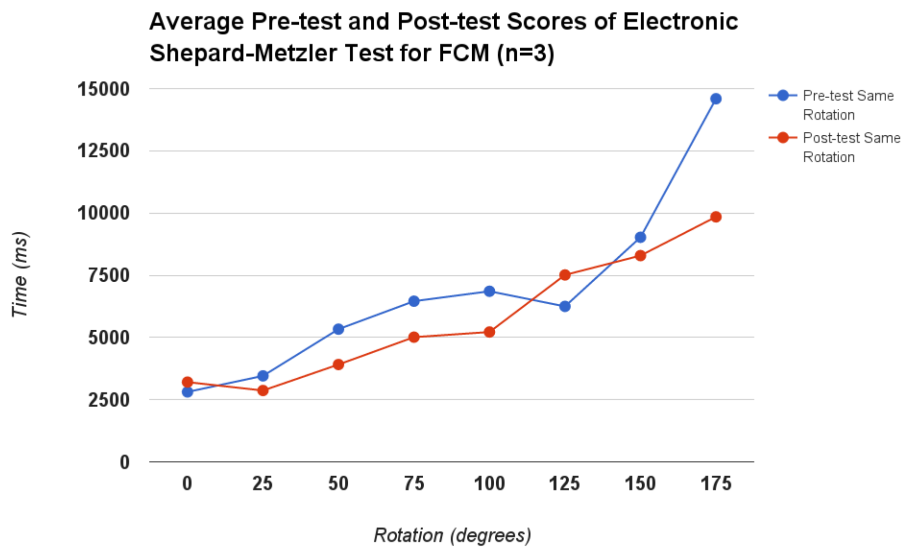

Figure 6.4: Average Pre-test and Post-test for Same Rotation Times of the Electronic Shepard-Metzler Test for FCM

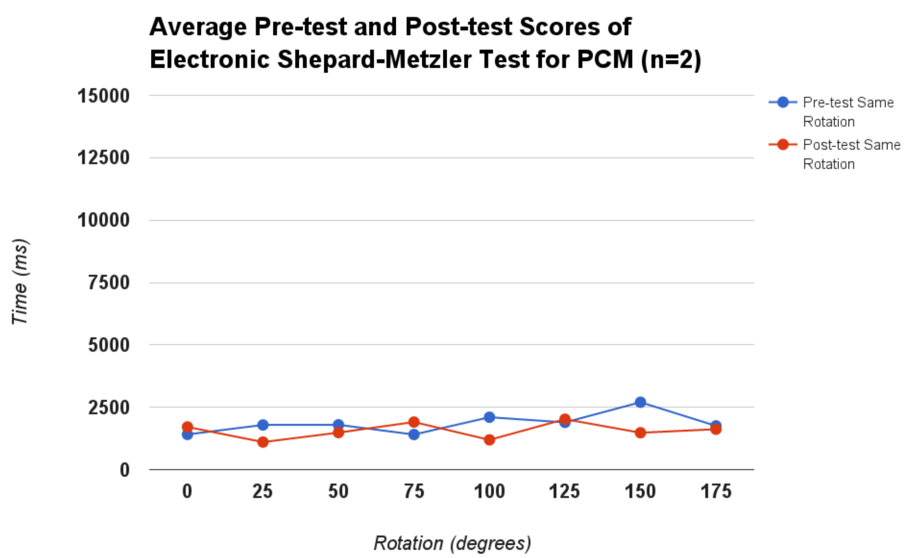

Figure 6.5: Average Pre-test and Post-test Scores for Same Rotation Times of the Electronic Shepard-Metzler Test for PCM

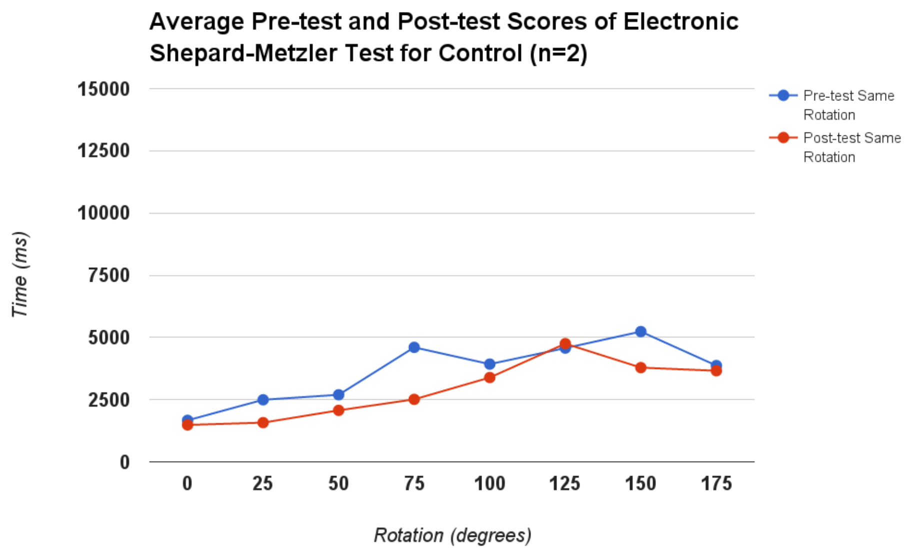

Figure 6.6: Average Pre-test and Post-test Scores for Same Rotation Times of the Electronic Shepard-Metzler Test for Control

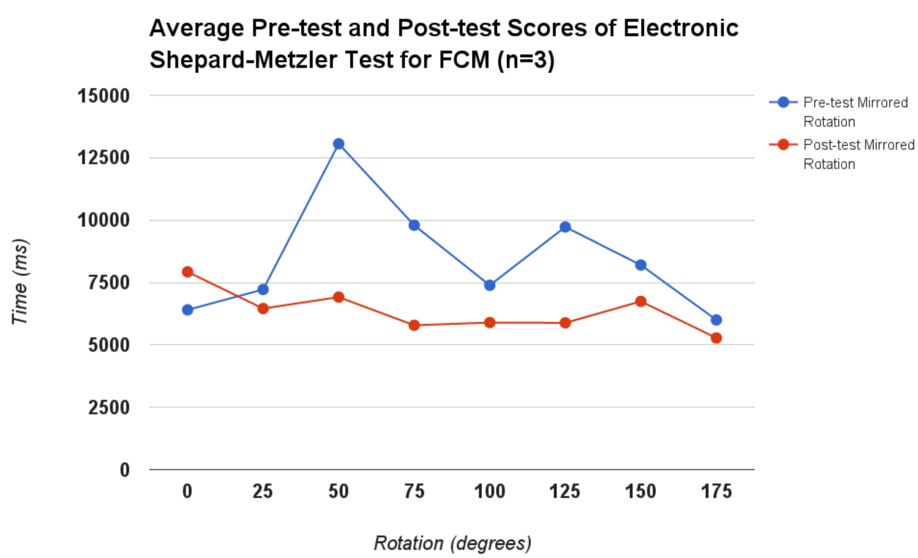

Figure 6.7: Average Pre-test and Post-test Scores for Mirrored Rotation Times of the Electronic Shepard-Metzler Test for FCM

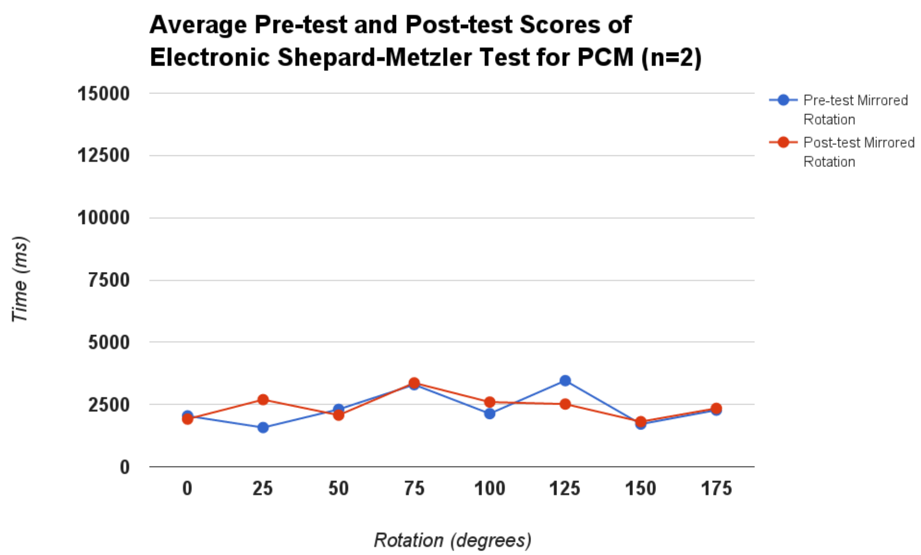

Figure 6.8: Average Pre-test and Post-test Scores for Mirrored Rotation Times of the Electronic Shepard-Metzler Test for PCM

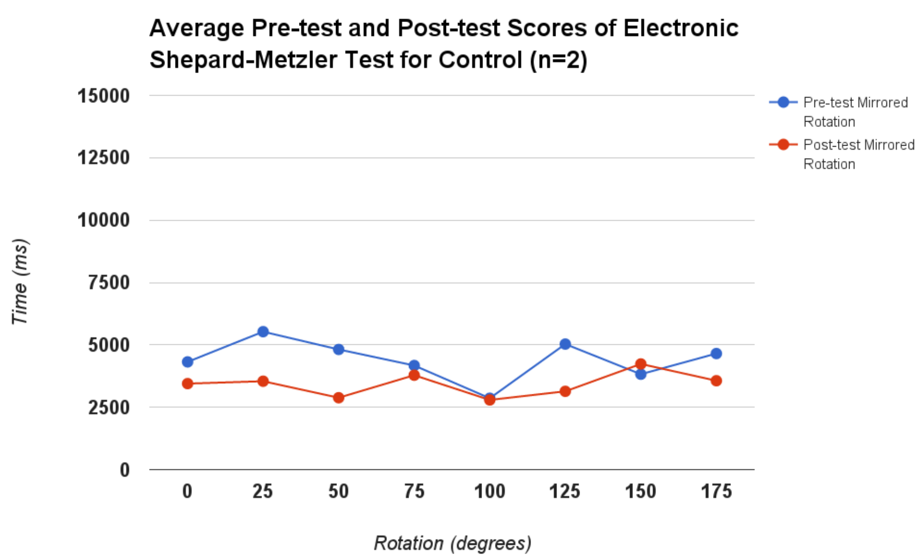

Figure 6.9: Average Pre-test and Post-test Scores for Mirrored Rotation Times of the Electronic Shepard-Metzler Test for Control

Increases in performance through speed were revealed through decreases in time spent on each test item in the post-test. While the control condition demonstrated improvements in performance, the results of participants in the FCM condition indicated that the approach had an effect. For mirrored figures, participants in the FCM condition had a considerable performance increase as seen from the decrease of time spent on each figure.

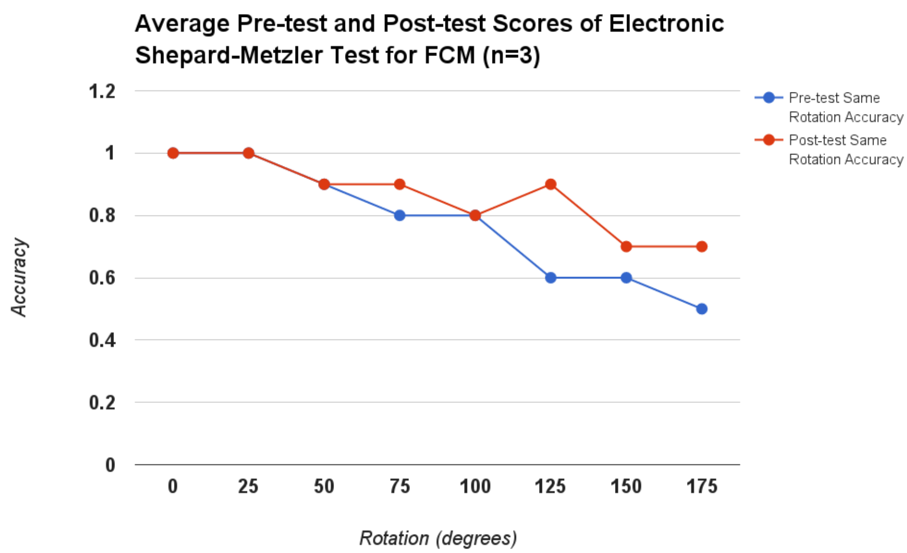

Figure 6.10: Average Pre-test and Post-test for Same Rotation Accuracy of the Electronic Shepard-Metzler Test for FCM

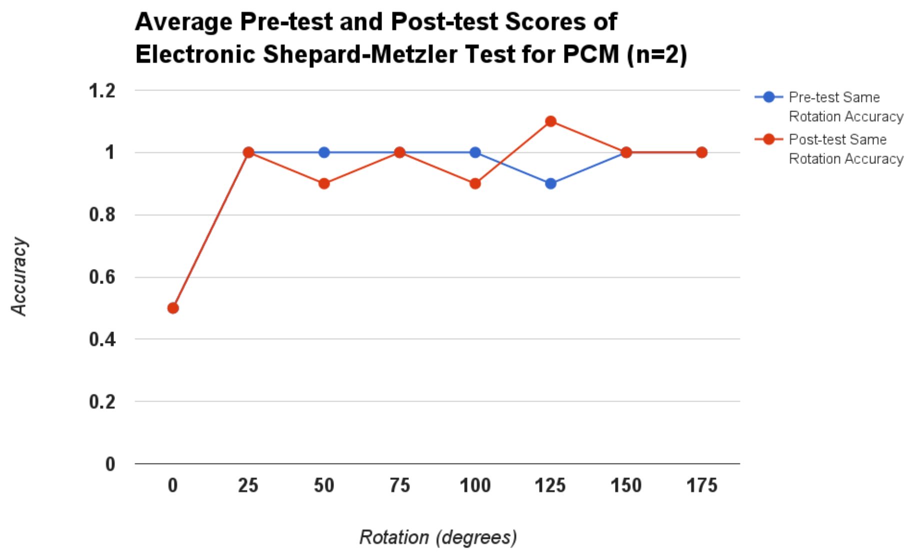

Figure 6.11: Average Pre-test and Post-test Scores for Same Rotation Accuracy of the Electronic Shepard-Metzler Test for PCM

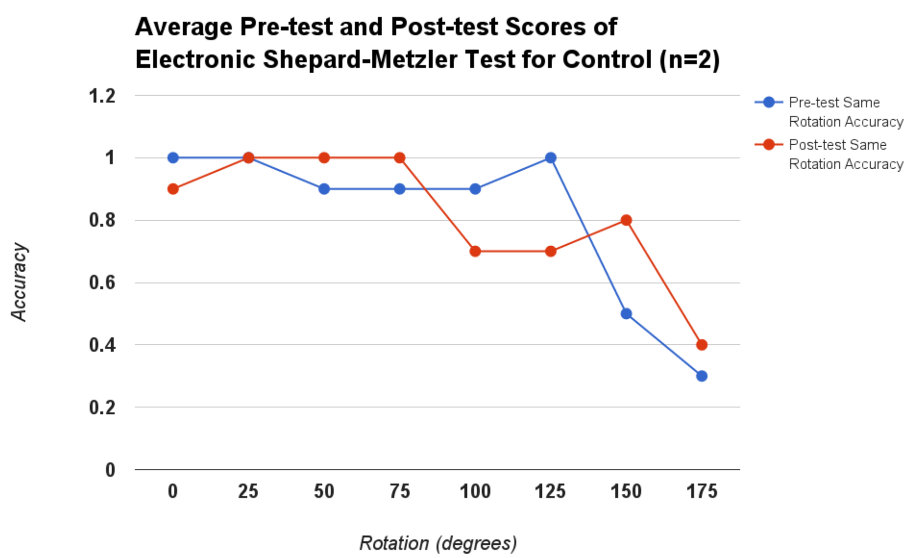

Figure 6.12: Average Pre-test and Post-test Scores for Same Rotation Accuracy of the Electronic Shepard-Metzler Test for Control

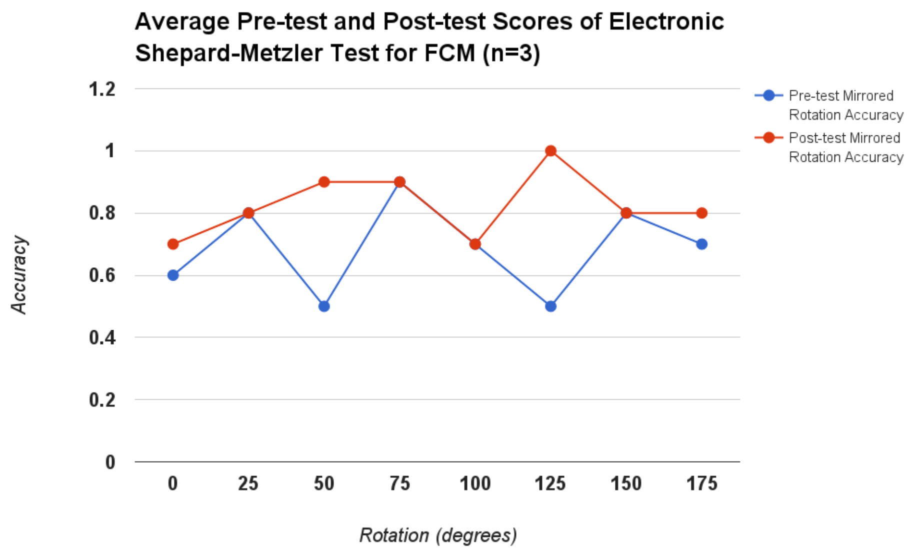

Figure 6.13: Average Pre-test and Post-test Scores for Mirrored Rotation Accuracy of the Electronic Shepard-Metzler Test for FCM

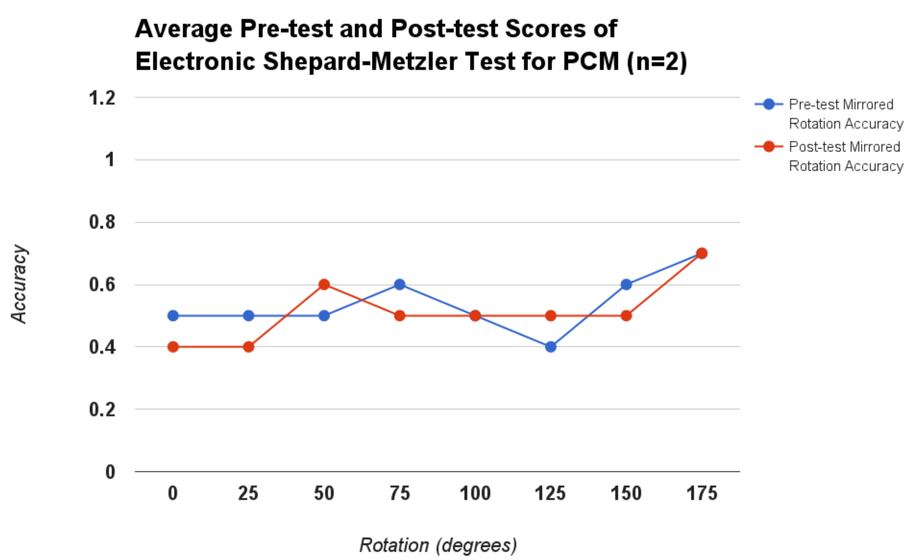

Figure 6.14: Average Pre-test and Post-test Scores for Mirrored Rotation Accuracy of the Electronic Shepard-Metzler Test for PCM

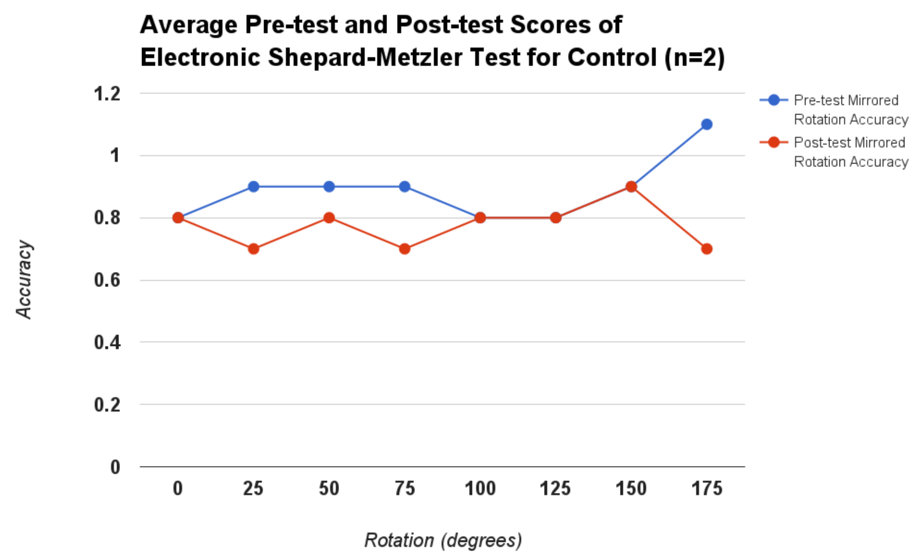

Figure 6.15: Average Pre-test and Post-test Scores for Mirrored Rotation Accuracy of the Electronic Shepard-Metzler Test for Control

Increases in performance through accuracy were revealed through increases in the accuracy value in the post-test. The results indicated that the approach had an effect as participants in the FCM condition consistently had improvements across the levels of rotation when compared to the PCM and control conditions.

Due to the small number of subjects in the pilot study, an analysis of statistical significance was not warranted, but the results indicated that the approach has the expected effect and can be used in larger scale testing. In future work where the sample size is addressed, we would use t-tests to determine the statistical significance between conditions. This method of analysis is appropriate our approach by examining the effect of the intervention by using means.

6.2 Qualitative Analysis

At the end of the second session, we collected qualitative data through the use of surveys. We asked demographic questions and questions about previous game-playing experience. The instrument we used for gathering information about previous game-playing experience is the Video Game Experience Survey [Newcombe and Terlecki n.d.]. We adapted the instrument to exclude non-multiple choice items as we were more concerned with the general interest and motivation to play video games. The adaptation is referred to as the Player Gameplaying Experience Survey.

6.2.1 Player Gameplaying Experience Survey

We observed the results from the Player Gameplaying Experience Survey, which we adapted from Terlecki and Newcombe. Table 6.2 lists the questions we asked in the order that the questions were presented to the participants.

Table 6.2: Player Gameplaying Experience Survey

No.	Question
1	Have you ever played computer games?
2	Do you currently play computer games?
3	If you answered no to either of the questions above, why don't you play video games?
4	How long have you been playing computer games?
5	How did you get started playing computer games? Who or what motivated you to play?
6	How often (approximately) do you currently play computer games?
7	How good do you feel you are at playing computer games?
8	How do you play games?

The results of the survey indicated that a majority of the participants were experienced gamers. Similar to the quantitative data, an analysis of statistical significance was not warranted.

6.3 Limitations

There were two key limitations to the study that were consequences from the design of the study. The findings were restricted and cannot be generalized due to the small sample size. While the study was heavily advertised through several avenues, the population we were targeting was unresponsive. There were concerns about participating relating to the time commitment. In the design phase, we made an effort to reduce the time commitment while still allowing for enough time for the participants to spend time building in *Minecraft* by cutting most times in half. This decision was made after testing the set-up at various levels of completion. For example, in FCM, we reduced the time limit for building the castle tower from 60 minutes to 30 minutes.

The environment, physically and mentally, that the participants worked in may have an influence on the results. The physical space in which the study occurred was not a private space enclosed from other activity. While *Minecraft* does not require much computational power from the machine, the commands used to construct the interface PCM did. We used a machine within the graduate labs to conduct sessions. Participants had access to headphones to experience the audio of *Minecraft*. However, during the pre- and post-test activities, participants were subject to conversations happening in the lab space and the general noise in the room from machines. The sessions occurred past the halfway point of the term and often later in the day to accommodate the schedule of participants. Since Drexel University operates on an intensive 10-week program, participants often came to the study exhausted to some degree. This is important to note for future studies involving more than one hour of participation from undergraduate students.

Chapter 7: CONCLUSION

This research provided an approach to examine which elements of gameplay can contribute to successful game-based training regimens. We focused on the role of spatial involvement and observe its impact on training MR based on previous successes on training MR using action first person shooter games.

The expected outcome of the pilot study was a viable approach to gather evidence to support that MR performance will improve after the training using FCM, which has the strongest spatial involvement, when compared to PCM, which has less. The FCM intervention incorporated gameplay that resembled those of action computer games, specifically FPS games, and story. Past research has shown that, separately, these aspects improved spatial abilities. Compared to previously researched games, *Minecraft* and its modification environment offered the opportunity to create scenarios with alterations restricted to one aspect of gameplay while keeping the rest the same. This approach can have a beneficial influence on effect sizes as there is the potential to reduce the placebo effect seen in multi-game studies.

7.1 Summary of Contributions

We were unable to provide direct experimental data on training MR, but our results showed the viability of the approach and increased our understanding on how to use *Minecraft* for future research endeavors. Due to our small sample size in the pilot study, our results showed no statistical significance in changes between the pre-test and post-test performance for MR or wider spatial skills. Our apparatus showed promise in answering the research question we posed as we successfully extended a previous non-digital intervention. The benefit of using *Minecraft*'s modification environment was that we are able to reuse the files associated to each scenario or have other scholars make a copy and edit the existing source files.

7.2 Future Work

Minecraft has a powerful environment that was designed to allow players to create interesting scenarios. We demonstrated how *Minecraft* can be used as a platform in an apparatus that has been applied to games such as *Call of Duty*, *Medal of Honor*, *Tetris*, and *The Sims*. Researchers can utilize *Minecraft*'s modification capabilities for future work. Since the set-up of the scenarios presented in our research was done in *Minecraft*, there is an opportunity for future work to extend the findings in multiple ways. One way would be to address the limitations and conduct the study with a larger sample size.

All of the *Minecraft* files are digital and can be made readily available. Anyone with access to *Minecraft* can modify the contents of the level. The button interface found in PCM is one solution to abstracting the level of control for block building in *Minecraft*. Improvements can be made to the interface by reconfiguring the existing set-up. There will be additional opportunities when new tools are introduced to *Minecraft* as the game continues to expand and enhance its modification capabilities.

Minecraft is an engaging platform for a wide population. The controls are relatively easy to learn when compared to action first person shooters. Our study deviated from the source material by training undergraduate students at Drexel University. Future work can use the scenarios designed for the study on students in elementary or middle school.

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Appendix A: Terms

This section provides concise definitions of terms used throughout the thesis that the reader might be unfamiliar with.

Computer game: Games that are displayed via digital graphics on a screen where players interact with the objects within a game through an interface, such as a mouse or joystick; within this document, this term also encompasses the terms "video games", "mobile games", "PC games"

Full control *Minecraft* (FCM): The default control schematic in *Minecraft* where players play in the third-person point of view and have access to full omni-directional rotation via mouse movement and translate across terrain using WASD keys. Blocks can be placed using the right mouse button and destroyed with left mouse button.

Partial control Minecraft (PCM): A modified control schematic made for *Minecraft* where players play in the first-person point of view but do not have access to full omni-directional rotation and cannot translate across terrain using WASD keys. The implementation for this thesis involves placing players in a mine cart, restricting their movement to forwards or backwards along a rail path. Rather than place blocks down one at a time, players interface with the block-building aspect of *Minecraft* through buttons that lay down entire structures at once.

Mental rotation (MR): One of three domains within spatial abilities involving the ability to rotate a 2-dimensional (2D) or 3-dimensional (3D) object around an axis a specified number of degrees.

World: An interactive *Minecraft* environment that encompasses the map, creatures, and any formal game elements, such as quests, narrative, etc.

Map: Terrain within *Minecraft* either user- or computer-generated.

Spatial involvement: An aspect of the Calleja's player involvement model that is defined by the "players' engagement with the spatial qualities of a virtual environment in terms of spatial control, navigation, and exploration" [Calleja 2011].

Multi-link Shepard-Metzler Test: The Shepard-Metzler test (SMT) evaluates MR performance by utilizing 2-dimensional (2D) representations of 3-dimensional (3D) figures. Test-takers are given one key object and four options of similar figures but at different orientations (rotations). Among the four options, one option is the key figure at a different orientation. The multi-link SMT is a modified version of the procedure described developed by Casey et al. [2008]. Test-takers are given two figures—one is the key figure and the other the key figure at a different orientation. The task is to rotate the second figure to match the key figure under specified constraints.