The Role of Action Videogame Training in Spatial Cognition: a Study of Training and Transfer Effect

by

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Ethics Statement

The author, whose name appears on the title page of this work, has obtained, for the research described in this work, either:

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Abstract

Spatial skills are a strong predictor of success in learning in science, technology, engineering, and mathematics (STEM) areas. There is ample research investigating whether playing videogames (specifically action games) can alter spatial performance. This dissertation presents a study that investigates the training effect of playing action games (specifically first-person shooter (FPS) games) - a game genre that has received the most attention in gaming literature - compared to playing non-action videogame on basic and complex spatial performance. The spatial abilities studied are: (1) spatial attention (or the useful field of view) as a basic skill; (2) mental rotation as a complex skill; and (3) navigation as a complex skill. After selecting the games, 32 participants were randomly assigned to two groups to play one of the assigned games for an average of 11 hours within one month. Both groups (action and non-action videogames) showed significant improvement compared to their baseline levels in spatial attention and mental rotation. Navigation did not improve. Also, results showed participants were able to maintain their improved performance for one month after the training. Training was beneficial for both males and females as they both improved similarly. The improvement in performance after training with both action and non-action games was surprising. There are possible explanations for this finding, and they were discussed in this dissertation.

Keywords: Gender differences; videogame effect; videogame training; spatial abilities;

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Chapter 1

Introduction

1.1 Overview

Spatial intelligence is a vital cognitive ability that facilitates success in the fields of science, technology, engineering, and mathematics (STEM). Even though research has shown that individuals can be trained to develop spatial skills, the education system pays much less attention to these than to verbal or mathematical abilities (Adams, 2013). Given that strong spatial skills are critical to working in the STEM fields, it is important to identify practical training regimens that help individuals to build these skills. Over the past decade, some researchers who have studied subjects related to spatial cognition and technology have focused on the spatial skills that individuals develop when they play action videogames (AVGs). However, their work constitutes a body of research that is still at an emergent stage, and many questions remain unanswered. Sex differences in spatial ability (favouring men) are widely recognized, leading many scholars to believe that this is one of the main reasons why females are underrepresented in STEM fields (Reilly, Neumann, & Andrews, 2017). These findings highlight the necessity of exploring ways to improve females' spatial abilities. Therefore, examining whether playing AVGs can reduce the spatial ability gap between sexes could be of considerable importance.

1.2 Objectives

The goal of my research is to extend this enquiry by investigating whether regular AVG playing improves complex as well as simple spatial skills through high-level cognitive demands. As the literature presents conflicting findings, and does not investigate whether playing AVGs improves an individual's general ability to perform complex (large-scale) spatial tasks, my enquiry addresses a gap in the research.

My investigations assess whether or not playing an average of 11 hours of AVGs improves basic and complex spatial abilities. The type of AVG I use is the one that has received the most attention in gaming literature, first-person-shooter games (FPS). I propose to answer the question of whether training with FPS games helps to improve performance in three spatial abilities (spatial attention, mental rotation, and virtual navigation), as well as whether it helps to reduce sex differences in these abilities.

Further, effectiveness and durability are two important outcomes that make a training regimen useful. I consider FPS game-training to be useful when it is both effective and durable, which means that the training gains should: (1) transfer to spatial skills (effective); and (2) last for a period of time (durable). It should be noted that to our knowledge, no previous research has provided empirical evidence of the durability of training with FPS games.

In this dissertation I carried out two experiments to explore whether spatial abilities are trainable by FPS videogame. The first study was a preliminary experiment to examine if two selected games (chosen based on specific criteria) were suitable for the main study. The main study was to test participants' spatial performance before and after they played the selected videogames .The purpose of the second study was to answer the question of whether FPS training is effective, durable, and reduces the sex differences reported in spatial attention, mental rotation, and virtual navigation. These are very important questions to be answered in order to gain awareness of the possibility of improving those abilities by playing a videogame in the FPS genre.

1.3 Contributions

Expanded knowledge about how digital (FPS videogame) training improves spatial abilities will be valuable for some individuals and educational reasons.

1.3.1 Individuals

This research objective is to provide evidence that FPS videogame training can improve spatial abilities. Playing videogames is not only a fun activity, but also vastly convenient since nearly every household in developed countries such as Canada (including low socio-economic status) possesses at least one digital device capable of running videogames (Government of Canada, 2013). If spatial abilities are improved through videogames, then individuals with low spatial abilities will have the option to improve their performance. Awareness of this possibility is especially important for women. According to a report in Women in Science and Engineering in Canada

(Government of Canada, 2014), women are often underrepresented in STEM fields, and this may be due to their spatial abilities tending to be lower than men (Reilly et al., 2017). The report stated that:

> The lack of women in the university system can not explain their under representation in the natural sciences and engineering (NSE). Females make different discipline choices as compared to males when entering university. Figures 1-3 present the bachelor's level enrolment distribution patterns for females and males, respectively. The NSE disciplines rank near the bottom as a discipline choice for women as compared to men. Figure 3 highlights the ratio of females to males for 2008-09 bachelor's enrolment. While women outnumber men in most non-NSE disciplines, the ratio drops off dramatically for the major NSE disciplines and is only above 1.0 for the life science disciplines. (p. 9)
>
> Figures referred to in this quote have been included below:

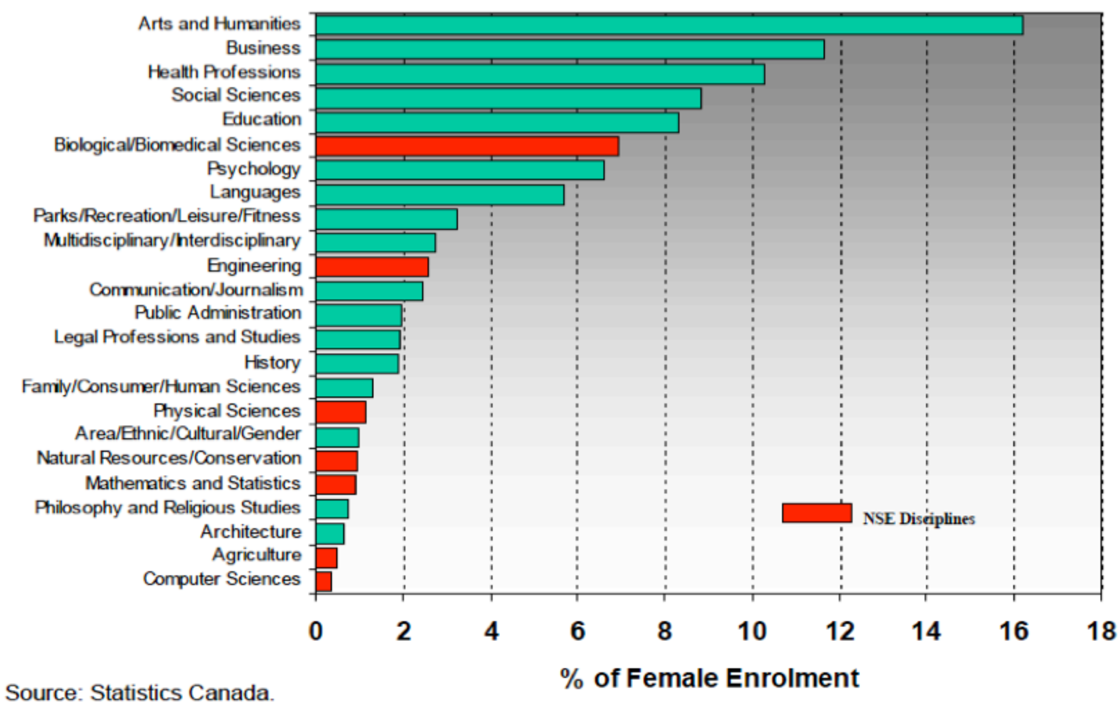
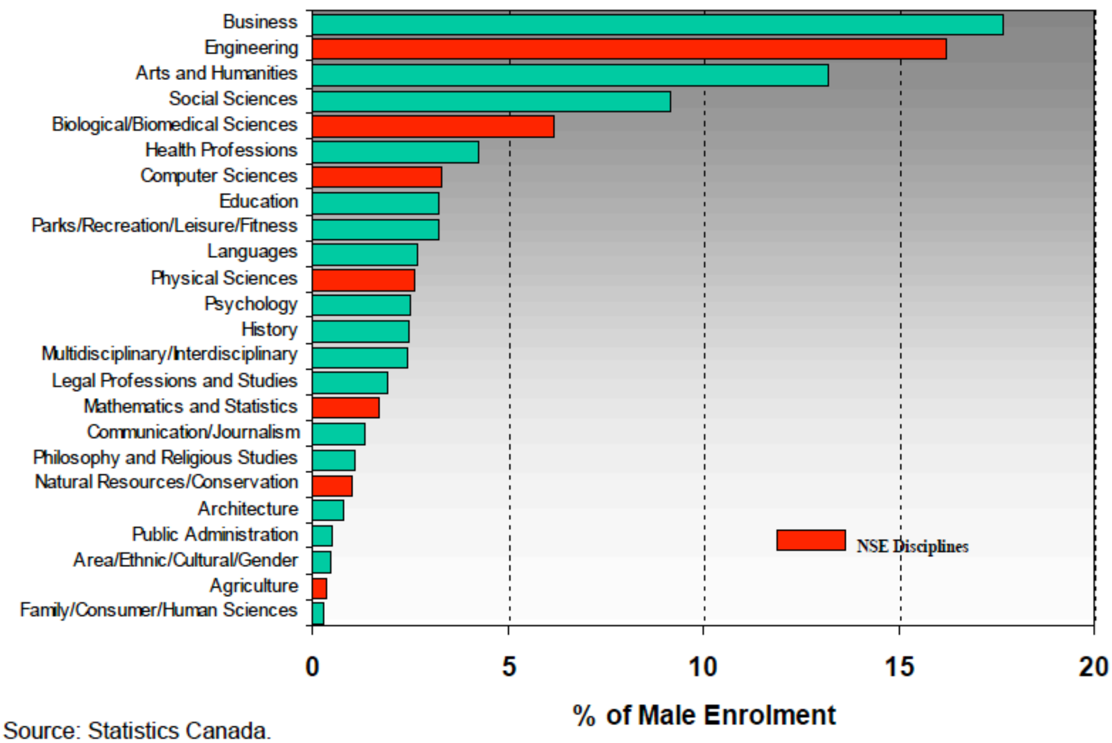
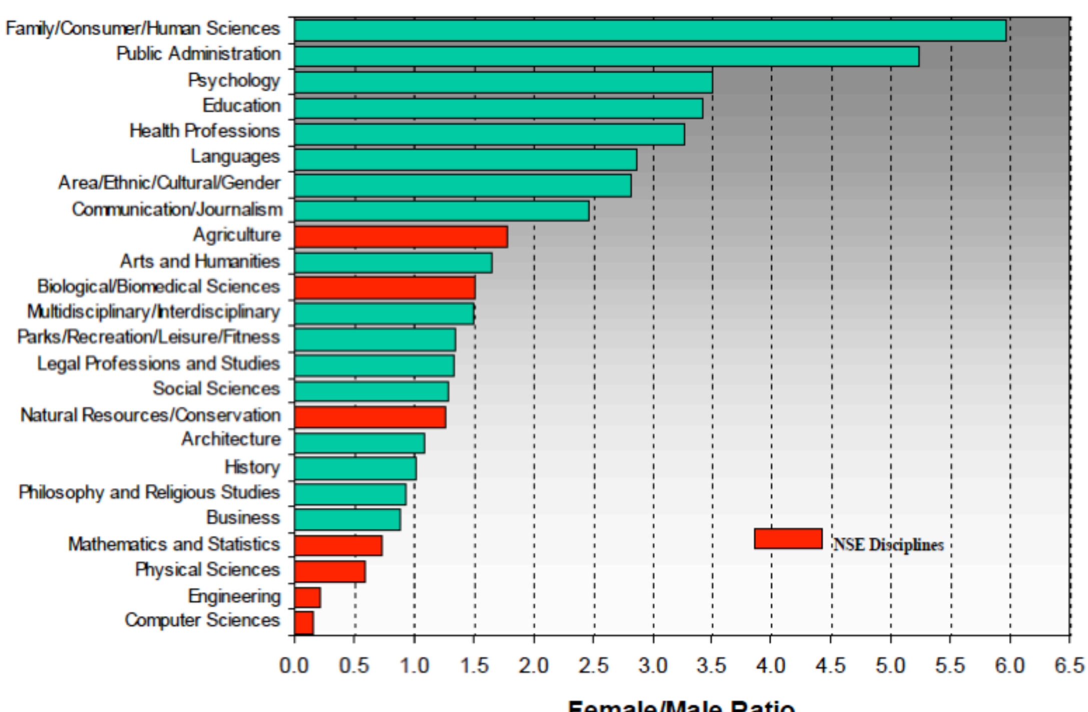


Figure 1 Full-time Female Bachelor's Enrolment by Discipline, 2008-09



Source: Statistics Canada.

Figure 2 Full-time Male Bachelor's Enrolment by Discipline, 2008-09



Source: Statistics Canada.

Figure 3 Full-time Bachelor's Enrolment by Discipline, Female/Male Ration, 2008-09

Knowing that spatial cognition is trainable may be of value not only to women but also to educators aiming to increase the number of women in STEM fields (see section 1.2.3).

This research may also be a catalyst that leads parents and other adult caregivers to realize that playing videogames can elevate spatial cognition. As a result, they could be motivated to encourage their children (both girls and boys) to spend time playing videogames. Parents have a critical role to play in the development of children's spatial cognition. Lytton and Romney's (1991) meta-analysis suggests that play is the one of the main areas where gender-typed behaviour is encouraged by parents. This might account in part for the finding that boys typically get involved in more activities with a spatial component, which may facilitate the development of spatial skills.

1.3.2 Education System

As discussed earlier, even though there has been evidence of an association between spatial intelligence and success in STEM fields, spatial cognition has been often neglected by the education system. Traditional education systems offer no training regimens for students that aspire to help them improve their spatial cognition. This research objective is to investigate if spatial abilities are trainable. Having this knowledge may encourage educators to include spatial cognition training regimens in the curriculums, which may lead to increasing the percentage of students entering the STEM fields. Furthermore, if videogames do help training spatial abilities, they represent an easily accessible source of training until other official sources are implemented within the education system (of which videogames could be one).

1.4 Thesis Guide

In Chapter 1, I provide an overview of the main topics addressed in my thesis.In Chapter 2, I describe the theoretical and methodological background of videogame training research conducted to enhance spatial abilities.

In Chapter 3, I discuss the pilot study I conducted to select the videogames for my study.

In Chapter 4, I describe how I validated the assigned videogames before they were used in the training experiment. This chapter includes the methodology, the results, and the discussion of the results.

In Chapter 5, I discuss the training study in full, including the methodology, the results, and the discussion of the results.

In Chapter 6, I discuss the practical and methodological implications of the results. In addition, I discuss the limitations and the possible areas of future research.

Chapter 2

Theoretical Background

To recognize whether a cognitive ability has been enhanced, it is important to comprehensively understand it. For this reason, in this chapter, I provid a thorough description of spatial abilities and their definitions, their scales (basic vs. complex), and how the scales relate/depend to/on each other. I also identify some previous research gaps in action videogame training literature, and discuss how I address them. Finally, I provide the reasons why I decided to use a FPS game in training spatial abilities. I conclude this chapter with my research questions and hypotheses.

In the following sections, spatial abilities are defined, their scales are described, the relationship among those scales are explained, and their importance to human cognition is discussed. Also discussed are three spatial abilities I am interested in improving due to their role in cognition: (1) spatial attention, (2) mental rotation, and (3) virtual navigation. Finally, I provide a summary of previous research findings on the influence of sex on spatial abilities.

2.1 Spatial Abilities

The significant amount of research on human spatial abilities that has been conducted since the 1920s has revealed that these abilities are significantly associated with important life-skills (such as wayfinding) that contribute to an individual's capacity to perform well in the cognitively demanding STEM fields. In his 1983 book "Frames of Mind: The Theory of Multiple Intelligences", Howard Gardner stated that spatial abilities are one of the nine primary forms of human intelligence.

Categorizing spatial abilities has been a challenge because they comprise such a multiple and varied set (Voyer, Voyer, & Bryden, 1995). However, scholars have made several attempts to classify these abilities. In the 1990s, there was general agreement that there were four main types of spatial ability: mental rotation, spatial perception, spatial visualization, and object location memory (Linn & Petersen, 1985; Silverman & Eals, 1992; Voyer et al., 1995). As research advanced in the 2000s, additional spatial abilities were identified and categorized according to the scale of the space in which the spatial task is performed, and the cognitive demands needed to perform the task. These classifications are discussed in the next two sections.

2.1.1 Spatial Abilities at Different Scales

Spatial abilities have been classified into two types of space scales: small- and large-scale. Small-scale spatial abilities are “psychometric paper-and-pencil tasks that are performed in the ‘figural scale’ of space in that they involve perceptually inspecting, imagining or mentally transforming small shapes or objects” (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006). Small-scale spatial abilities include mental rotation, spatial perception, spatial visualization, and object location memory. Researchers often use small-scale tests to measure participants’ spatial abilities and/or to explore the relationships between small-scale spatial abilities and large-scale task performance.

Large-scale spatial abilities – which are also called environmental spatial tasks – are carried out in larger real or virtual spaces and involve integrating sequences of visual and spatial information that change as one moves physically or virtually through such an environment (Hegarty et al., 2006). These abilities include learning the layout of new environments such as buildings or cities, navigating known environments, wayfinding, and interpreting and communicating verbal navigation directions (Hegarty et al., 2006). Exercising environmental spatial abilities places more complex and high-level cognitive demands on individuals than exercising small-scale spatial abilities, because they are performed in larger spaces and generally require more spatial information to be encoded, maintained, and inferred (Hegarty et al., 2006). Large-scale spatial abilities thus demand more cognitive functions than small-scale, including mental imaging, problem-solving, encoding, inspecting and transforming spatial representations, and spatial updating.

2.1.2 Spatial Ability Levels Based on Cognitive Demands

Spatial abilities vary substantially according to the cognitive demands placed on the attention process, working memory, and problem-solving skills. According to Spence et al.’s (2009) classification, spatial abilities can be categorized as either basic or complex (see Figure 4). Basic spatial abilities are bottom-up (lower-level) capacities such as spatial selective attention, spatial working memory, or other fundamental perceptual skills and act as the building blocks for many types of higher spatial abilities (i.e. small- and large-scale spatial abilities) (Feng, Spence, & Pratt, 2007; Spence et al., 2009). Both small- and large-scale spatial abilities fall into the category of 'complex' because they place greater demands on cognition. Basic and complex abilities are further explained in section 2.1.4.

Before proceeding, I will define the three spatial abilities that my research investigates and delineate the tasks I use to measure each ability: spatial attention (a basic spatial ability), mental rotation (a small-scale spatial ability), and virtual navigation (a large-scale spatial ability).

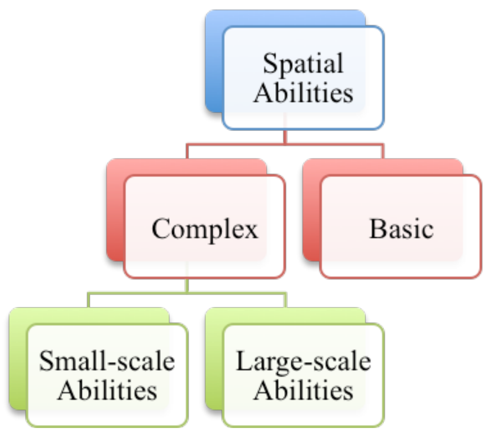


Figure 4 Spence et al.'s Classification of Spatial Abilities

2.1.3 Spatial Abilities: Definitions and Measures

2.1.3.1 Spatial Attention Ability (SA)

Spatial attention is the ability to allocate attention throughout a visual field in order to locate a target amongst distractors (Ball, Owsley, Beard, Roenker, & Ball, 1989). In my research, I use the Useful Field of View (UFOV) task to measure spatial attention. The UFOV is the visual area from which information can be extracted at a brief glance without eye or head movements. The UFOV task measures how quickly an individual processes visual information, how proficiently an individual divides attention between central and peripheral locations, and how effectively an individual ignores irrelevant information in increasingly complex visual settings (Edwards et al., 2005). The task test-retest reliability is 0.884. This skill is important because it functions as a building block of important higher spatial abilities such as mental rotation and navigation. If there is a deficit in mental rotation or navigation, it might be due to a deficit in spatial attention. Therefore, enhancing this ability is essential.

2.1.3.2 Mental Rotation Ability (MRT)

As mentioned earlier, spatial cognition is not only fundamental in predicting overall success in STEM education and jobs, but also plays an important role in survival skills such as navigation (Newcombe & Frick, 2010; Wai, Lubinski, & Benbow, 2009). Because mental rotation is a central metric of spatial cognition (Shepard & Metzler, 1971), enhancing this ability is vital.

Mental rotation is defined as "the ability to rotate quickly and accurately two- or three- dimensional figures, in imagination"(Voyer, Voyer, & Bryden, 1995, p. 250). In my research, I used the Vandenberg Mental Rotation Test to measure mental rotation before and after the videogame training. The test's internal reliability is 0.88.

2.1.3.3 Virtual Navigation (VN)

In a survival state (i.e. travelling in isolated areas or hiking in a wild forest without navigations aids), it is important to be able to determine not only your location, but also the most effective route to reach your destination. If a person has good navigation skills, they could increase their chances of surviving the situation. Navigation is defined as "the process of determining and following a path or route between an origin and a destination" (Golledge, 1999, p. 6). Navigation requires individuals to exercise a number of skills, including planning a route with specific goals (i.e. shortest path, less travel duration, etc.), constructing a mental map of the navigated space, and responding to both proximal and distal environmental cues in order to update position and reorient themselves (Rieser, Guth, & Hill, 1982). In my research, I was interested to discover whether this ability could be improved via videogame training, and used the Virtual Morris Water Maze (VMWM) task to measure virtual navigation before and after that training.

Studies of the VMWM have shown that it is a valid and reliable method of measuring navigational performance and identifying sex differences in navigational performance (Goodrich-Hunsaker, Livingstone, Skelton, & Hopkins, 2010; Jacobs, Laurance, & Thomas, 1997). In addition, performing well on the VMWM has been significantly correlated with individuals' mental rotation abilities (Astur, Tropp, Sava, Constable, & Markus, 2004; Choi, McKillop, Ward, & L'Hirondelle, 2006; Saucier et al., 2002; Silverman et al., 2000). This strong correlation makes the VMWM task a good fit for my research, as I investigated whether an improvement in mental rotation occurs after participants play a FPS game for an average of 11 hours, which in turn leads to an improvement in virtual navigation.

2.1.3.3.1 Morris Water Maze

The Morris Water Maze (MWM) task is one of the most widely used methods of examining navigation in mammals (Morris, Garrud, Rawlins, & O'Keefe, 1982). The subject (usually a rodent) is placed multiple times in a water pool to find an escape platform that is hidden a few millimeters under the water, each time starting from a different location in the pool ("Morris water navigation task," 2017), (see Figure 5). To measure human navigation, virtual platforms of the water maze were designed and used in cognitive human research (Goodrich-Hunsaker, Livingstone, Skelton, & Hopkins, 2010; Jacobs, Laurance, & Thomas, 1997). "Virtual versions of the water maze have shown behavioral and neurobiological similarities between humans and rodents in spatial memory acquisition" (Luna & Martínez, 2015, p. 284).

The Virtual Morris Water Maze (VMWM) is a virtual version of the classic MWM designed for humans (Mueller, Jackson, & Skelton, 2008) . In both versions, the subject must find a hidden platform. The subject thereby uses a navigation strategy to find the target. The hidden platform can normally be identified using a cognitive map that is constructed using distal cues, proximal cues, and geometric information from the environment. Several outcome measures are used to assess the efficiency of the subject's navigation in the virtual water maze, including (1) latency to find the target on each trial, (2) length of the search path, and (3) distribution of search time in each of the four quadrants of the arena on a probe trial, during which the target is absent from the arena (Thomas, 2003). Good navigation performance is indicated when the subject finds the hidden platform faster, searches for the platform in the correct quadrant, and uses more direct navigation paths on each subsequent trial. See Table 1 for details about the VMWM trials.

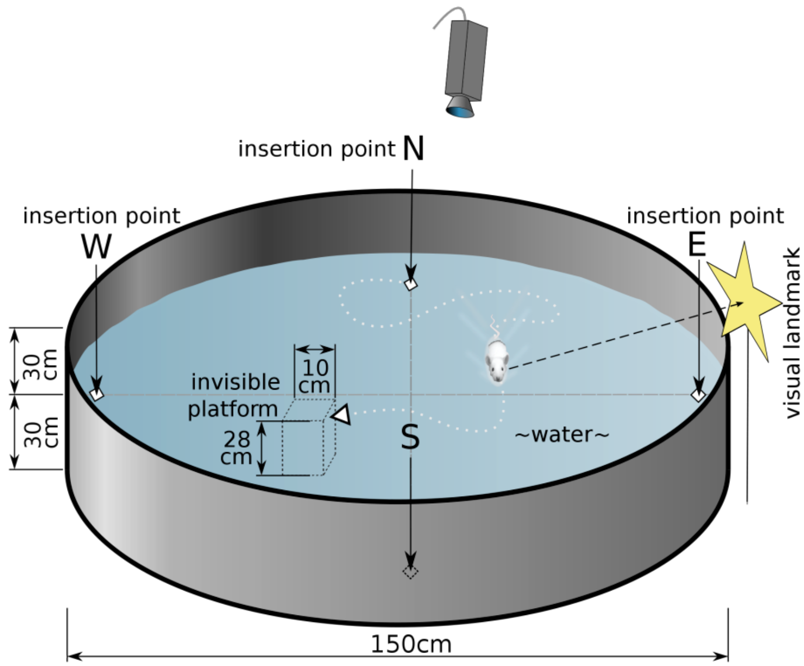


Figure 5 Drawing of the Morris water navigation test for rats
Source: Samueljohn.de, CC 3.0. Retrieved from
https://commons.wikimedia.org/wiki/File:MorrisWaterMaze.svg

Although the measures of spatial attention, mental rotation, and virtual navigation I used in this research have high validity and reliability, it is worth mentioning that spatial ability tests were originally developed for men during the World War I to test recruits' spatial abilities before admitting them into the military (Council, 2015). This may lower the validity of spatial ability tests to test women's spatial performance.

2.1.4 The Relationships between Spatial Abilities

In this section, I explain and summarize the research findings on the relationships between basic and complex spatial abilities. It is important to know if training one spatial ability could influence another.

2.1.4.1 Basic and Small-scale Spatial Abilities

As previously mentioned, Spence (2009) assumed that basic visual-perceptual and attentional processes like spatial attention ability provide the foundation for many types of higher spatial abilities (i.e. both small- and large-scale), such as mental rotation and navigation. Neuroscience literature supports this assumption in providing evidence that activation in the right posterior parietal cortex occurs when individuals perform attentional or mental rotation tasks, which indicates that there is a linkage between the two abilities (Behrmann, Geng, & Shomstein, 2004).

This relationship was evident in some AVG training studies. Feng (2007) found that participants' spatial attention and mental rotation performance improved after 10 hours of playing AVGs. Another study found that participants improved in both abilities after just 25 minutes of playing AVGs (Sanchez, 2012). This research lends credence to the assumption that an improvement in spatial attention may lead to an improvement in mental rotation ability.

Summary: Based on the neuroscience and cognitive literature, there is a linkage between spatial attention (basic ability) and mental rotation (small-scale ability). When one improves, the other improves as well.

Table 1 Description of trials administered in the VMWM

Type	Number of Trials	Description
Practice	1	The participants will navigate an empty pool to familiarize themselves with the controls and the environment.
Visible platform	4	The participants will teleport into one of the four randomly determined starting locations (NSEW) and search for the platform visible in one of the four quadrants. On subsequent trials, the starting location will be random and the platform will change location around all four quadrants.
Hidden platform	10	Participants will begin testing in a pseudorandomly determined starting location and will have three minutes to find the hidden platform, which will be always located in the SE quadrant. If they failed to find it, the platform will appear and a message will announce, "Time has expired. Please swim to the platform."

2.1.4.2 Small- and Large-scale Spatial Abilities

2.1.4.2.1 Partial Dissociation Model

As Hegarty et al. (2006) explained that when individuals perform a large-scale task, they need to encode, maintain and mentally transform spatial information (see Figure 6). Spatial information can be received visually, orally, or through touch. When spatial information is received visually, individuals rely on small-scale abilities to process the information. On the other hand, when spatial information is received orally or through touch, individuals rely on distinct spatial processes that are not part of small-scale spatial abilities. Hegarty et al.'s Partial Dissociation Model (see Figure 7) therefore proposed that small- and large-scale spatial abilities involve some common cognitive processes when processing visual spatial information, and that large-scale spatial abilities involve distinct processes not used by small-scale spatial abilities when information is received orally and through touch. Hegary only examined processes that are common to small- and large- scale spatial abilities and processes that are distinct to large-scale abilities. Examining cognitive processes that are distinct to small-scale abilities was beyond the scope of her research. Hegarty et al.'s (2006) main findings are summarized as follows:

1. The cognitive processes common to small- and large-scale spatial abilities are specific to spatial information processing.

2. The cognitive processes common to small- and large-scale spatial abilities are only specific to spatial representations constructed from visual inputs. Thus, measures of small-scale spatial abilities are very highly predictive of environmental learning from visual media, but less predictive of learning from the direct experience which occurs in environmental spaces and involves other sensory inputs such as kinesthetic inputs. The ability to process spatial information based on these other sensory inputs is in turn responsible for the dissociation that Hegarty et al. observed between measures of small-scale spatial abilities and measures of learning from direct experience.

Research findings indicating that wayfinding (a large-scale task) is correlated with mental rotation ability support Hegarty et al.'s model (Astur, Tropp, Sava, Constable, & Markus, 2004; Choi, McKillop, Ward, & L'Hirondelle, 2006; Saucier et al., 2002; Silverman & Eals, 1992). According to Hegarty et al. (2006), the correlation is more pronounced in simulated environments than in real environments, which explains why small-scale spatial abilities are a stronger predictor of navigation performance when learning is based on visual media (path coefficient = 0.87 with a 95% confidence interval of 0.74 to 0.99) rather than the moderate predictor of direct learning experience (path coefficient = 50 with a 95% confidence interval of 0.36 to 0.63).

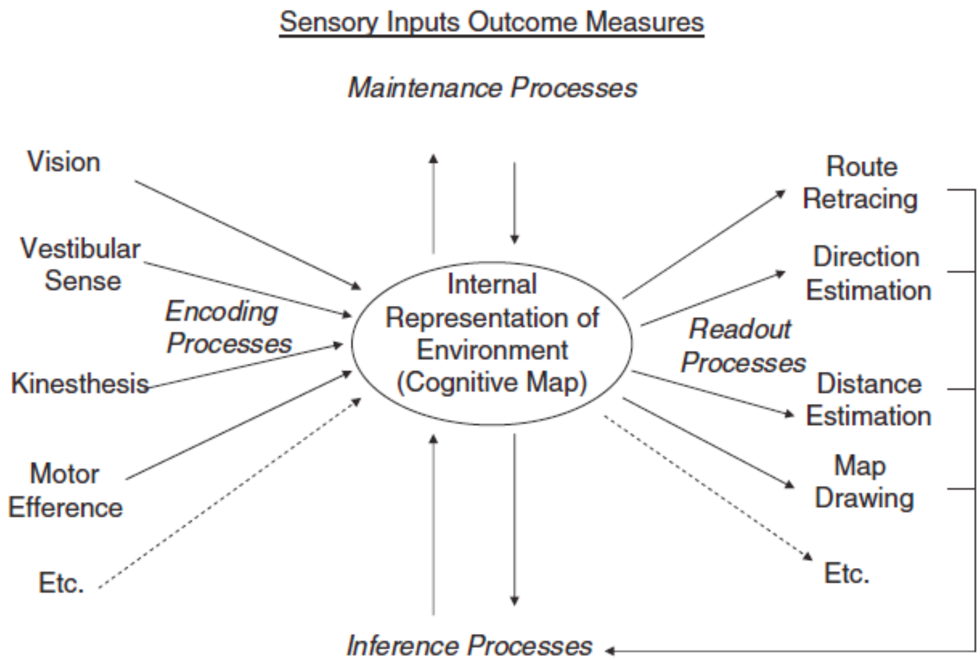


Figure 6 **The cognitive processes involved in constructing a cognitive map of a large-scale space**

Note: Reprinted from Intelligence, 34, Hegarty, M., Montello, D. R., Richardson, A. E., Ishikawa, & Lovelace, Spatial Abilities At Different Scales: Individual Differences In Aptitude-Test, 151– 176, 2006, with permission from Elsevier.

Summary:

1. Small-scale spatial abilities such as mental rotation is a strong predictor of navigation performance

2. There is a linkage between mental rotation (small-scale ability) and navigation (large-scale ability). When one improves, the other improves as well.

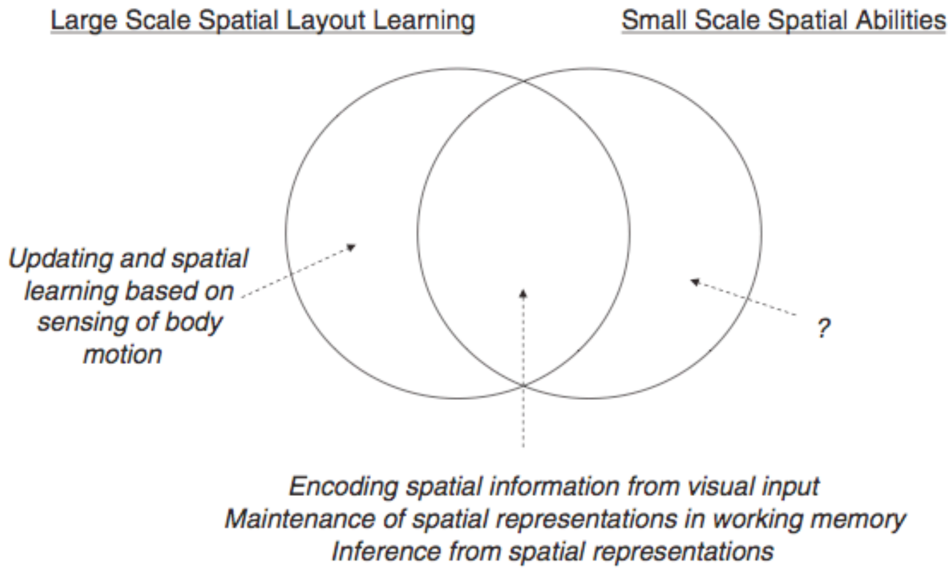


Figure 7 The Partial Dissociation Model
Note: Reprinted from Intelligence, 34, Hegarty, M., Montello, D. R., Richardson, A. E., Ishikawa, & Lovelace, Spatial Abilities At Different Scales: Individual Differences In Aptitude-Test, 151– 176, 2006, with permission from Elsevier.

2.1.5 Spatial Abilities and Sex

Sex differences in spatial abilities are well-documented in research on spatial cognition, which finds that on average, men are much stronger in several spatial abilities than women. The term, "sex" refers to the biological differences between males and females, such as differences in hormones or brain structure (Halpern, 2013; Levine, Foley, Lourenco, Ehrlich, & Ratliff, 2016). On the other hand, "gender" refers to the environmental differences between males and females such as the role of a male or female in society or gender identity (Halpern, 2013; Levine et al., 2016). Because I investigated the training of a low level (bottom-up) brain activity (i.e. spatial attention), which refers to a biological cause, I used the term "sex" to indicate the difference between men and women in this research.

In this section, I present research findings on sex differences in low-level, small-scale and large-scale spatial abilities.

2.1.5.1 Basic Spatial Abilities

Two studies have investigated sex differences in basic spatial abilities. The first was conducted by Kaufman , who explored the impact of working memory on sex differences in spatial cognition. Kaufman (2007) found a significant difference between the performance of male and female participants who took visuospatial working memory tests, favouring men. He also found that sex differences in visuospatial working memory account for some of the sex differences in mental rotation ability. Feng et al. (2007), who conducted the second study, found sex differences between the spatial attention of men and women, as measured by the UFOV. Again, the difference favoured men.

2.1.5.2 Small-scale Spatial Abilities

Findings have shown that men have greater strength in a number of small-scale spatial abilities. The largest and most consistent sex difference is in mental rotation, while there is a less prominent difference in spatial perception (Linn & Petersen, 1986; Voyer et al., 1995). Although these findings have led researchers to conclude that in general, men have better spatial abilities than women, some observed that women outperform men on certain spatial tasks, such as those that require object location memory (Silverman & Eals, 1992). Finally, spatial visualization has not proven to be a useful indicator of sex differences in spatial cognition, as research focusing on this subject has provided inconsistent results (Linn & Petersen, 1986; Voyer et al., 1995).

2.1.5.3 Large-scale Spatial Abilities: Virtual Wayfinding

Researchers have observed stylistic differences in how males and females represent both real and simulated environments. Men rely more on allocentric spatial representations and women rely more on egocentric spatial representations (Lawton, 1994, 1996; Montello, Lovelace, Golledge, & Self, 1999).This implies that men and women deploy different strategies for reaching a destination: an allocentric strategy for men and a egocentric strategy for women (Lawton, 1994, 1996; Montello et al., 1999). Female strategies tend to emphasize the use of proximal landmarks (i.e. buildings, traffic lights, and signs) as cues and they orient according to personal directions (i.e. left and right). In contrast, males tend to navigate according to distal cues (i.e. the sun and mountains) and distances (i.e. walk a mile towards the north), orient themselves according to absolute directions (i.e. cardinal directions), and use environmental geometric properties to support their navigation. Scholars assume that this sex difference in wayfinding may relate to sex differences in small-scale spatial abilities such as mental rotation and object location memory (Dabbs, Chang, Strong, & Milun, 1998). The rationale behind this assumption is that navigation behavior is highly associated with these abilities, particularly in virtual environments (Hegarty et al., 2006). One accepted explanation for the association is that when men wayfind, they orient themselves by using mental rotation to support their ability to mentally visualize, manipulate, and transform internal representations of space, which are stored as 3D maps in travelers' minds. Men usually pay attention to distal cues in their environment while using mental rotation ability to inspect their mental map. In contrast, when women wayfind, they generally pay attention to nearby cues in the environment and use object location memory to support their ability to remember and recall those cues.

Researchers assert that the allocentric navigational strategy is more efficient than the egocentric strategy, particularly in environments that lack distinct environmental cues (Lawton, 1994; Saucier et al., 2002). Saucier et al. (2002) explain that the allocentric strategy imparts greater flexibility to navigation, allowing Point 3 to be reached either indirectly via Point 2 or directly from Point 1. Spatial representation based on nearby cues is relatively rigid and sequential in that Point 3 follows from Point 2, which follows from Point 1. Allocentric strategies may also confer an advantage in situations where the navigator has left a specified route (i.e. taken a wrong turn). In these situations, navigators who use allocentric strategies can rely on cardinal directions to assess their position, whereas navigators using egocentric strategies may become disoriented due to the absence of familiar cues.

2.1.5.4 Egocentric Intelligence

Although much of spatial research has focused on the importance of allocentric point of view in spatial thinking, and it was found that allocentric strategy in wayfinding is more efficient comparing to egocentric, there is a gap in literature to investigate how egocentric point of view is useful in spatial reasoning, and what are the important spatial activities that they rely on it. Also, there is a lack of research to investigate the relationship between egocentric spatial intelligence and STEM (Science, Technology, Engineering and Mathematics) fields.

2.1.5.4.1 Wayfinding Efficiency

As previously indicated, men tend to be more successful navigators than women. In general, they not only travel faster, but also travel shorter route distances in navigating their way to target locations (Astur et al., 2004; Cánovas, Espínola, Iribarne, & Cimadevilla, 2008; Devlin & Bernstein, 1995). The sex difference in navigation is highly pronounced when a virtual environment contains only distal landmarks, and less pronounced – but still present – when a virtual environment contains both distal and proximal cues (Ross, Skelton, & Mueller, 2006).Some of the strongest evidence of sex differences in navigation has been generated by studies on VMWM navigation (e.g. Astur et al., 2004). As I mentioned in section 2.1.3.3, navigation performance is measured by how rapidly a subject locates the platform across a number of trials. Results from studies on the VMWM have demonstrated that female participants find it more difficult to navigate in the absence of proximal cues than male participants do.

In the previous sections, I discussed three spatial abilities: (1) spatial attention, (2) mental rotation, and (3) virtual navigation. Due to their importance, many studies investigated if these cognitive functions are trainable via videogame playing. In the coming sections, I provide a summary of those research findings, and I identify some gaps, which I address through my study.

2.2 Action Videogames and Spatial Cognition

Green and Bavelier (2003) were pioneers in research on the influence that playing AVGs has on lower-level (bottom-up) visual-perceptual and attentional processes in the human brain. They found that playing AVGs improves perceptual and attentional processes, and several other researchers have subsequently investigated their claim. In this section, I review studies that have focused specifically on whether playing AVGs enhances the lower-level attentional processes (i.e. spatial attention) that support spatial cognition.

2.2.1 Why First-Person-Shooter AVGs?

The following are some FPS game features that specifically target spatial attention ability (Walter R. Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Walter Richard Boot, Blakely, & Simons, 2011a; Oei & Patterson, 2014):

1. FPS players are often required to detect, track and respond to enemies quickly. These demands are coupled with the need to simultaneously respond to multiple stimuli in both the central and peripheral vision.

2. The need for players to quickly switch attention from one target to another is tremendously emphasized because enemies appear simultaneously or one after another in rapid succession.

3. Players have to resist being distracted by task-irrelevant stimuli regardless of how appealing these distractors are. Ignoring distractors leads to improved performance.

4. Failing to successfully perform any of the above three tasks may cause individuals to lose the game, which gives players the motivation to develop spatial attention.

2.2.2 The Hypothesis of Common Demands

Oei and Patterson (2014) used their review of studies that examined the effect of playing AVGs on lower-level information processing skills (i.e. visual-perceptual and attentional processes) as the basis for their “Hypothesis of Common Demands”. This hypothesis assumes that a specific skill transfer occurs if the demands of the game and the transfer task are the same or similar. In other words, to ensure that the transfer occurs and that the player’s performance of the transfer task improves, the demands of playing the game should be partially or wholly similar to the demands of performing the transfer task. For instance, some studies find that participants’ scores on the UFOV task improve as a result of playing FPS games (Feng et al., 2007; Spence et al., 2009).

As mentioned, successful FPS gameplay requires players to quickly detect and respond to ‘enemies’ as they move around the screen. This requirement is coupled with the need to simultaneously respond to details in central and peripheral vision – demands that are similar to the demands posed by the UFOV task (the transfer task). According to the hypothesis of common demands, playing FPS games can improve performance on the UFOV task because it requires players to exercise the attentional skills that underpin spatial attention ability. According to various learning theories (Schunk, 2012), this type of transfer is called a near transfer.

In contrast to a near transfer, a far transfer (general transfer) occurs if the game task and transfer task are not similar in terms of context, setting, and level of difficulty.

Far transfer tasks can be more difficult to perform than near transfer tasks because they involve more variables and cognitive processes. A "far transfer also requires more modification of the original knowledge than the near transfer to adapt to the target transfer condition" (Hung, 2013, p. 29). To date, there is a lack of empirical evidence as to whether a far (general) transfer has resulted from playing AVGs. This needs to be addressed in order to judge the effectiveness of training with action videogames. Generally speaking, training that results in a near transfer is good, but if it results in far transfer it is more effective.

A specific transfer effect occurs when a FPS game enhances spatial attention. In the present study, I measure mental rotation and navigation performance to determine whether the abilities developed by playing a FPS game are general. As the mental rotation and wayfinding tasks are not similar to the game task (playing the FPS), improvements in the performance of these tasks would indicate a general transfer. I assume this transfer will occur due to the relationships between spatial attention and mental rotation and between mental rotation and virtual navigation (as discussed in section 2.1.4). An improvement in spatial attention may therefore lead to an improvement in mental rotation, while an improvement in mental rotation may lead to an improvement in virtual navigation.

2.2.3 Review of AVGs Studies

There are two main streams of investigation that look at the effect of playing AVGs on spatial cognition abilities. The first stream consists of cross-sectional studies that compare AVG players and non-AVG players. These studies show that experienced AVG players outperform non-players in a variety of cognitive and perceptual tasks. However, they share a common limitation in terms of recruitment. As participants are generally recruited based on their gaming experience (expert vs. novice), it is uncertain whether they developed strong spatial skills by playing games or, conversely, became gamers because they already had strong spatial skills.

Training non-players to play AVGs is a more sound methodological approach to investigating the effects of gameplaying on spatial cognition, and this has been the focus of the second stream of studies, which are longitudinal. Their results are mixed, as some find that AVG training strengthens spatial cognition, while others find it does not.

2.2.3.1 Training Benefit Observed

Green and Bavelier (2003) found that the spatial attention of non-AVG players (as measured by the UFOV) improved after 10 hours of playing the AVG 'Medal of Honor' (compared to the puzzle game 'Tetris'), while participants in the control group did not exhibit any improvement.

The non-AVG players' spatial attention also improved when they performed a more challenging UFOV task that included trials with more distractors (Green & Bavelier, 2006). Such studies provide evidence that playing AVGs enhances spatial attention. Moreover, they also show that playing AVGs reduces gender differences in spatial attention, which highlights the importance of AVG training (Feng et al., 2007).

2.2.3.2 No Training Benefit Observed

Other studies have failed to replicate the findings of the previously mentioned studies. For example, Boot, Kramer, Simons, Fabiani, & Gratton (2008) and Murphy and Spencer (2009) provided 21 hours of AVG and non-AVG training to two groups of participants and did not find any difference in their improvement on the UFOV.

2.2.3.3 Reasons for Conflicting Findings on the Effect of AVG Training

These mixed and conflicting research findings raise a number of questions: Who is right? Whom should we believe? What should we do in terms of future research? What does it mean when experts disagree? Although the reasons for inconsistencies in the findings are unclear, one way to address them is to employ a more robust methodology to re-examine the training effect of AVGs on spatial attention. Methodology robustness can be increased by avoiding design elements that weaken the outcome of AVG training and by adopting design elements that can increase the strength of AVG training. Some researchers have noted that the placebo, practice, and test fatigue effect have weakened the methodologies employed in previous studies. As I propose to do in my research, it is important to employ design elements that maximize the transfer effect. I discuss this further in section 2.3.3

2.2.3.3.1 Placebo Effect

Boot, Simons, Stothart, and Stutts (2013) identified a methodological flaw in studies that found AVG training to be beneficial in terms of improvements to spatial cognition. They claimed that the control groups involved in previous studies did not prevent placebo effects. The placebo effect is an improvement that occurs as the result of factors other than experimental treatment factors. Boot et al. specifically stated that research on AVG training failed to control for the possibility that the experimental group's (AVGs condition) improvement in task performance resulted from the placebo effect of differential expectations. For example, differential expectations can occur when the control group and experimental group have different expectations of how much the training will improve their spatial attention. This can happen if participants in the control group realize that they are in the control group and not in the treatment group. Participants might realize that they are in the control group if they consider that playing the game is unlikely to improve their spatial attention because playing the game is different from performing the spatial attention task. In this case, they will then expect that their spatial attention will not be improved by playing the videogame. On the other hand, participants in the experimental group will expect that their spatial attention will improve as a result of playing an FPS, because the demands of playing the game are similar to the demands of performing the spatial attention task. The control group's expectation may negatively impact their performance, while the treatment group's expectation may positively impact their performance. This may lead researchers to draw incorrect conclusions about the benefits of training to the experimental group, in that the benefits may actually be the result of differential expectations.

In order to avoid a placebo effect due to differential expectations, I must ensure that participants in both the control and experimental groups have the same expectations about the effects of playing a videogame. Therefore, I need to measure differences in the two groups' perception of how the training task will impact their performance on the spatial ability test, as discussed in Chapter 4.

2.2.3.3.2 Practice Effect

Some previous research on AVG training did not find that control groups showed improvements in terms of any of the outcome measures, which conflicts with some learning theories (Ackerman, Kanfer, & Calderwood, 2010). As Boot, Blakely, and Simons argued (2011b), these theories assert that participants' performance on a cognitive task usually improves when they perform the task for a second time. However, the performance of control groups in some previous studies on AVG training did not improve when they repeated a task. This may indicate an unexpected lack of improvement in the control condition, rather than the benefit of training in the experimental group, as Boot et al. explain (2011):

> In order to draw strong inferences about training benefits, it is important to make sure that the control condition performs as expected and that it is not an anomalous baseline. A lack of improvement in the control condition is worrisome unless there is experimental evidence that a particular outcome measure typically does not show improvement upon retesting. (p. 4)

To address this issue effectively in my research, I must expect improvements to outcome measures for both the treatment and control group. At the same time, if the AVG training is beneficial, I should expect the members of the treatment group to improve more than the members of the control group.

2.2.3.3.3 Test Fatigue Effect

Studies that did not find AVG training to be beneficial may have had null findings due to the test fatigue effect. For example, participants in the research of Boot et al. (2008) performed 12 cognitive tasks before and after participating in AVG training. As Strobach, Frensch, & Schubert (2012) argued, participants may have been fatigued by the large number of transfer tasks they had to perform, which might have weakened the transfer effects.

To minimize the test fatigue effect in my research, I only used three tasks to measure spatial abilities. This number is comparable to the number of tasks used in studies that observed spatial cognition improvements as a result of AVG training (most used two or three tasks).

2.3 Training and Cognitive Knowledge Acquisition

Because my study investigated training effects and gain, it was important to know: (1) how the human mind works when acquiring skills and learning information; (2) how this information is processed in the working memory; and (3) how knowledge is stored and retrieved from long-term memory. The following sections address these three points.

2.3.1 Usefulness of Training

Training is considered to be useful if it achieves its intended goals. As mentioned at the start of the thesis, from an educational perspective, training needs to be effective and durable in order to be beneficial. Effective training means that: (1) trainees' skills will improve substantially by the end of the training session, and (2) trainees should be able to apply their improved skills to other tasks with similar cognitive demands to the training task (specific transfer) or to other tasks that are not similar to the training task (general transfer). Durability of training means that trainees should be able to retain the knowledge they gained from their training in their long-term memory for future use. These three outcomes (improving skills, transferring skills, and retaining knowledge) are essential if a training task is to be useful.

It should be noted that no study to date has investigated the general transfer effect of AVGs or provided empirical evidence of the durability of AVG training. My research addresses this gap. In order to determine whether training with FPS is useful (effective and durable) and to answer my research questions, I investigate the following (see Figure 8):

1. Whether trainees' spatial attention improves after FPS training (specific transfer).

2. Whether improvements to performance on spatial attention tasks leads to improvements in performance on mental rotation tasks (general transfer). This is pertinent to the hypothesized relationships between spatial attention (a basic spatial ability) and mental rotation (a small-scale ability) that were discussed in section 2.1.4.

3. Whether improvements to performance on mental rotation tasks (small-scale spatial ability) lead to improvements on virtual wayfinding tasks (large-scale spatial ability), which is indicative of the general transfer effect. This is pertinent to the relationships between mental rotation (small-scale spatial ability) and virtual wayfinding (large-scale ability) discussed in section 2.1.4. I would like to examine whether improvement in mental rotation will lead to improvement in virtual wayfinding (general transfer).

4. Whether training is durable. Durability is achieved if participants maintain their enhanced spatial ability level for at least a month after the training ends.

5. Whether there are sex-related differences in the training and transfer effect.

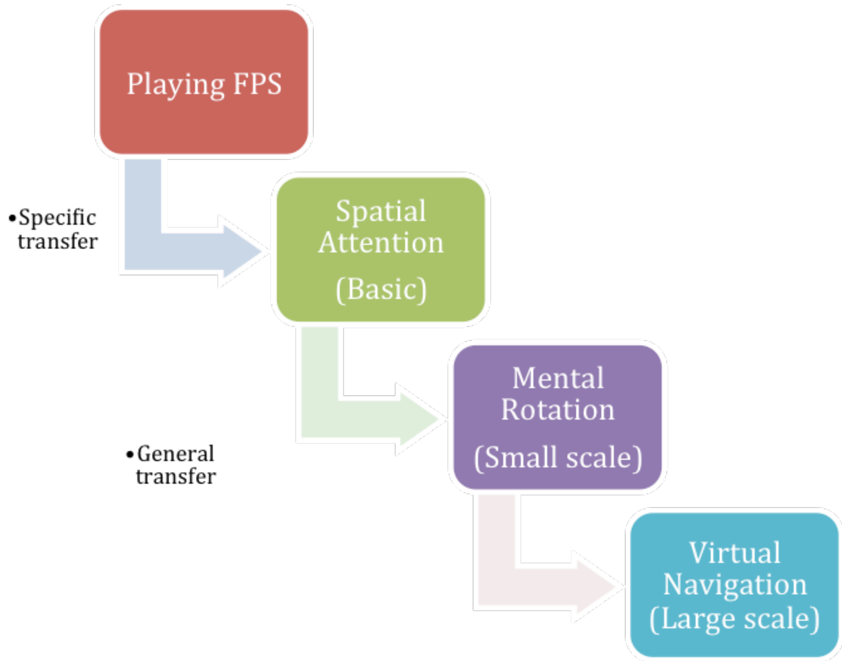


Figure 8 Specific and general transfer of playing FPS

2.3.2 Cognitive Knowledge Acquisition

2.3.2.1 Declarative and Procedural Knowledge

According to Anderson's (1996) Adaptive Control of Thoughts Theory (ACT), when individuals learn a cognitive task, the initial type of knowledge they acquire is declarative knowledge, which is the first major stage in the development of a cognitive skill. Declarative knowledge "may be thought of as 'what' or rules, definitions, or examples" (Goldwater & Zahller, 2010, p. 63) . It is acquired by performing tasks such as reading, following instructions, and learning rules. Individuals usually possess this type of knowledge when they start to learn a new cognitive task. Although it is useful, it does not on its own enable individuals to become skilled at the new tasks. For example, a novice video game player can play a game by following general rules, but this alone will not make them skillful at playing the game (e.g. reduce the time needed to accomplish tasks or navigate through the game or achieve a high score). In order to become more skilled at a new cognitive task, the learner must transform declarative knowledge into procedural knowledge, which "may be thought of as 'how' or the direct application of declarative knowledge to analysis or problem solving" (Goldwater & Zahller, 2010, p. 63).This is the final major stage in the development of a cognitive skill. Experts in a variety of areas posses this type of knowledge, which enables them to perform advanced problem-solving tasks. The process of transitioning from declarative to procedural knowledge is called knowledge compilation. The learner transforms declarative knowledge to mental schemas in long-term memory, which contributes to the development of a cognitive ability. To accomplish this, learners need to make the necessary effort to learn and remain motivated to learn. When the cognitive skill has been learned and stored in long-term memory as cognitive knowledge, individuals become able to quickly, automatically and unconsciously retrieve that knowledge and recall it to working memory in order to perform certain problem-solving tasks. Goldwater & Zahller (2010) state:

> When the learner realizes that the procedural knowledge applicable to one domain may be relevant in whole or part to another domain, transfer learning occurs . . . and that human working memory is limited, whereas long-term memory is not; thus, transferring knowledge and skills to long-term memory leads to much greater and deeper learning, improved performance, and the development of expertise through the ability to recognize the applicability of existing schemas to new problems. (p. 64)

According to ACT, if my participants are able to store a spatial skill gained from the videogame training as procedural knowledge, they will be able to maintain it for a period of time, and able to retrieve it when needed.

2.3.3 Maximizing the Transfer Effect

In this section, I discuss some of the factors that may maximize the transfer effect in my research experiment.

2.3.3.1 Effort and Motivation

In order to maximize the transfer effect, I need to ensure that my research participants successfully make the transition from declarative knowledge to procedural knowledge (see Figure 6). As stated, making the transition requires both effort and motivation. Choosing an FPS game that is challenging in terms of locating 'enemies' will help to ensure that participants make an effort to learn how to play the game well and support the enhancement of spatial attention.

With respect to motivation, it was important to find less gender-biased FPS game that women can enjoy just as men do. This motivated my female participants to strive to improve their game playing skills. I reviewed games websites to find an FPS game that appeals to women.

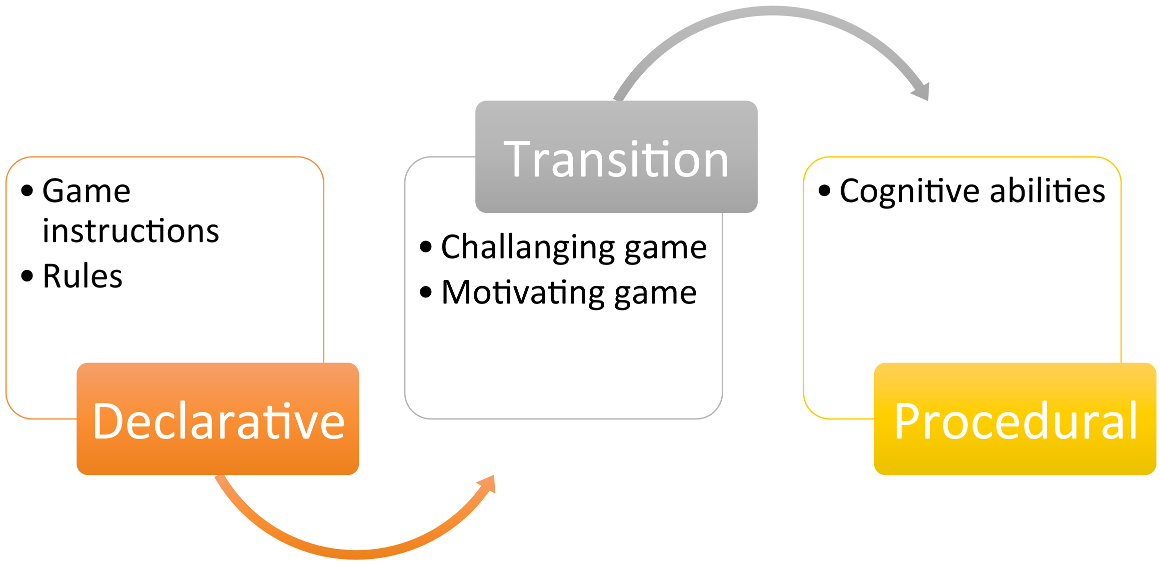


Figure 9 Knowledge Transition

2.3.3.2 The Delivery of Training

Some studies have examined how the type of computer training that is delivered (massed vs. distributed) influences learning. Training is considered to be massed when it involves an amount of rest time that is considered short, and to be distributed when it involves an amount of rest time that is considered long. Cherney (2008) found that massed training enhances mental rotation performance more significantly than distributed training. Her research involved comparing the performance of participants who completed three 1-hour practice sessions over more than two weeks (distributed training) to the performance of participants who completed three one-hour training sessions within three days (massed training). The findings suggest that the massed delivery of training may maximize the transfer effect. I would therefore like to provide my participants with massed training. Accordingly, I asked them to complete three 50-minute practice sessions a week to be completed in a maximum of five weeks.

2.3.3.3 Type of Action Game

My criteria for choosing a game that maximized the transfer effect are as follows:

1. It should be a fast-paced FPS game which has a higher rate than others in terms of the speed and number of ‘enemies’ appearing simultaneously in both central and peripheral vision fields.

2. It should be a gender-unbiased FPS game that appeal equally to men and women.

3. The game tasks should challenge participants and prompt them to put effort into learning.

2.4 Research Questions and Hypotheses

In my study, I examine the effect of action video game training using sound methodology. Also, I investigate if navigation can be improved by videogame training. Finally, I study whether the training reduces sex differences in the three spatial abilities (UFOV, MR, and VG). Therefore, my primary research questions and hypotheses were as follows:

Training Effect: Effectiveness of Training Gain

Research Question 1: Does playing a FPS game improve spatial attention ability?

Hypotheses:

1. Playing FPS games will improve spatial attention as measured by the UFOV task.

2. Female players will exhibit more spatial attention development than male players.

Transfer Effect: Effectiveness of Training Gain

Research Question 2: Does playing a FPS game enhance users’ mental rotation and virtual navigation abilities, which are indicative of their general ability to perform complex spatial tasks that place considerable demands on their attention?

Hypotheses:

1. Improvements in spatial attention will lead to improvements in the performance of mental rotation tasks.

2. Improvements in mental rotation will lead to improvements in the performance of virtual navigation tasks.

Durability of the Transfer Effect: Durability of Training Gain

Research Question 3: If improvement occurs in any or all of the three spatial abilities (spatial attention, mental rotation, and virtual navigation), is it sustained over the short term (one month)?

Hypothesis

If improvement occurs in any or all of the three spatial abilities (spatial attention, mental rotation, and virtual navigation), it will be sustained over at least one month.

Chapter 3

Pilot Study

3.1 Overview

The purpose of conducting a pilot experiment of the full-scale research project (Study 1+ Study 2) was to examine its feasibility, predict its session time, refine the game selection criteria, and improve upon its study design. The pilot study is mixed quantitative and qualitative approach between groups to measure the expectations and motivations of participants after they had played either an action or a non-action video game for 15 minutes each. The experimental procedure of the pilot study was a duplicate of the proposed procedure of study 1 (the preliminary experiment), where the purpose of study 1 was to find two games (one action and one non-action) that have equivalent expectation and motivation effects on players. It is important in order to distinguish the training effect from the expectation and motivation effect, if training effect occurs as a result of playing the games. In other words, the purpose of the preliminary experiment is to enable me to identity appropriate videogames for the training experiment (study 2), because the training study is the focus of this research.

3.2 Methodology

This is a mixed method experiment between groups to compare two games, *Call of Duty* (an AVG) and *Oddworld: New 'n' Tasty!* (a NAVG game), in terms of their expectation and motivation effect on players. The dependent variables in this study are expectation and motivation, the data for which were collected quantitatively. Also, I used a qualitative method to learn more about player's expectations.

3.2.1 Participants

Twelve participants engaged in in the pilot study. Their ages ranged from 19 to 39 years old with a mean age of 25.67 years. Participants have varied gaming experience including habitual, occasional, and non-videogame playing history. They were recruited through a variety of methods, including the SFU Research Participation

System (SONA), online mailing lists, email invitations, and face-to-face invitations. There were some selection criteria to recruit participants for my pilot study:

1. Participants must be fluent in spoken and written English.
2. Participants must be between 18 and 39 years of age.
3. Participants must have never had brain injuries or cognitive disorders.

Those criteria were posted on the study invitations and were verified before admitting each participant to the study.

3.2.2 Setting

To run the experiment and collect data, study sessions were organized in an isolated room (Room 3916) in lab 3910 in the School of Interactive Arts and Technology (SIAT) in the Surrey campus of SFU. When a session was in progress, I left a “Do Not Disturb” sign to ensure that no one interrupted the study session while it was going. The lab was equipped with a video-game console (PlayStation 4), a computer (Windows 10), and a display unit. Both games were played on the PlayStation console. I used the computer to run three video demos to demonstrate the three spatial tasks of interest to the participants (i.e. UFOV, MRT, and VN). Each study session accommodated a single participant at a time.

3.2.3 Materials

3.2.3.1 Demographics Questionnaires

To collect general information about the participants (e.g. sex, age, occupation), and their academic information, I required that participants fill out the demographic questionnaires used in Adam’s study (2013). Adam is a game researcher who studied the effect of games on cognition.

3.2.3.2 Prior Videogame Experience Questionnaire (PVE)

I used the Prior Videogame Experience Questionnaire (PVE) (Adam, 2013) to capture participants’ prior gaming experience. My pilot study invited participants with a range of gaming experience, including habitual, occasional, and non-videogame players. an example of a question in the PVE questionnaire is “How many hours a week do you typically play action video games?”

3.2.3.3 User Expectation Measure

The user expectation measure is used to report whether participants expect their performance on three spatial tasks would improve as a result playing the assigned video game. I used Boot's Likert Scale questionnaire (2013) to measure user expectations. I also interviewed (written interviews) to learn more about their expectations. The objective of this interview process is to refine the game selection criteria. The interview included both closed- and open-ended questions. I used the results of the written interview to inform the criteria for selecting suitable games for the preliminary experimental study (Study 1).

Data collected using Boot's questionnaire were analyzed using an independent-samples t-test. Interview answers collected using the closed-ended questions were analyzed using Fisher's exact test, whereas answers collected using the open-ended questions were analyzed using a thematic analysis.

3.2.3.4 User Motivation Measure

Participants were asked to rate their motivation using the Intrinsic Motivation Inventory (IMI) and the Player Experience Needs Satisfaction (PENS) Metrics created by Ryan & Deci (2000). The IMI instrument "is a multidimensional measurement device intended to assess participants' subjective experience related to a target activity in laboratory experiments". This measurement tool has six subscales and uses a 7-point Likert scale with responses from 1= "not at all true" to 7= "very true". I used only one of the subscales, 'interest/enjoyment', to assess motivation. Regarding the PENS scale, it is a 7-point Likert scale with responses from 1= "not at all true" to 7= "very true" that has three subscales: competence, autonomy and relatedness. Data collected using this measure were analyzed using an independent-samples t-test.

3.2.3.5 The Action Game

General Criteria for selecting the Game

1. The game should be motivating to play.
2. The game should be a first-person shooter game (FPS).
3. The game should be fast-paced.

4. The game should be male- and female-friendly.

3.2.3.5.1 The Selected Game

Based on the above criteria, I selected *Call of Duty* (*CoD*). *CoD* is a first-person shooter video game series released in 2003. The series was developed by Infinity Ward and Treyarch and owned by Activision. “In the series, the player assumes the role of an infantry soldier set in various settings, from World War II and the Cold War to modern times and the near-future” (“Call of Duty,” n.d.). According to Activision, “about a fifth of Call of Duty’s 40 million monthly players are female and that percentage is rising, which is why playable female characters are being added for the first time in Ghosts.”

3.2.3.6 The non-Action Game

3.2.3.6.1 General Criteria for selecting the Game

1. The game should be motivating to play.
2. The game should provide no or insignificant spatial training.
3. The game should be male- and female-friendly

3.2.3.6.2 The Selected Game

Based on the above criteria, I selected *Oddworld: New 'n' Tasty*! (*Oddworld*). The game is a platform video game developed by Just Add Water and published by Oddworld Inhabitants The video game was released in 2014. In the game, the player assumes the role of Abe, a happy floor waxer in Oddworld's plant. Abe “stumbles across his boss's secret plan to turn the factory's slave labor force into the latest in the RuptureFarms Tasty Treats line of novelty meat snacks. Abe now has to save his own skin from the grinders, but simply escaping the flesh farm is only the start of his Oddysee - for many dangers await Abe on his journey to discover his destiny” (“Oddworld,” n.d.).

3.2.4 Procedure

The scheduled duration of each study session was one hour. However, participants were allowed unrestricted time at the start of a session to get familiar with game. Familiarization was an important factor that could influence the motivation for playing the game. Allowing participants enough time to familiarize themselves with the game was based on an assumption that unfamiliarity with the game mechanics might bias their self-reporting of motivational responses.

Participants were randomly assigned to two groups. Both groups were balanced in terms of sex and past videogame experience. The first group played the action videogame (*CoD*) and the second group played the non-action videogame (*Oddworld*). I had between groups design for my pilot because the training study is a between group experiment. Then, participants signed the consent forms, provided relevant demographic data, and identified prior gaming experience. After that, the participants were asked to become familiar with the assigned game. They had no time restriction to do this. After they familiarized themselves with the game, they played it for 15 minutes. After playing, they were asked to rate their motivation using the IMI and PENS questionnaire. Then, participants were asked to watch video demos that demonstrate three spatial abilities of interest: 1) spatial attention, 2) mental rotation, and 3) virtual navigation. After this, they completed an expectation questionnaire and were interviewed as to explore whether they expected that their performance on the three spatial tasks would improve as a result of playing the videogame, and why.

3.3 Results

3.3.1 Expected Session Time

The average duration of a study session was around 1 hour, with a maximum duration of 1 hour 20 minutes. Not many participants needed prolonged time to familiarize themselves with the game, even though some of them were non-videogame players, which implies that the games I chose — *CoD* and *Oddworld*— did not require unreasonable time to get familiar with. I added this as a minor criterion in selecting games. This criterion indicates that choosing a game that is not complicated to get familiar with is more likely to maintain player's motivation and will not require a study session of unreasonable duration.

3.3.2 The Demographic Questionnaire

I modified Adam's demographic questionnaire to capture more information about my participants, e.g., for more details about their education level and major.

3.3.3 Player Types

My pilot-study invited participants with varied gaming experience including habitual, occasional, and non-videogame players, but the original PVE questionnaire did not identify occasional players. I, therefore, adapted some of the items, for example, by adding the words ‘other’ and ‘specify’. Here are the types I identified:

Non-videogame Players

Participants who do not play videogames. PVE does identify non-videogame players.

Non-action Videogame Players

1. Habitual Players: Participants who play non-action videogames regularly. The PVE identifies the habitual non-action videogame players.

2. Occasional Players: Participants who play non-action videogames occasionally. The PVE did not identify occasional non-action videogame players.

Action Videogame Players

1. Habitual Players: Participants who play action videogames regularly. The PVE identifies habitual action videogame players.

2. Occasional Players: Participants who play action videogames occasionally. The PVE does not identify occasional action videogame players.

3.3.4 Motivation Analysis

Motivation scores (enjoyment, competence, autonomy, and relatedness) were normally distributed, as assessed by Shapiro-Wilk's test ($p > .05$), and there was homogeneity of variances, as assessed by Levene's test for equality of variances ($p = .174$). I used independent t-tests to analyze the data. Motivation has four subscales: (a) enjoyment, (b) competence, (c) autonomy, and (d) relatedness. I analyzed each subscale separately. Results showed that there is no significant difference between the groups (AVG vs. NAVG groups). Further, the analysis showed a non-significant difference between sexes (for all four variables).

3.3.4.1 Enjoyment Analysis

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between the two groups. The subjects in the AVG condition demonstrated scores on enjoyment that were similar to those shown by subjects in the NAVG condition (for AVG group, Mean = 5.2, SD = 0.5; for NAVG, Mean = 5.4, SD = 0.5).

3.3.4.2 Competence Analysis

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between the two groups. The subjects in the AVG condition demonstrated scores on competence that were similar to those shown by subjects in the NAVG condition (for the AVG group, Mean = 3.9, SD = 0.6; for the NAVG group, Mean = 4.2, SD =0.6).

3.3.4.3 Autonomy Analysis

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between the two groups. The subjects in the AVG condition demonstrated scores on autonomy that were similar to those shown by subjects in the NAVG condition (for AVG group, Mean = 4.2, SD = 0.6; for NAVG, Mean = 5.1, SD =0.6).

3.3.4.4 Relatedness Analysis

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between the two groups. The subjects in the AVG condition demonstrated scores on relatedness that were similar to those shown by subjects in the NAVG condition (for AVG group, Mean = 3.2, SD = 0.6; for NAVG, Mean = 3.8, SD =0.6).

3.3.5 Expectation

3.3.5.1 Boot's Likert Scale

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between the two groups. The subjects in the AVG condition demonstrated scores on expectation that were similar to those shown by subjects in the NAVG condition (for AVG group, Mean = 4.8, SD = 0.5; for NAVG, Mean = 5.3, SD =0.5).

3.3.5.2 Closed-ended Questions (Yes/No Questions)

To test if the expectation differed between the two groups, results were analyzed using Fisher's exact test. The fact that p value is not significant confirms that players' expectations were not significantly different across the conditions.

3.3.5.3 Open-ended Questions (Why Questions)

I used a thematic analysis to generate themes, where those themes were used to generate additional criteria(see Table 2 for a complete list). The following is an example of how I used a theme in generating a game selection criterion. When I analyzed the virtual navigation answers, 53% of the answers showed that participants expected that the NAVG would improve their virtual navigation skill if the game character moved from one point to another, which was themed as 'locomotion' in my analysis. On the other hand, 23% of the answers showed that participants expected the game would improve their virtual navigation skills if the game environment was moulded in a 3D form, because the virtual water maze task they watched in the video was performed in a 3D space. This was themed as a space dimension. From these answers, we can see that locomotion is more important than the space dimension in the participants' decision-making process. As a result, in choosing games, I should select a game that has a moving character, and it should not be fixed in its location. In addition to thematic analysis, two researchers (I and a graduate student from SIAT) employed inter-rater reliability to verify coding decisions. The inter-rater reliability coefficient Kappa was .78, which showed a substantial agreement.

Table 2 A list themes used to code user responses.

Term	Researcher Description
Object Identifying	The process of locating and identifying an object such as a target in the game. This manner of locating and identifying objects is sometimes important to advance in the game.
Locomotion	The movement from one place to another.
Mental Manipulation	The mental manipulation (e.g. rotation) of the game objects in the player's mind.
Object Dimension	Games object can have the form of a 3D object or 2D image.
Reaction time	Amount of time it takes to respond to a stimulus.
Object Recalling	The ability to recall an object situated in a previously visited location in the game.
Space Dimension	The game environment is generated in the form of either 2D or 3D space.

3.4 Discussion

3.4.1 Expectation and Motivation

The results provided empirical support that there is no statistically significant difference in the expectation and motivation levels inspired by the video games *CoD* and *Oddworld*. Therefore, I chose both games to be tested again in Study 1 (detailed in chapter 4) with a larger sample (35 participants) to ensure that I could replicate these results (i.e. equal expectation and motivation) before using the games in the training experiment (detailed in chapter 5).

3.4.2 Player Types

The pilot studies revealed three main types of videogames players: (1) non-videogame players, (2) non-action videogame players (habitual and occasional), and (3) action videogame players (habitual and occasional). Occasional players had difficulty in reporting their gaming experience using Adam's questionnaire (2003). Therefore, the questionnaire was modified to better capture the responses of all the types of videogames players. This is important to help me balance the players' past gaming experience in study 1 and recruit non-videogame players and non-action videogame players (habitual and occasional) to participate in the training study of my research (Study 2). I need to make sure my participants for study 2 have no prior spatial skills gained as a result of playing FPS games because it may bias the results of the training study (study 2).

3.4.3 Additional Criteria for the Selection of the AVG and Non-AVG

Analyzing the answers to the open-ended questions for expectation has helped me to identify some criteria that may predict which type of games can generate an equal expectation between the conditions. Based on the analysis of the participants' responses to the open-ended questions, the following additional criteria were derived for selecting the games for the preliminary experimental study.

1. The games should be easy to become familiar with. This is more likely raise motivation and will not require an unreasonable duration of testing session.
2. The games should have many objects. Participants believed that identifying many objects would improve their spatial attention. This criterion is derived from responses to the spatial attention question where the common theme was 'Object Identifying'.
3. The games should support locomotion. It is worth mentioning that while locomotion does not necessarily enhance navigation.
4. It is highly recommended if the games are 3D. This criterion is derived from responses to the virtual navigation question where the common themes were 'Locomotion' and 'Space Dimension'.
5. Regarding mental rotation, participants will more likely expect that both games will not improve their mental rotation, due to the lack of similarity between the videogames environment and the mental rotation task.

3.4.4 Selected Game

I decided to use *CoD* and *Oddworld* for the preliminary experiment since they fulfill both my initial and additional criteria.

Action Game

Call of Duty (any series)

Non-Action Game

Oddworld: New 'n' Tasty!

3.4.5 Summary of Modifications

The results of the pilot test helped me to:

1. Predict the session time for Study 1 (one-hour session time).

2. Improve the game usage questionnaire to capture different types of videogame players as described in section 3.4.2.

3. Select the games for Study 1.

4. Improve and refine the criteria of the games selection for present and future use, as described in section 3.4.3. Those criteria were first generated based on findings from previous research, then refined after analyzing the participants' responses to the interview questions. I can conclude that I have created firm criteria that could be used by other researchers in similar studies.

5. The results of the pilot study showed that *CoD* (a FPS-AVG game) and *Oddworld* (a NAVG game) are suitable to be tested in the preliminary experiment study.

Chapter 4

Study 1: Preliminary Game Validation

4.1 Overview

The purpose of conducting this preliminary experiment was to examine whether the games I selected (based on the criteria in the pilot study in Chapter 3) were appropriate videogames for the training experiment (study 2). The games are suitable for the training study if and only if they provide players equally with both an expectation for improvement, and a motivation to play the games.

4.2 Methodology

The methodology used for this study was a between-groups experiment where the independent variables were the game condition and sex and the dependent variables were player's motivation and expectation.

4.2.1 Participants

Thirty-five participants participated for study 1 (18 males and 17 females). Ages ranged from 19 to 35 years old with a mean age of 22.80 years. Participants had varied gaming experience including habitual, occasional, and non-videogame playing history. They were recruited through a variety of methods, including online mailing lists, email invitations, and face-to-face invitations. There were some selection criteria to recruit participants for this study:

1. Participants must be fluent in spoken and written English.
2. Participants must be between 18 and 39 years of age.
3. Participants must have never had brain injuries or cognitive disorders.

Those criteria were posted on the study invitations, and were verified before admitting participants to the study.

4.2.2 Setting

To run the experiment and collect data, study sessions were organized in an isolated room (Room 3916) in lab 3910 in the School of Interactive Arts and Technology (SIAT) in the Surrey campus of SFU. When a session was in progress, I left a “Do Not Disturb” sign to ensure that no one interrupted the study session while it was ongoing. The lab was equipped with a video-game console (PlayStation 4), a computer (Windows 10), and a display unit. Both games were played on the PlayStation console. I used the computer to run three videos to demonstrate the three spatial tasks of interest to the participants (i.e. UFOV, MRT, and VN). Each study session accommodated a single participant at a time. The scheduled duration of each study session was one hour. However, participants were allowed unrestricted time at the start of a session to become familiar with game.

4.2.3 Materials

4.2.3.1 Demographics Questionnaires

To collect general information about the participants (e.g. sex, age, occupation), and their academic information, I asked that participants to fill out the modified version of the demographic questionnaires used in Adam’s study (2003).

4.2.3.2 Prior Videogame Experience Questionnaire

I used the Modified Prior Videogame Experience Questionnaire (MPVE) to capture participants’ prior gaming experience. An example of a question in the MPVE’s questionnaire is “How many hours a week do you typically play FPS video games”.

4.2.3.3 User Expectation Measure

To report whether players expect that their performance on three spatial tasks would improve as a result of playing the assigned video game. I used Boot’s Likert scale questionnaire (2013) to measure user expectations. Data collected using Boot’s questionnaire were analyzed using an independent-samples t-test.

4.2.3.4 User Motivation Measure

Participants were asked to rate their motivation using IMI and PENS scales created by Ryan & Deci (2000). The IMI “is a multidimensional measurement device intended to assess participants’ subjective experience related to a target activity in laboratory experiments". This measurement tool has six subscales and uses a 7-point Likert scale with responses from 1= "not at all true" to 7= "very true". I use only one of the subscales, 'interest/enjoyment', to assess motivation. Regarding the PENS metric, it is a 7-point Likert scale with responses from 1= "not at all true" to 7= "very true" that has three subscales: competence, autonomy and relatedness. Data collected using both scales were analyzed by an independent-samples t-test.

4.2.4 Procedure

I had 35 participants randomly assigned to two groups. The first group played an action videogame (*CoD*) and the second group played a non-action videogame (*Oddworld*). Both groups were balanced in terms of sex and past videogame experience. First, participants signed the consent form, identified prior gaming experience, and provided relevant demographic data. Second, the participants were asked to get familiar with the assigned game. They had no time restriction to do this. Third, they played the videogame for 15 minutes. After playing, they were asked to rate their motivation using the IMI and PENS questionnaires. Fourth, participants were asked to watch videos that demonstrated three spatial abilities: (1) spatial attention, (2) mental rotation, and (3) virtual navigation. Both groups then reported (using Boot's questionnaire) whether they expect their performance on three spatial tasks would improve as a result of playing the video game.

4.3 Results

4.3.1 Session Time

The average duration of a study session was around 1 hour. No participants needed more than 15 minutes to familiarize themselves with the game

4.3.2 Motivation Analysis

Motivation scores (enjoyment, competence, autonomy, and relatedness) were normally distributed, as assessed by a Shapiro-Wilk's test ($p > .05$), and there was homogeneity of variances, as assessed by Levene's test for equality of variances. I used independent t-tests to analyze the data. Motivation has four subscales: (a) enjoyment, (b) competence, (c) autonomy, and (d) relatedness. I analyzed each subscale separately. Results showed that there is no significant difference between the groups

(AVG vs. NAVG groups). Further, the analysis showed a non-significant difference between sexes (for all four variables).

4.3.2.1 Enjoyment Analysis

Game Condition

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between the two groups. Subjects in the AVG condition demonstrated scores on enjoyment that were similar to those shown by subjects in the NAVG condition (for AVG group, Mean = 5.1, SD = 0.3; for NAVG, Mean = 4.8, SD =0.3).

Sex

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between sexes. Females demonstrated scores on enjoyment that were similar to those shown by males (for females, the Mean = 5.1, SD = 0.3; for males, the Mean = 4.8, SD =0.3).

4.3.2.2 Competence Analysis

Game Condition

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between the two groups. Subjects in the AVG condition demonstrated scores on competence that were similar to those shown by subjects in the NAVG condition (for AVG group, the Mean = 4.9, SD = 0.3; for NAVG, the Mean = 4.3, SD =0.3).

Sex

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between sexes. Females demonstrated scores on competence that were similar to those shown by males (for females, the Mean = 4.2, SD = 0.3; for males, the Mean = 5.1, SD =0.3).

4.3.2.3 Autonomy Analysis

Game Condition

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between the two groups. Subjects in the AVG condition demonstrated scores on autonomy that were similar to those shown by subjects in the NAVG condition (for AVG group, the Mean = 4.2, SD = 0.3; for NAVG, the Mean = 4.6, SD =0.3).

Sex

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between sexes. Females demonstrated scores on autonomy that were similar to those shown by males (for females, Mean = 4.7, SD = 0.3; for males, Mean = 4, SD =0.3).

4.3.2.4 Relatedness Analysis

Game Condition

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between the two groups. Subjects in the AVG condition demonstrated scores on relatedness that were similar to those shown by subjects in the NAVG condition (for AVG group, Mean = 3.9, SD = 0.4; for NAVG, Mean = 3.7, SD =0.4).

Sex

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between sexes. Females demonstrated scores on relatedness that were similar to those shown by males (for females, Mean = 4.1, SD = 0.4; for males, Mean = 3.4, SD =0.4).

4.3.3 Expectation

4.3.3.1 Boot's Likert Scale

Results were analyzed using an independent-samples t-test. This analysis showed a non-significant difference between the two groups. Subjects in the AVG condition demonstrated scores on expectation that were similar to those shown by subjects in the NAVG condition (for AVG group, the Mean = 4.7, SD = 0.2; for NAVG, the Mean = 4.7, SD =0.2).

4.4 Discussion

4.4.1 Expectation

The objective of this study is to make sure that the active-control game (*Oddworld* condition) possesses an equivalent expectation of improvement as the treatment group (*CoD* condition) to ensure that both groups do not hold different expectations for the effectiveness of the playing the videogames. In his paper, Boot (2013) identified a methodological flaw in studies that found AVG training to be beneficial in terms of improvements to spatial cognition. He claimed that previous studies did not rule out this expectation effect, which may have weakened its design and findings. Also, he provided a guideline on how to minimize this effect. This is the first study that adequately follows Boot's guidelines, see figure 10. As a result, my active-control group received a similar intervention that does not specifically target participants' spatial cognition. Both games were picked based on the specific selection criteria discussed in Chapter 3. My study results showed that the participants who played *Oddworld* expected the same levels of improvement on each outcome measure as those who played *CoD*.

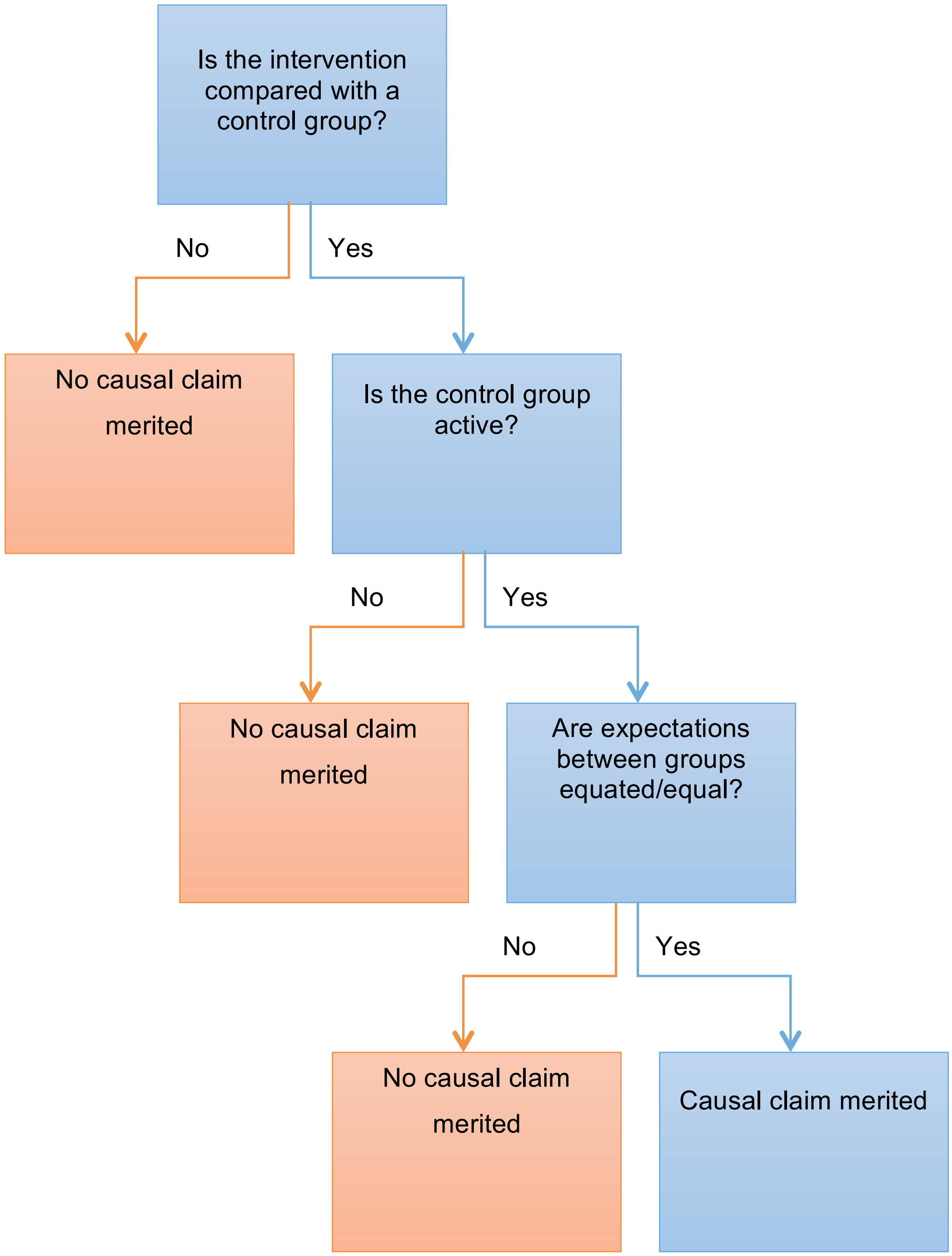


Figure 10 Boot et al.'s (2013) guidelines in designing a study in which the experimental group improves from pretest to posttest (reprinted with permission)

4.4.2 Motivation

The results provided empirical support that there is no statistically significant difference in motivation levels for the video games *CoD* and *Oddworld*. Also, there is no motivational difference between the sexes. Participants experienced moderate motivation to play both gams, promoting the likelihood of continued playing rather than quitting due to boredom. It also ensures that participants make knowledge transition from declarative to procedural knowledge if there is a spatial training effect caused by playing.

This study helped me to validate *CoD* and *Oddworld* as suitable games to be used in the training study due to their ability to inspire equal levels of players' expectation and motivation. The following chapter describes how I used both games to train non-action video game players.

Chapter 5

Gameplay Impact on Social Cognition

5.1 Overview

There are some fundamental questions that were investigated in my second study. First, whether AVG training leads to specific and general improvements in basic (UFOV) and complex spatial abilities (MRT + VN). In addition, I was interested to know whether male and female gamers differ in their performance on the same battery of transfer tasks used in the study, both before and after the videogame training. Because research has shown there are sex differences in these three abilities (i.e. UFOV, MRT, and VN), a comparison of these two groups can in principle address the question of whether AVG training reduces or even eliminates this difference through an intensive game practice period (around 11 hours of training). Also, I have examined the short-term durability of cognitive improvements one month after the cognitive remediation training concluded. Figure 11 shows the timeline of the experiment.

	Training		Short-term Durability	
Point A	———————	Point B	———————	Point C

Figure 11 Training Experiment Timeline

5.2 Methodology

The methodology used for this study was a between-groups experiment where the between subject factors were the game condition and sex, and the within-subject factor is time. The dependent variables of this experiment were the UFOV, MRT, and VN.

5.2.1 Participants

Thirty-two students (16 males and 16 females) from Simon Fraser University (SFU) participated. They were recruited through a variety of methods, including online mailing lists, email and face-to-face invitations. There were some criteria for selecting participants for my second study:

1. Participants must be fluent in spoken and written English.
2. Participants must be between 18 and 39 years of age.
3. Participants must never have had brain injuries or cognitive disorders.

Those criteria were posted on the study invitations. Before admitting participants to the study, I verified if they met those criteria, and I made sure that they do not have a significant history of playing action video games. Only non-action video game players were admitted to the study. I determined this using the game usage questionnaire.

5.2.2 Setting

To run the experiment and collect data, study sessions were organized in two quiet labs; the Video Analysis Lab (room 3762) in the School of Interactive Arts and Technology (SIAT) in the Surrey campus of the Surrey campus of SFU and the Global Media Monitoring Lab (room Shrum-K-8669) in the School of Communication of SFU Burnaby. When a session was in progress, I left a “Do Not Disturb” sign to ensure that no one interrupted the study session. The labs were equipped with a video-game console (PlayStation 4), a computer (Windows 10), and a display unit. I used the computer to run the UFOV and VN spatial tasks. The scheduled duration of each study session was one hour.

5.2.3 Materials

Demographics and Game Usage Questionnaires

To collect general information about the participants (e.g. sex, age, occupation), their academic information about their field of study, and their gaming usage and experience, I required that participants fill out the demographic and videogame usage questionnaires. The latter questionnaire helped me assess each participant’s videogame experience in order to remove any habitual action video game players.

Spatial Test Battery (STB)

Spatial Attention Task (UFOV)

I measured spatial attention via the UFOV task used in Green's research (2003 and 2006). This task's stimuli and procedure were similar to those previously used in Beard, Roenker, Miller, and Griggs's study (1988), except that Green made the test suitable for younger participants. He decreased the stimulus size and presentation time "to account for the increased ability of comparatively younger subjects (target stimulus was a filled triangle within a $3^{\circ}\times3^{\circ}$ circle outline; distracting squares subtended $4^{\circ}\times4^{\circ}$, no central task)". "Separate timings were used to ensure equal difficulty at each eccentricity: 6 ms for targets presented at 10°; and 12 ms for targets presented at either 20°or 30°"(pp. 536-537).

In the UFOV task, the main screen consisted of a central stimulus (letter T), a peripheral stimulus (a filled triangle inside a circle) and peripheral distractors (white outlined squares) - see Figure 12. This screen was briefly flashed. When the response screen appeared the participant had to make two responses: they had to indicate whether the T was either upright or upside-down and they had to indicate on which side the triangle appeared. The total score for each participant is the sum of correct answers.

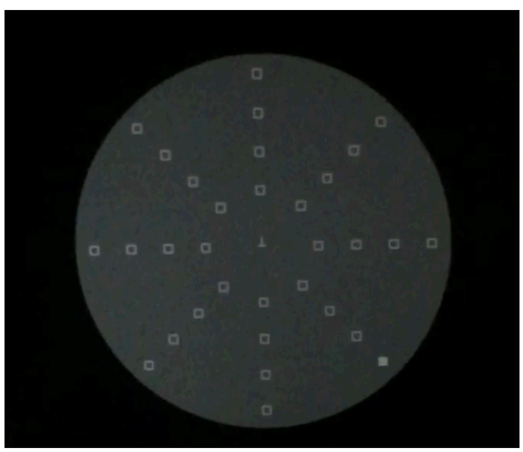


Figure 12 UFOV task

Mental Rotation Task (MRT)

Mental rotation is measured using the Vandenberg Mental Rotation Test (Vandenberg & Kuse, 1978). This test involves presenting participants with a three-dimensional target figure and four test figures (see Figure 13). Participants were asked to find two test figures that are rotations of the target figure in order to receive a score. The test has two sections with 12 items and each section has to be solved inside three minutes. According to the test's rules, I used a method of scoring "where one and only one point is given if both of the stimulus figures that match the target figure are identified correctly. No credit is given for a single correct answer" (Voyer et al., 1995). This means that the maximum score obtainable on the test is 24.

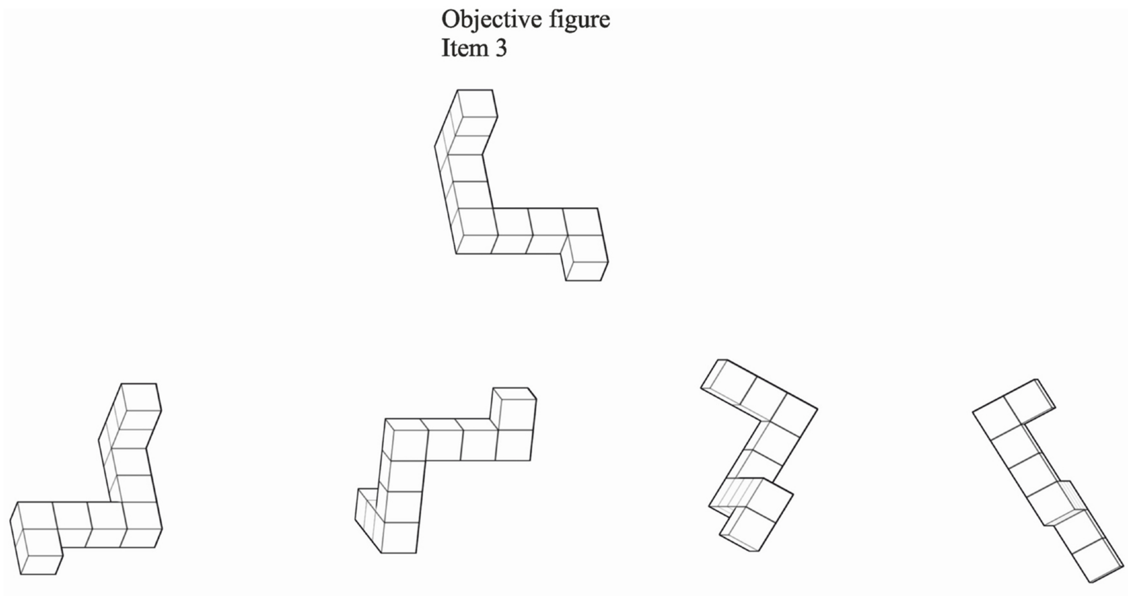


Figure 13. Sample question of Mental Rotation Test

Note: Reprinted with permission from Krüger, J. K., & Suchan, B. (2016). You Should Be the Specialist! Weak Mental Rotation Performance in Aviation Security Screeners – Reduced Performance Level in Aviation Security with No Gender Effect. Frontiers in Psychology, 7, licensed under CC-BY.

Virtual Navigation Task (VN)

To measure participants' navigation performance, we asked them to perform a search task in the VMWM (described in chapter 2). In the VWMW search task, testing involved performing a series of trials, with participants using arrow keys to navigate. The search task has three mini tasks: 1 practice task, 4 visible platform (VP) tasks, and 10 hidden platform (HP) tasks. After becoming familiar with the VWMW environment (e.g. practicing using the keys to navigate), participants moved into one of the four randomly determined starting locations in the VP trials. Once they found the platform, their avatar was held in place and a message announced, "Congratulations. You have found the platform and escaped from the water." After finishing the VP trials, participants performed 10 HP trials where the platform is invisible. Participants' navigation performance is their escape latency in the 10 HP. Escape latency is the time it takes to find the platform. The less time the participants take to find the hidden platform, the better their performance is.

Participants used a PC workstation to access the VMWM, which they viewed on a 21.5-inch monitor. The virtual pool is designed in Unity, which is a cross-platform game engine primarily used to develop video games. The pool is 40 meters (m) in diameter within a rectangular room (60 x 60 x 17.5 m); it is filled with water to a depth of 20 m and is bounded by a 1.5 m high wall. The platform on the water is 1.5 m in diameter and is located in one of the quadrants at a distance of 7 m from the pool wall. A practice area was created with an empty pool located inside a rectangular room

Videogames

Based on the pre-experiment study results, I decided to use the FPS game *CoD* in the treatment group and the non-action game *Oddworld* in the active-control group, because neither game generates equal motivation and expectation for improvement between the groups (AVG vs. NAVG).

5.2.4 Procedure

Participants in both groups performed the Spatial Test Battery (STB) (see section 5.2.3) at three points in time, designated: A, B, C (see Figure 11). At point A, participants performed the Pre-STB task; at point B, they performed the Post-STB task; and, finally at point C they performed the retake STB task (Retake). All the above- mentioned STB testing sets (Pre-STB, Post-STB, and Retake) consist of the same tasks presented in the same order of STB (the spatial attention task first, mental rotation task second, and virtual wayfinding task last). Participants were asked to refrain from playing the assigned videogames after the training sessions (a total of 4 weeks from Point B to Point C). This helped me determine if the trainees were able to retain the gained skills (if any) after a period of time.

5.2.4.1 At Point A: Pre-STB Task

At this point, participants in both groups completed the Pre-STB task to measure their spatial performance before training (see section 5.2.3 for more details). Participants in both groups were asked to schedule their first training session within the subsequent two days. They were told that they were going to have to complete an average of 11 hours of training (tracked via game summary/logs) within a maximum of five weeks. It was left up to the participants to decide when to do their training sessions, as long as: (1) they finished an average of 11 hours of playing in no more than five weeks; (2) they played a minimum of three hours weekly; and (3) they played a minimum of one hour per session.

5.2.4.2 First Period (A to B): Training Period

Participants in both groups started playing the assigned videogames within the subsequent two days from point A and finished playing the game (an average of 11 hours training) before point B. Participants in the treatment group played *CoD* while participants in the active-control group played the *Oddworld*. The period between point A and point B was of five weeks' duration. Participants were asked to bring something that verifies their hours of playing, such as screen shots of hours they played with dates, or screenshots of their playing logs.

5.2.4.3 At Point B: Post-STB Task

At this point, participants in both groups completed the Post-STB task to measure their spatial performance after training. Participants in both groups were asked to stop playing the assigned games and return in four weeks to retake the STB task (Retake) at point C.

5.2.4.4 At Point C: Retake-STB Task

I asked the participants to retake the STB task four weeks after their training session (Retake). Measuring spatial performance at this point helped me understand whether or not the transfer effect remained for a short period of time (4 weeks).

5.3 Results

5.3.1 Session Time

The average duration of a study session was around 1 hour.

5.3.2 Useful Field of View

As described in the methodology section, UFOV scores were collected three times from both groups (AVG vs. NAVG): once before the training (Baseline UFOV scores at point A); once after the training (Post UFOV scores at point B); and a final time after 4 weeks of not playing the games (Follow-up UVOF scores at Point C). Table 3 demonstrates the descriptive statistics, which include the UFOV means and standard deviations in both groups at the three points. It also shows the means of males and females in each group.

5.3.2.1 Descriptive Statistics

Table 3 UFOV Descriptive Statistics

Descriptive Statistics					
	Sex	Training	Mean	Std. Deviation	N
Baseline	Male	AVG	28.3	6.1	8
		NAVG	25	8.6	8
		Total	26.6	7.4	16
	Female	AVG	30.1	9	8
		NAVG	29.1	4.4	8
		Total	29.6	6.8	16
	Total	AVG	29.2	7.5	16
		NAVG	27.1	6.9	16
		Total	28.1	7.2	32
Post	Male	AVG	33	5.9	8
		NAVG	31.1	8.6	8
		Total	32.1	7.2	16
	Female	AVG	36	5.4	8
		NAVG	34.6	6.9	8
		Total	35.3	6	16
	Total	AVG	34.5	5.7	16
		NAVG	32.9	7.8	16
		Total	33.7	6.8	32
Follow-up	Male	AVG	31.3	4.5	8
		NAVG	33.8	6.2	8
		Total	32.5	5.4	16
	Female	AVG	36.6	6.9	8
		NAVG	36.9	91	8
		Total	36.8	7.8	16
	Total	AVG	33.9	6.3	16
		NAVG	35.3	7.7	16
		Total	34.6	6.9	32

As shown in the table, the results for both games have improved after the training and have been sustained after 4 weeks. To understand the training effect, and whether there is a sex effect on the results, I needed to understand the interaction of type of training, sex, and time on UFOV scores. To do so, I analyzed the data using a three-way mixed ANOVA, as explained in the following section

5.3.2.2 The Effect of Training on UFOV

A three-way mixed ANOVA was run to understand the effects of sex, type of training and time on UFOV scores. UFOV scores were normally distributed, as assessed by Shapiro-Wilk's test ($p > .01$), and there were no outliers in the data, as assessed by the inspection of a boxplot, see Figures14-17. There was homogeneity of variances for baseline scores ($p = 0.112$), post scores ($p = 0.111$), and follow-up scores ($p =0.159$), as assessed by Levene's test for equality of variances. The three-way interaction between time, sex and type of training was not statistically significant: $F(2, 56) = 0.577$, $p = 0.57$. All two-way interactions (time * gender, time * training, and gender * training) were not statistically significant($p > .01$). However, this analysis did reveal a significant effect for Time on UFOV measure, $F(2, 56) = 22.16$, $p < 0.0001$. Post-hoc tests found that UFOV scores at the post-treatment and follow-up times were significantly higher than the scores observed at baseline (Time 1) with $p < 0.0001$. Results of Post-hoc tests are shown in Table 4.

Table 4 Pairwise Comparisons

Measure: UFOV_Post_Hoc						
					99% Confidence Interval for Difference[a]	
(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	-5.6*	1.1	.000	-9	-2.2
	3	-6.5*	1.2	.000	-10.2	-2.9
2	1	5.6*	1.1	.000	2.2	9
	3	-.9	.9	.9	-3.8	1.9
3	1	6.5*	1.2	.000	2.9	10.2
	2	.9	.9	.9	-1.9	3.7

Based on estimated marginal means.
*the mean difference is significant at the .01 level.
[a]Adjustment for multiple comparisons: Bonferroni.

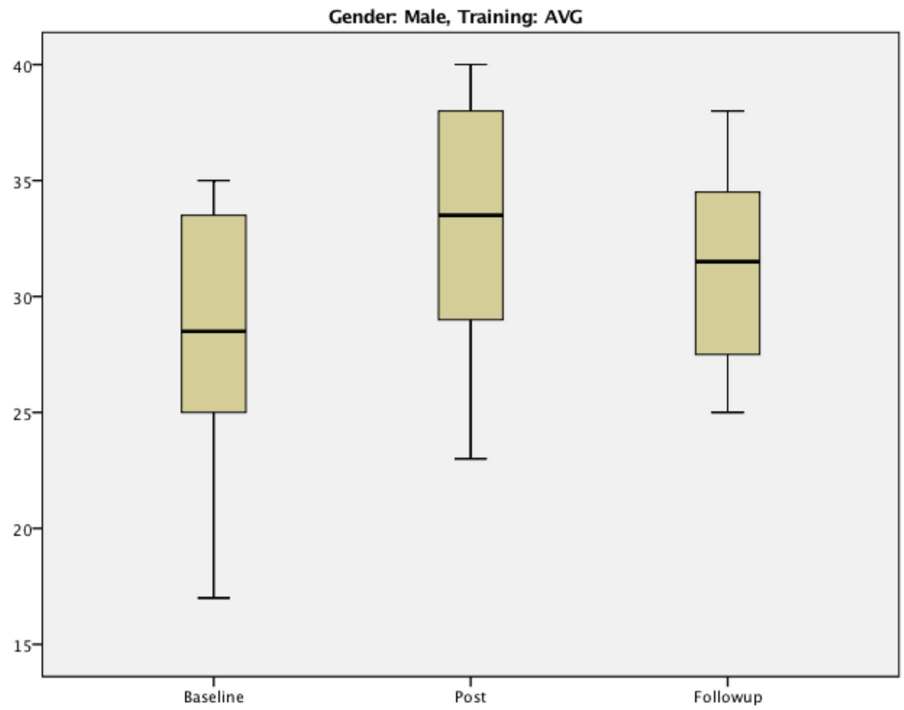


Figure 14 UFOV outlier boxplot 1

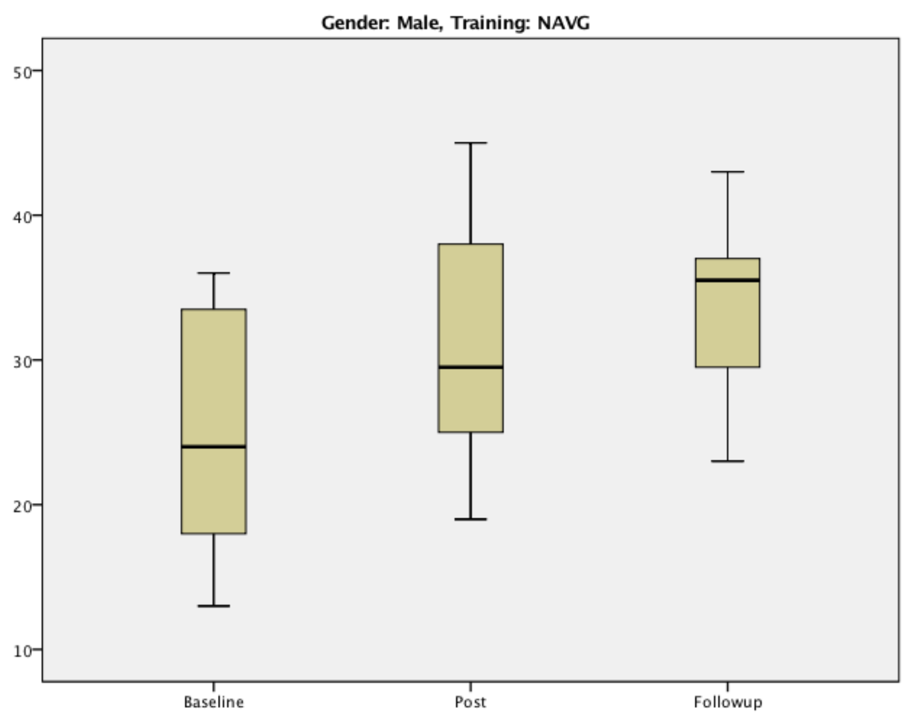


Figure 15 UFOV outlier boxplot 2

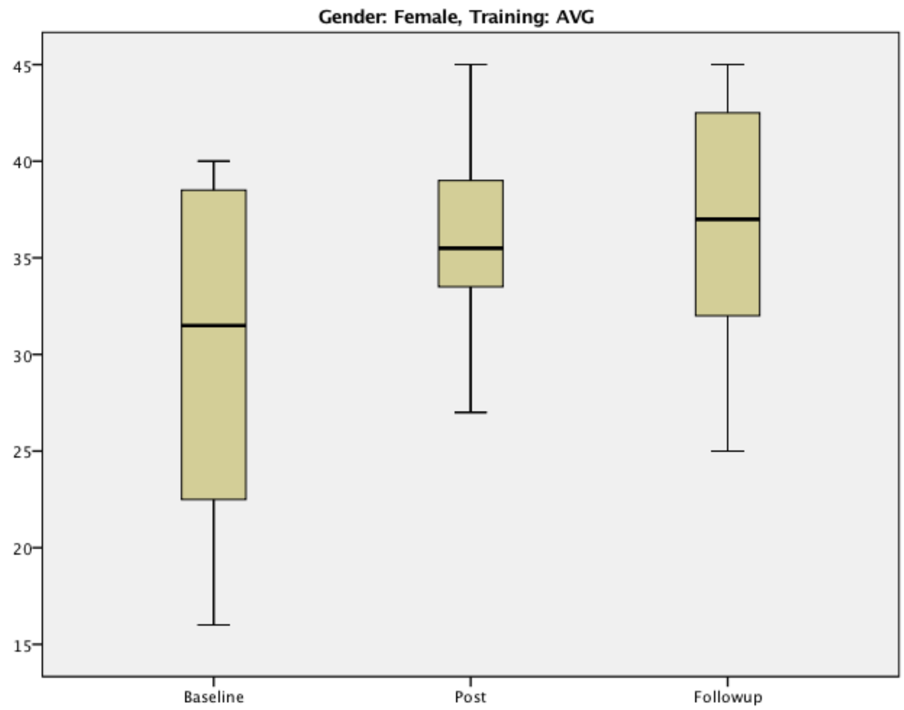


Figure 16 UFOV outlier boxplot 3

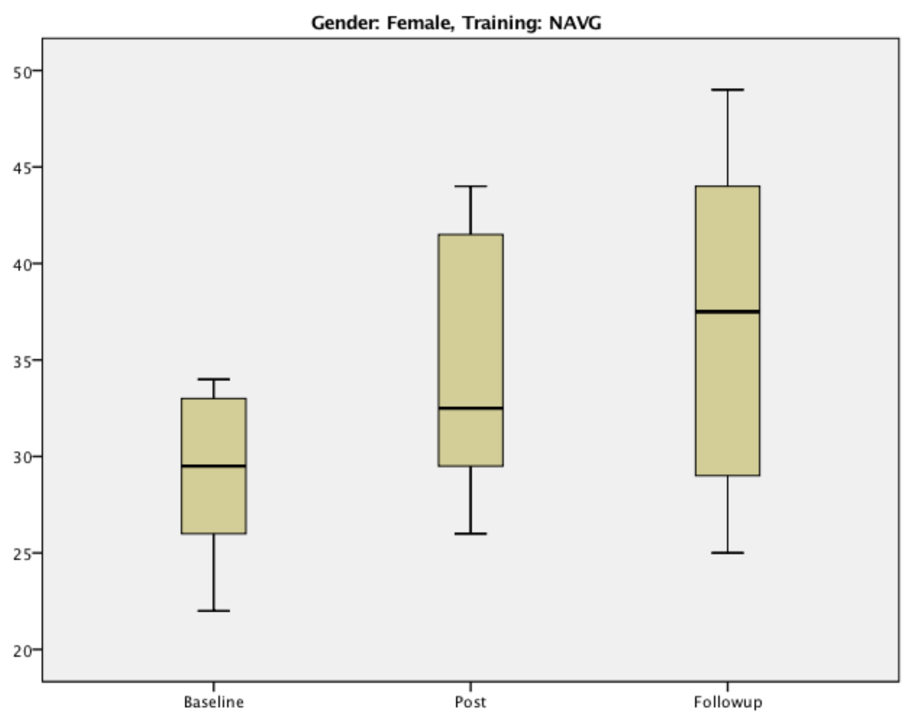


Figure 17 UFOV outlier boxplot 4

Mental Rotation

MRT scores were collected three times from both groups (AVG vs. NAVG): (1) at Baseline, (2) after the game training (Post), and (3) after 4 weeks of not playing the games (Follow-up). Table 5 demonstrates the descriptive statistics, which include the MRT means and standard deviations in both groups at the three points. It also shows the means of males and females in each group.

Table 5 Descriptive Statistics

	Gender	Training	Mean	Std. Deviation	N
Baseline	Male	AVG	11.4	2.6	8
		NAVG	12.6	5.6	8
		Total	12	4.2	16
	Female	AVG	11.6	5.2	8
		NAVG	10.5	4.9	8
		Total	11.1	4.9	16
	Total	AVG	**11.5**	**4**	**16**
		NAVG	**11.6**	**5.2**	**16**
		Total	11.5	4.5	32
Post	Male	AVG	14.6	4.7	8
		NAVG	16.1	4.5	8
		Total	15.4	4.5	16
	Female	AVG	15	4.5	8
		NAVG	13	5.7	8
		Total	14	5	16
	Total	AVG	**14.8**	**4.5**	**16**
		NAVG	**14.8**	**5.1**	**16**
		Total	14.8	4.7	32
Follow-up	Male	AVG	18	4	8
		NAVG	19.3	3.5	8
		Total	18.6	3.7	16
	Female	AVG	17.4	6.5	8
		NAVG	15.8	5.3	8
		Total	16.6	5.8	16
	Total	AVG	**17.7**	**5.2**	**16**
		NAVG	**17.5**	**4.7**	**16**
		Total	17.6	4.9	32

As shown in the table, the results for both games have improved after the training and increased further after 4 weeks. To understand the training effect, and if there is a sex effect on the results, I needed to understand the interaction of type of training, sex, and times on MRT scores. To do so, I analyzed the data using a three-way mixed ANOVA as explained in the following section.

5.3.2.3 The Effect of Training on MRT

A three-way mixed ANOVA was run to understand the effects of sex, type of training and time on the MRT score. MRT scores were normally distributed, as assessed by Shapiro-Wilk's test ($p > .01$), and there were no outliers in the data, as assessed by inspection of a boxplot, see Figures 18-21. There was homogeneity of variances for baseline scores ($p = 0.194$), post scores (0.815), and follow-up scores ($p = 0.263$), as assessed by Levene's test for equality of variances. The three-way interaction between time, sex and type of training was not statistically significant, $F(2, 56) = 0.039$, $p = 0.962$. All two-way interactions (time * sex, time * training, and sex * training) were not statistically significant($p > .01$). However, this analysis did reveal a significant effect for time, $F(2, 56) = 52.768$, $p < 0.0001$. Post hoc tests (Table 6) found that MRT scores at the post-treatment and follow-up times were significantly higher than the scores observed at baseline (Time 1), with $p < 0.0001$.

Table 6 Pairwise Comparisons

Measure: Post Hoc MRT						
					99% Confidence Interval for Difference[a]	
(I) Time	(J) Time	Mean Difference (I-J)	Std. Error	Sig.[a]	Lower Bound	Upper Bound
1	2	-3.3*	.5	.000	-4.8	-1.8
	3	-6.1*	.7	.000	-8.2	-4
2	1	3.3*	.5	.000	1.8	4.8
	3	-2.8*	.5	.000	-4.5	-1.1
3	1	6.1*	.7	.000	3.9	8.2
	2	2.8*	.5	.000	1.1	4.5

Based on estimated marginal means.
*the mean difference is significant at the .01 level.
[a]Adjustment for multiple comparisons: Bonferroni.

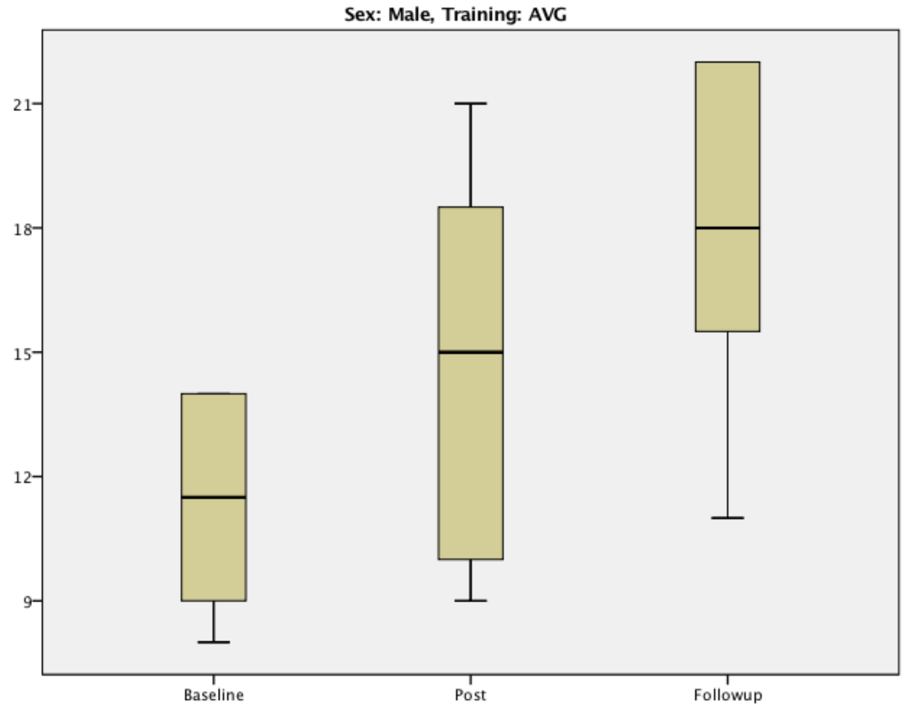


Figure 18 **MRT outlier boxplot 1**

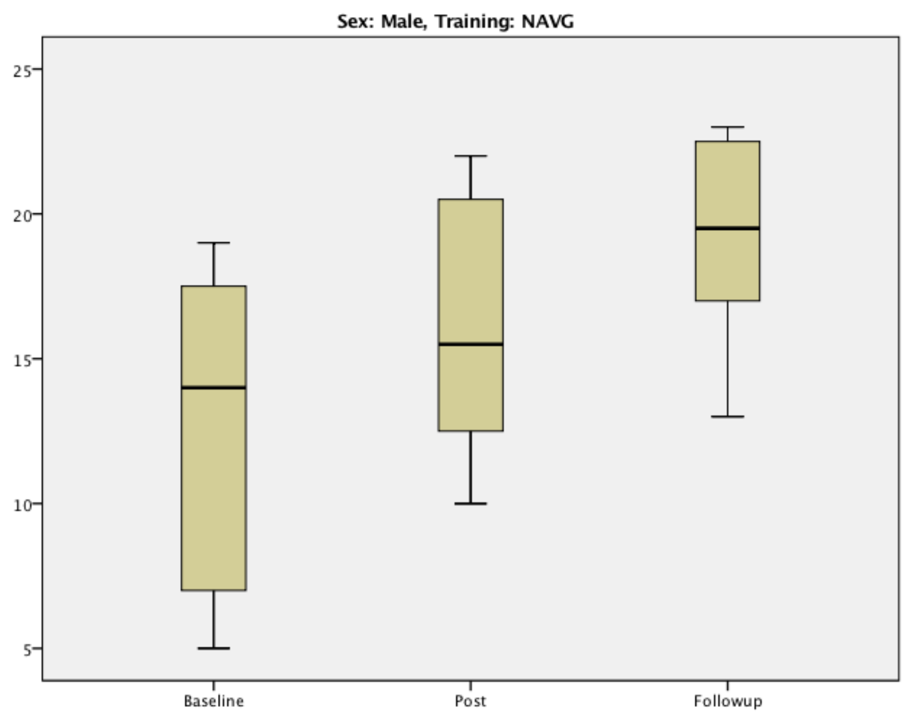


Figure 19 **MRT outlier boxplot 2**

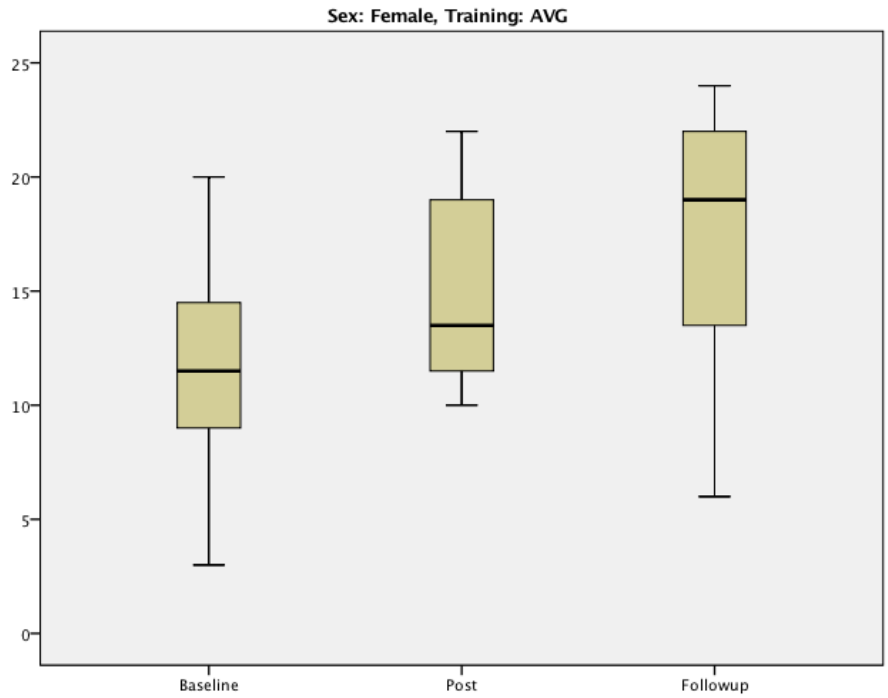


Figure 20 **MRT outlier boxplot 3**

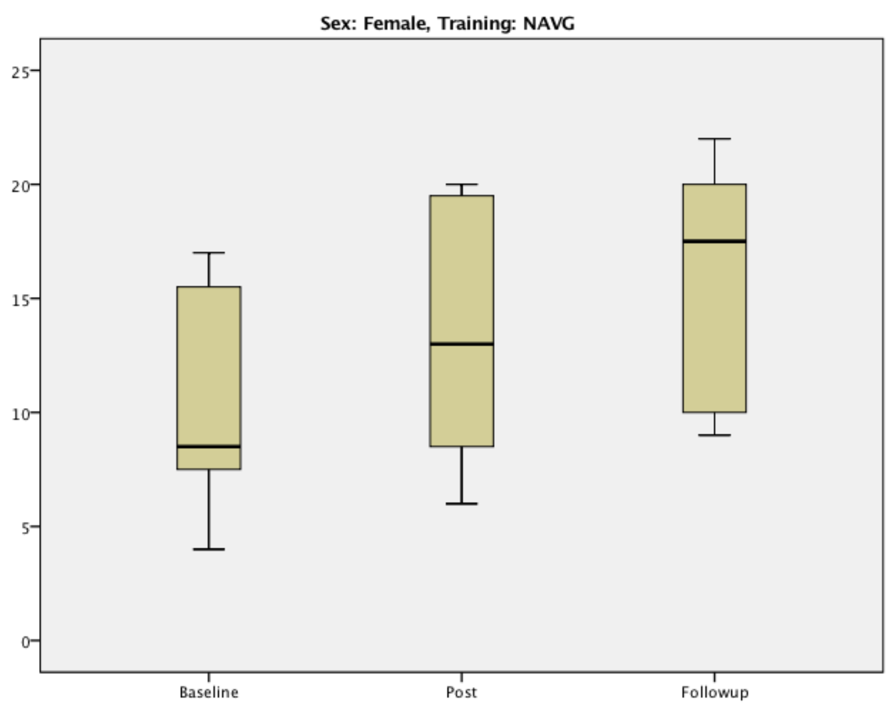


Figure 21 **MRT outlier boxplot 4**

Virtual Navigation (VN)

Similarly to the UFOV and MRT measures, VN data were collected three times (i.e. Baseline, Post, and Follow-up). Table 7 demonstrates the descriptive statistics, which include the VN means and standard deviations in both groups at the three points. It also shows the means of males and females in each group.

Table 7 Descriptive Statistics

	Gender	Training	Mean	Std. Deviation	N
Baseline	Male	AVG	14.8	4.5	8
		NAVG	16.4	6	8
		Total	15.6	5.2	16
	Female	AVG	18.6	11.2	8
		NAVG	21.6	7.4	8
		Total	20.1	9.3	16
	Total	AVG	**16.7**	8.5	16
		NAVG	**19.0**	7	16
		Total	17.9	7.8	32
Post	Male	AVG	14.2	5.8	8
		NAVG	15.3	6	8
		Total	14.7	5.8	16
	Female	AVG	12.4	7.4	8
		NAVG	18.6	4.9	8
		Total	15.5	6.9	16
	Total	AVG	**13.3**	6.5	16
		NAVG	**17**	5.6	16
		Total	15.1	6.2	32
Follow-up	Male	AVG	12.2	5.9	8
		NAVG	11	4.5	8
		Total	11.5	5.1	16
	Female	AVG	13.3	6.7	8
		NAVG	19.2	9	8
		Total	16.2	8.3	16
	Total	AVG	**12.7**	6.1	16
		NAVG	**15.1**	8.1	16
		Total	13.9	7.2	32

As shown in the table, according to the means, the results for both games have improved (decreased) after the training, and slightly improved after 4 weeks. To understand the training effect, and whether there is a sex effect on the results, I needed to understand the interaction of type of training, sex, and time on VN scores. To do so, I analyzed the data using a three-way mixed ANOVA as explained in the following section.

5.3.2.4 The Training Effect on VN

A three-way mixed ANOVA was run to understand the effects of sex, type of training and time on VN score. VN scores were normally distributed, as assessed by a Shapiro-Wilk's test (p> .01), and there were no outliers in the data, as assessed by inspection of a boxplot, see Figures 22-25. There was homogeneity of variances for Baseline scores (p = 0.06) , Post scores (p=0.35), and Follow-up scores (p =0.07), as assessed by Levene's test for equality of variances. The three-way interaction between time, sex and type of training was not statistically significant: F(2, 56) = 0.829, p = 0.44. All two-way interactions (time * sex, time * training, and gender * training) were not statistically significant(p > .01). Unlike the analyses for UFOV and MRT, this analysis revealed no significant effect of Time.

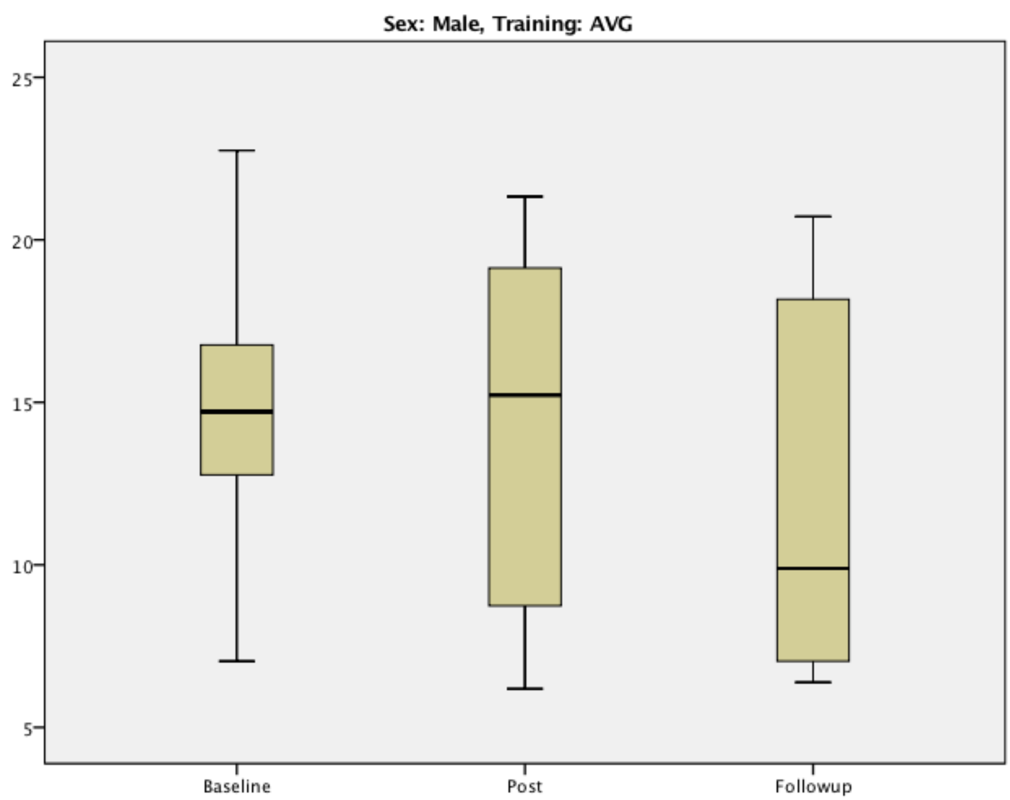


Figure 22 VN outlier boxplot 1

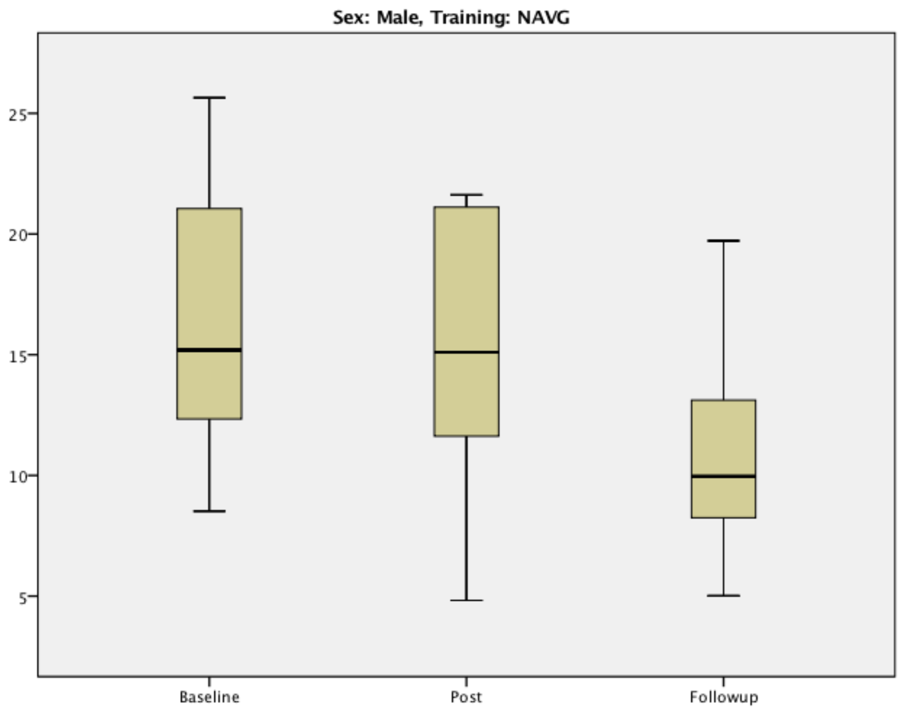


Figure 23 VN outlier boxplot 2

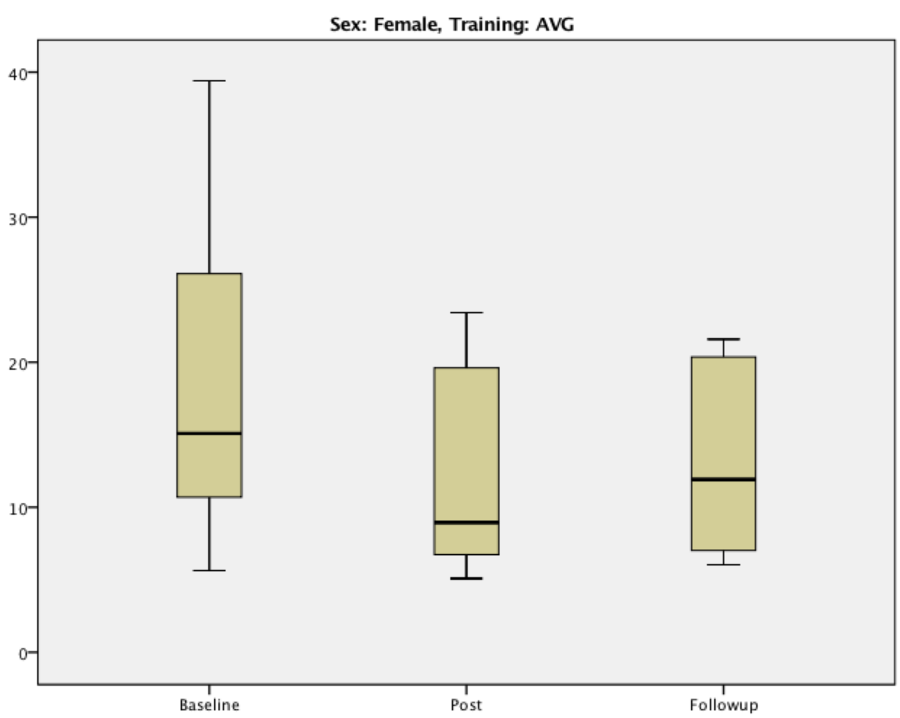


Figure 24 VN outlier boxplot 3

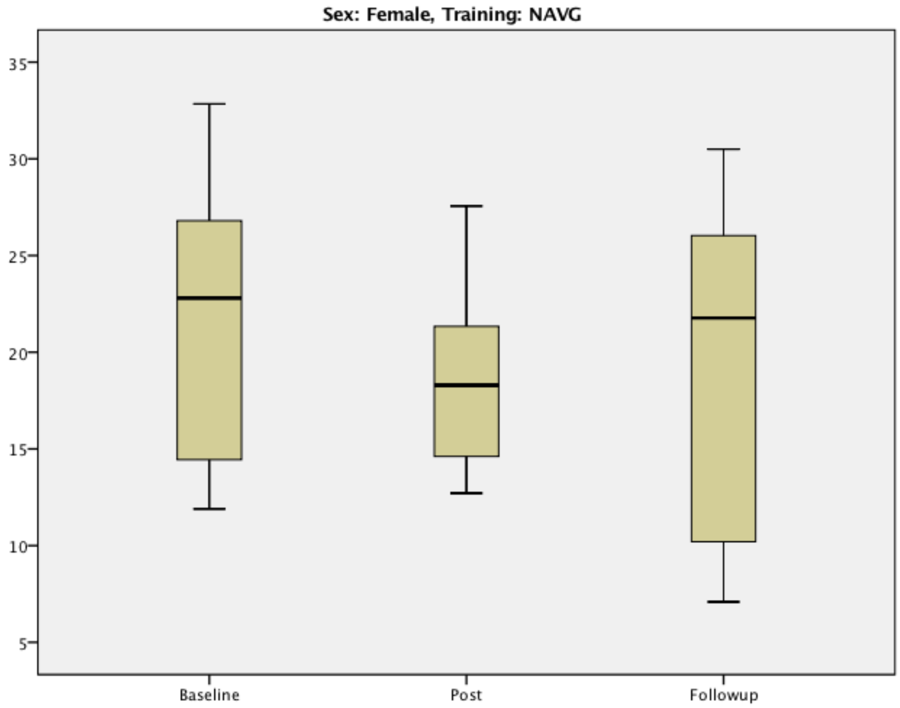


Figure 25 VN outlier boxplot 4

5.4 Discussion

5.4.1 UFOV and MRT

My post training session results showed that the participants' spatial performance in the AVG (*CoD*) and NAVG (*Oddworld*) groups improved similarly on the UFOV and MRT, compared to their results at the baseline measurements (there were no significant interactions). As I presumed, playing a FPS video game improves spatial attention and mental rotation. After an average of 11 hours of training, participants in the AVG group were able to faster extract information at a brief glance without eye or head movements and to perform better on rotating 3-dimensional shapes in their minds. The difference in their performance before and after the game training was significant. This finding is similar to number of previous studies. For example, Feng et al. (2007) found that the spatial attention (as measured by the UFOV) and mental rotation of non-AVG players improved after 10 hours of playing the FPS 'Medal of Honor' (comparative to the puzzle game 'Ballance'). Green and Beliver's (2006a) study results also showed that participants' spatial attention was improved as result of playing the FPS 'Medal of Honor' (compared to the puzzle game 'Tetris'), while participants in the control group did not exhibit any improvement. I theorize that the improvement in UFOV was due to a near transfer effect of playing the FPS game, where improvement in MRT was due to a far transfer. In other words, improvement in spatial attention may lead to improvement in mental rotation. The rational behind this assumption is due to the fact that spatial attention works as a building block for some higher spatial abilities such as mental rotation (Feng et al., 2007; Spence et al., 2009). However, I am a little surprised to see similar improvement in the active-control group who played *Oddworld*. According to the Hypothesis of Common Demands discussed in chapter 2, there are no obvious common demands between the skills required to play this game and the UFOV task. Due to the nature of this game, players do not need to simultaneously respond to multiple stimuli in both the central and peripheral vision in order to advance in the game. Therefore, it is unlikely that *Oddworld* improves performance on the UFOV task because it does not put emphasis on challenging the player's reflexes (instantaneous movement in response to a stimulus). To this point, I am not clear why the participants who played *Oddworld* improved in both UFOV and MRT. If I use " The Hypothesis of Common Demands" to explain these findings, results from the active-control group indicate that the players have improved in the UFOV and MRT indirectly (far transfer) from playing the game. However, I am not sure what median skill(s) were trained directly (near transfer) via playing the game that led to improvement in both the UFOV and MRT spatial tasks, and whether these skills were spatial or other skills (see Figure 26). Further research is needed to know the potential of games such as *Oddworld* in improving spatial skills.

Summary

1. Videogames can train basic and complex spatial abilities directly (specific transfer) and indirectly (general transfer).

2. Not only action games but other game genres have the potential to train spatial abilities. This opens up opportunities for future research.

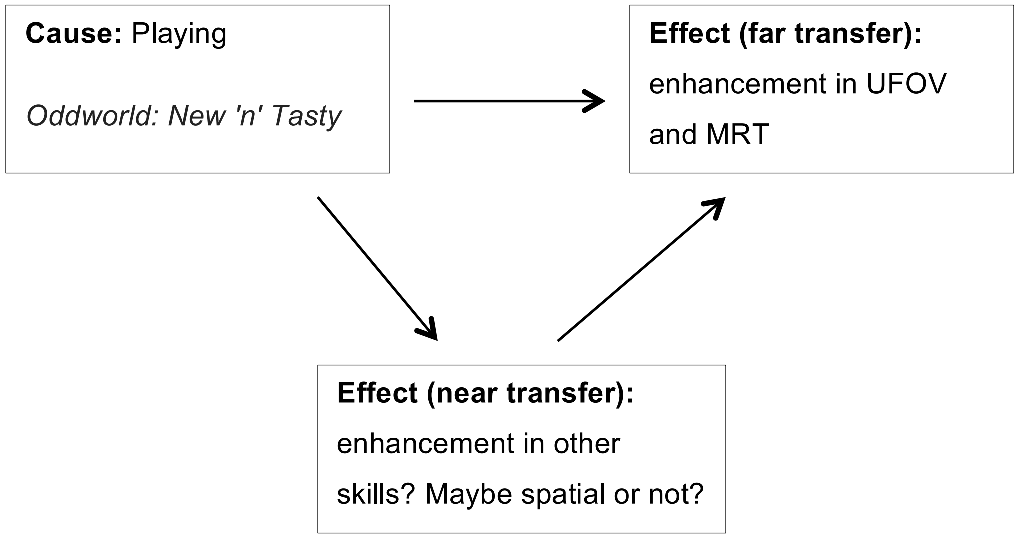


Figure 26 Far and Near Transfeers

5.4.2 Virtual Navigation

Virtual navigation did not improve in both groups although MRT improved. MRT is a strong predictor of navigation performance, as previous research results showed. Wayfinding is correlated with mental rotation ability (Astur, Tropp, Sava, Constable, & Markus, 2004; Choi, McKillop, Ward, & L'Hirondelle, 2006; Saucier et al., 2002; Silverman et al., 2000). The correlation is more pronounced in simulated environments than in real environments (Hegarty, Montello, Richardson, Ishikawa, & Lovelace, 2006). Unlike previous research, I did not see an indication of this correlation in my results (no improvement in VN although MRT has improved). This may be because MRT did not improve enough to improve VN. Virtual navigation is a complex spatial task (a large-scale spatial ability), and it depends on multiple small-scale spatial abilities, and more importantly it depends on MRT. The rationale behind this assumption is based on findings in a Hegarty et al. study (2006), in which the participants' MRT mean score was 19.7 (almost 20 out of 24), which is a higher mean score than the MRT average score in my study (14.8). Having said that, other studies showed significant improvement in mental rotation, especially in women after a short period of training (i.e. 4 hours) (Cherney, 2008)

Summary

Training with videogames has been shown to have significant effect on mental rotation after both short and long training periods. However, empirical evidence is still needed to investigate the key factors that enable training effects with shorter term training and to better understand the effects of videogame training on virtual navigation performance.

5.4.3 Equivalent Expectation

Compared to previous studies, the findings of a training effect in my study stand in the middle. Previous research results regarding the effect of videogame training are mixed, sometimes showing that AVGs improve spatial abilities compared to other genres and sometimes not as discussed in chapter 2. My findings showed improvement not only by training with AVG, but also a similar and significant improvement by the participants in the active-control group using a non-AVG. Unlike previous studies, I employed a methodology to ensure that both groups possessed an equivalent expectation to improve as a result of playing the games (as suggested by Boot's guidelines). Such equivalent expectations by both groups may work as another explanation to describe the unexpected discovery of the improvement by the active-control group. Equivalent expectations may lead to similar improvement by both groups (equal expectation effect). In other words, in my first study, I ensured that participants in both the control and experimental groups had the same expectations about the effects of playing *CoD* and *Oddworld* games (both groups expected to improve). So, playing a video game under the expectation to improve created this effect (e.g. an expectation effect). If this is true, it seems that I cannot eliminate a placebo (with regard to expectation) in general. I tried to control for it by creating the conditions to make it equal between the groups; however, since both groups improved, perhaps there is a placebo effect at work. In other words, both groups expected to improve, so they improved as a result of having this expectation in mind. Having said that, participants' skills in virtual navigation did not improve. If the expectation effect was a factor, participants should expect that VN would improve as well. However, UFOV and MRT both improved, and perhaps the fact that VN did not may weaken the explanation that improvement was due an equal expectation effect.

5.4.3.1 Summary

Another explanation for the spatial improvement by both groups may be due to an expectation effect. However, this is explanation is weakened due to the fact that some spatial skills have improved and some have not.

5.4.4 The Training Effect of Action and non-Action Videogames on Eliminating Sex Differences

Some studies have shown that men outperformed women in spatial skills, and other studies that after AVG training women would show better enhancement in their spatial abilities simply because they have more room for improvement. In my study, however, males and females started with similar level of spatial skills and improved similarly in UFOV and MRT abilities after they were trained by the *CoD* and *Oddworld* games. Also, similarly, neither improved their navigation skills (no significant difference from time to time). Male and females who participated in my study are undergraduate students from SFU (of a similar age range) who have no action videogame experience. This may explain why the gender difference was not pronounced. Experiential theories indicate that spatial gender differences are experientially determined, and that differences minimize as women and men have similar spatial experience. Men often show better spatial performance than women because they are more likely to have had more experience with spatial activities. In my study, both females and males possess similar education levels, lifestyles and lack of action videogame experience, and this may explain why sex had no effect on the study results.

In terms of the spatial gain after training, my study results were also different than what was predicted. I expected that females would improve more than males. This assumption was based on what was evident in some previous studies, e.g., a study carried out by Gagnon (1985), in which participants played Targ and Battlezone (two shooter games). Females in Gagnon’s study demonstrated greater improvement in their performance on tests of visual pursuit and mental rotation than males. However, when it comes to spatial learning, there are multiple models proposed in the literature (Spence, 2009) that explain spatial learning trajectories. Those models are described by: (1) the spatial skill start level of males and females; and (2) whether the performance of males and females will eventually converge (Spence, 2009). As can be seen in Figure 27, there are four models of how males and females gain a spatial skill. If we look at Model m1, we can see that males and females learn at the same rate. According to this model, "if males and females start at the same low level, a greater gain is expected and the rate of learning decreases as experience is accumulated" (Spence, 2009, p. 1098). Thus, "females perform as well as males, given the same starting level and the same training" (Spence, 2009, p. 1098).

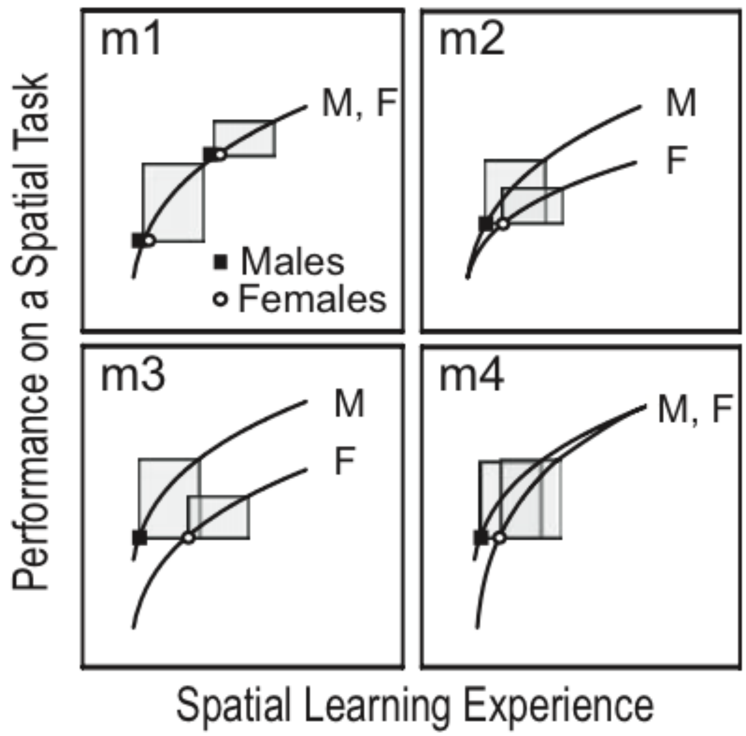


Figure 27 **The four models (m1–4) of spatial learning trajectories in men and women**

In my study, males and females started at the same low level, as you can see from Table 8 (no sex differences between male and females at the baseline level for all the three spatial scores). My study results showed that they improved similarly on UFOV and MRT and did not improve their VN skills. In agreement with my findings, Spence (2009) discovered that males and females who started their spatial training at similar levels (either high or low level) attained very similar spatial gains. Spence matched male and female participants together who possessed similar spatial attentional scores before the start of the training. He had matched 10 male–female pairs based on their starting scores levels. The study results showed that mean gains on the spatial selective attentional task were identical for both sexes.

Table 8 The means of the UFOV, MRT, and VN at the baseline level (no significant difference between gender)

Skill	Sex	Mean	STD
UFOV	Male	26.7	7.4
	Female	29.6	6.8
MRT	Male	12	4.2
	Female	11.1	4.9
VN	Male	15.6	5.2
	Female	20.1	9.3

Summary Men and women who start their spatial training at similar levels (either high or low level) attain very similar spatial gains.

5.4.5 The Durability of Training Effect of Action and non-Action Videogames

The purpose of the follow-up session is to examine the retention (durability over time) of the spatial tasks skills improved through training. I measured their short-time durability by retesting the participants' spatial abilities one month after their training with the games. I only discussed UFOV and MRT since only those abilities improved due to training. Participants' virtual navigation ability did not improve after training, as discussed previously, and they performed similarly in their follow-up session: displaying no improvement or degradation in their VN performance.

Participants were able to maintain their improved level of UFOV one month after finishing their training (at point C in the study timeline). Their results showed no significant difference between the improved scores after training and their scores after one month of quitting training. For MRT, participants were not only able to sustain their gained skill, but actually showed a significant enhancement in their follow-up session results (2.78, $p < 0.01$). However, I suspect that there is either a test-retest effect or other effects I am not aware of in the MRT follow-up session results, since the scores not only were sustained but also increased. I cannot verify this suspicion without the inclusion of a non-active control group in the study design. Including a non-active control group makes this a more rigorous study. The non-active control group lets me test the plausibility of alternative explanations that can account for the study results. For example, if the score for the experimental, active control, and non-active groups improved similarly in MRT scores, I could conclude that there were other effects at work. On the other hand, if higher improvement was noted in the groups who played the games, I could say that the improvement was due to the training effect, and the increases in skill performance were not due simply to a test-retest effect (or other effects).

5.4.5.1 Previous Studies

Durability of two spatial skills (UFOV and MRT) was studied by Spence (2009) and Feng (2007); however there were problems in their data, which weakens their claims. In the Spence's study there was incompletion in the data collection. Not all participants returned to perform the follow-up session. In the Feng's study, no formal statistical analyses (analyses of variance) were performed. Only the means and standard deviations from the follow-up testing were shared. The results of both follow-up data showed that the training effect of playing video games on UFOV and MRT persists for some time (around 5 months). My study is the first that provides empirical evidence for this claim, albeit over a shorter period of time.

5.4.5.2 Durability Effect Explanation

According to Anderson's (1996) Adaptive Control of Thoughts Theory, I assume that trainees were able to encode the skills gained from playing games as procedural knowledge in their long-term memory (knowledge compilation). The procedural knowledge gained by playing both games was transferred to UFOV and MRT abilities, as the results of this study clearly show. Therefore I can verify that training with videogames is capable of transferring spatial skills to long-term memory. Storing skills in long-term memory "leads to much greater and deeper learning, improved performance, and the development of expertise through the ability to recognize the applicability of existing schemas to new problems" (Arnold, Clinton, Wolfe, Lillis, & Roberts, 2010, p. 64). Participants were also able to recall those skills again from their long-term memory to perform the UFOV and MRT tasks after one month without training, which ensures that there is a durability of training gains for at least this period of time.

5.4.5.3 Summary

1. Playing with videogames can train basic and complex spatial skills.

2. The skills improved by playing videogames are sustained over the short-term (one month), which confirms that spatial knowledge gained by playing videogames is more likely to be stored as procedural knowledge in the long-term memory.

3. Empirical evidence is needed to know whether videogame trainees are able to sustain their improved spatial ability over the long term (between two to six months).

Chapter 6

Conclusion

The main finding of my study is that videogames can train spatial abilities. My participants spent an average of 11 hours to experience an improvement in their skills. Playing videogames enhanced their spatial attention (UFOV). Spatial attention is an important spatial ability that works as a building block for higher spatial tasks. In addition, participants' mental rotation enhanced significacntly after the training period (a complex spatial skill that depends on spatial attention). Mental rotation was improved even though its task was not similar to the training task. This indicates that training effect of playing videogames creates not only near but far transfer effects, which are more beneficial when it comes to learning.

In this chapter, I discussed the methodological and practical implications of this study, some of its limitations, and the potential for future work. After that, I conclude my thesis with some final remarks

6.1 Methodological Implications

This is the first study that used a methodology to eliminate some confounding effects that may damage the internal validity of the training experiment. Previous studies did not address this issue, which may indicate that there are unidentified effects that were not accounted for. This is a critical point because it may affect the validity of the results. In his paper "The Pervasive Problem With Placebos in Psychology: Why Active Control Groups Are Not Sufficient to Rule Out Placebo Effects", Boot (2013) pointed out that there are flaws in previous videogame training research. He identified a confounding effect that may become confused with the training effect: the expectation effect. For my study, I followed Boot's guidelines to select games that generated equal expectation and motivation in the players. This helped me rule out those placebo effects that weakened previous training methodologies.

6.2 Practical Implications

My study findings indicate that playing videogames playing can alter spatial thinking in both males and females. This finding is practical in multiple ways:

1. Spatial thinking and reasoning are correlated with success in STEM education and careers. Therefore, videogames games can be used to improve spatial thinking, which may lead to better achievement in STEM fields.

2. Playing videogames is a convenient, affordable, and fun activity, so it can be used as an accessible and informal way of teaching spatial skills to enhance spatial learning.

3. Videogame designers can benefit from videogame training research findings to design games that are not only fun but target users' spatial skills.

4. Videogames can be used to reduce individual differences in spatial performance such as sex differences.

6.3 Future Research

After performing this study, some questions remain unanswered for me. To address these, my future research must explore the following:

1. Whether training can improve spatial skills other than the ones studied in this research.

2. Whether children can benefit from videogame training more than adults, since their spatial and cognition abilities are still developing?

3. Whether videogame training can close the sex gap if further studies confirm its existence. For example, if women have lower spatial skills compared to men at the baseline stage, would they benefit more than men after training?

4. Would an informal way such as videogame training be more beneficial than a more formal way to teach spatial skills?

5. Is videogame training more efficient than other method of training (e.g. sport)? How does videogame training differ from other methods in terms of length and results?

6.4 Limitation

6.4.1 Recruiting

One of the biggest difficulties I encountered in this study was recruiting participants, as finding people with no action video game experience is very challenging. Beside the recruiting difficulty, the dropout rate in the study was high although participants were rewarded for their participation. To solve this, I decided to only study the short-term durability. Originally, I was planning to study long-term durability as well, but it was not possible with the high dropout rate.

6.4.2 Spatial Ability Measures

As mentioned in chapter 2, there is a historical bias in development of tests that measure spatial ability. Spatial ability tests were originally developed for men during the World War I to test recruits' spatial abilities before admitting them into the military (Council, 2015). This may lower the validity of spatial ability tests to test women's spatial performance.

6.5 Final Remarks

Studying the effects of videogame playing on cognition is promising. Videogames have become incredibly popular and the number of videogame players is increasing. Videogame players spend many hours of their lives playing, sometimes 30 hours a week or more. As shown in my study and in the literature, this activity has the potential to enhance spatial cognition. Therefore, it is important to keep studying the influence of videogames on spatial abilities in particular, and cognition in general. Findings from such studies could be very valuable not only to improve spatial skills, but also to increase the percentage of players who go on to be involved and be successful in spatially dependent fields such as STEM.

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