SPECIFIC EFFECTS OF ACTION VIDEO GAMES ON PERCEPTION AND ATTENTION

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To my parents and my wife
ACKNOWLEDGMENTS

I would like to thank my advisor, Evan Palmer for motivating me to do research on a topic that I truly enjoy and for the years of support and guidance. I would also like to thank the members of my committee, Alex Chaparro, Barbara Chaparro, Rui Ni, and Nancy Bereman for their valuable comments and suggestions and for their interest in this project.
ABSTRACT

Many research studies have established that playing action video games can lead to visual attention and perception benefits for the player. This dissertation pioneers the use of custom designed video game levels to determine if a single aspect of action video game play has specific effects on the player. In the following studies, specific aspects of action video games can indeed be isolated and thus potentially used as training tools for targeted perceptual benefits. Experiment 1 demonstrates that just two hours of training in a custom designed video game world that emphasizes friend vs. foe discrimination benefits players’ ability to focus on relevant visual information, and leads to marginally decreased flanker interference and marginally improved filtering capacity. Experiment 2 examines the beneficial effects of dispersed vs. narrowly focused attention in a second custom designed video game world. After two hours of game play, players in the dispersed attention condition significantly increased their visual working memory capacity and ability to allocate attention to peripheral items.
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CHAPTER 1

INTRODUCTION

Video games are a popular form of entertainment that add interaction and immersion to high quality graphics and story lines similar to those found in current blockbuster movies. According to the Entertainment Software Rating Board, 67% of US households play video games, with the average gamer playing eight hours every week (Entertainment Software Rating Board, 2011). In 2010, the video game industry generated more than $25 billion in sales, with just under $16 billion of that total coming directly from software sales (Entertainment Software Association, 2010). The “action” game genre, which includes games such as Halo, Call of Duty, and Half Life 2, was the most popular and accounted for almost 22% of software purchases (Entertainment Software Association, 2010).

This interactive form of entertainment has been the inspiration for some of the most popular and surprising research literature within the past twenty years. Some of this literature focuses on the violence in video games, showing that it can lead to increased aggressive behavior, aggressive thinking, and desensitization to real-life violence (e.g., Carnagey, Anderson, & Bushman, 2007). However, other literature has shown that these games can actually benefit the player. This side of the video game literature includes studies of the positive effects video gameplay can have on cognition, perception, and attention. This dissertation will focus on these potential benefits of video game play.

The literature that focuses on the positive aspects of video game play has primarily looked at which types of games lead to improvements in players but has stopped short of determining exactly what it is about the games that produce the observed benefits. In the
following dissertation, specific aspects of a video game will be tested to establish whether one or more of these aspects plays a larger role in producing benefits in the player than other aspects.

Video games have benefitted from advances in technology over their history. Originally, video games were quite simple. They involved reacting quickly to onscreen stimuli, or navigating a pixilated character through a maze of obstacles. This first generation of video games was only able to display a single screen environment within which the player guided the character. The perspective of the player was either from above, looking down onto the scene, or from the side (Figure 1A). Second and third generation games were able to display the environment in a more dynamic way (Figure 1B), which led to the addition of the first person viewpoint (Figure 1C). In this case, the player would view the game world through the eyes of the game character, even if the world was made up of blocks of color and poorly animated characters (VGmuseum, 2011). Within the last 15 years, the design of video games has made a dramatic leap forward. The current generation of games is incredibly realistic (Figure 1D). The characters in these games are lifelike and can show emotion through facial expressions, objects within the world react to interaction with accurate physics, and the player can become engrossed in the deep story lines and dramatic plots.
Figure 1. Illustration of advancement in video game technology from early generations of games to the current generation. In 1A, games were confined to a single screen and were comprised of very primitive graphics. 1B shows the updated graphics and scrolling game worlds of Generation 2. 1C illustrates the “action” genre of games in Generation 3. In 1D, the realistic lighting and physics, fast paced combat and realistic graphics of Generation 4 are shown. Images adapted from vgmuseum.com, weaponsfactory.com and bungie.net

The high level of realism in the current generation of video games has led a number of researchers to study the effects of these games on aspects of human interaction with the real world. In these studies, the video game is used as a singular training tool much as simple laboratory tasks are used to train participants in perceptual learning studies (e.g., Dosher & Lu, 1998). Many of these video games are very complex and require multiple types of interaction from the player, and the current literature examines how playing certain video games as a whole (e.g., Medal of Honor, Unreal Tournament, Tetris, The Sims 2) affects the perception and attention skills of the player. In particular, the action video game
genre seems to be the most effective at sharpening the perception and attention skills of those who play them (e.g., Green & Bavelier, 2007; Green, Pouget, & Bavelier, 2010; Green & Bavelier, 2006b).

The complexity of the game has required the literature to treat each game as if it is a “black box” of which there is no way of determining what happens inside. The purpose of this dissertation is to open the black box and determine whether specific aspects of FPS video games can be separated and used in experimental training and whether some of these aspects are leading to the observed benefits. To accomplish this, participants were trained on custom designed game levels that exposed them to only a single fundamental aspect of the FPS video game experience. This allowed causal inferences about which aspects of the game led to which specific changes in the player’s perception and attention skills to be made.
CHAPTER 2

HOW VIDEO GAMES AFFECT PERCEPTION AND ATTENTION

The increase in popularity of video games has spurred numerous studies into the effects they might have on the player. Much of this research has specifically focused on a genre of games called “action” video games. This genre is almost completely comprised of first-person shooter (FPS) and third-person shooter (TPS) games. FPS games show the game world through the eyes of the player’s character. Players must use virtual weapons to eliminate obstacles so the game character can reach a goal. In these games, players must interact with the world as though they are navigating through it themselves. FPS games require the player to perform actions such as responding quickly to the sudden appearance of stimuli and distractors, tracking and acting on many fast moving objects, and managing multiple tasks at once (Hubert-Wallander, Green, & Bavelier, 2010). The TPS style of game is very similar to the FPS, with the main difference being that the perspective of the game world is from above and behind rather than through the eyes of the character. Some examples of this type of game are *Gears of War,* and *Grand Theft Auto.* In TPS games, the perspective can shift to a FPS view when the player attempts to aim accurately or when an important scene takes place that the player is required to watch.

The “adventure” genre also has similarities with action video games. These games are not as focused on shooting as the FPS and TPS games, and tend to have a third person view of the world. This genre of game revolves more around exploration and interacting with other characters. Two examples of this genre are the *Fable* series and the *Legend of Zelda* series. The similarities between these games and FPS or TPS games are the
requirement of keeping track of the game environment, contending with conflict from enemy characters, and navigating accurately through the game world.

The FPS video game genre is one of the most popular and well known and is also the most extensively studied in the current literature. For these studies to be externally valid, they must be designed to match the real world as closely as possible. In this dissertation, a FPS game was used as the basis for training to provide results that are both comparable to the rest of the literature and applicable to the real world.

2.1 General Effects of Video Game Play

Playing video games can improve many aspects of the player’s perceptual and attentional systems whether the person has been playing them for years or even if they have only been playing them for a few hours (Achtman, Green, & Bavelier, 2008). Video game experience has been shown to improve players’ peripheral vision (Green & Bavelier, 2006a), mental rotation skills (Sims & Mayer, 2002), change detection (Clark, Fleck, & Mitroff, 2011), spatial resolution of attention (Green & Bavelier, 2007), contrast sensitivity (Li, Polat, Makous, & Bavelier, 2009), task switching ability (Karle, Watter, & Shedden, 2010), and efficiency in rejecting irrelevant objects (Castel, Pratt, & Drummond, 2005). These abilities are important for tasks such as driving or reading, and video games seem to engage them in a concentrated way, leading to big improvements in a short time. Within the game, players must be able to react to the fast pace of the game, respond quickly to unpredictable occurrences, learn from feedback, and improve skills so that they can handle increases in difficulty (Achtman et al., 2008; Cohen, Green, & Bavelier, 2007). The literature has focused on how these actions within the game can lead to such a wide variety of improvements and why other game types do not seem to have the same effects.
Studies in the gaming literature have primarily looked at the effects of different types of games on the player’s perceptual and attentional abilities, with many of the studies focusing on the effects of playing FPS games compared to the effects of playing a different genre of game altogether (e.g., Tetris, The Sims; Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Green & Bavelier, 2007). Standard laboratory tasks are generally used to assess these effects because the tasks are well understood and provide measurements that have been proven in the literature. In Appendix 1, the most commonly used tasks are explained in detail, while the effects found by using these tasks are described and categorized here.

In this review, the effects of playing video games will be grouped into five categories: Response Mapping and Hand-Eye Coordination, Executive Control, Instantaneous Attentional Capacity, Sustained Attentional Capacity, and Spatial Attention. Each of these categories not only relates to a fundamental aspect of human attention and perception, but may also relate to specific aspects of many action video games. The processes represented by these categorized effects are engaged in both the real world and in video games, which explains the research community’s intense exploration of this topic during the last decade.

2.1.1 Response Mapping and Hand-Eye Coordination

Response mapping is the ability to make fast connections between a stimulus and the appropriate response (e.g., Simon & Sudalaimuthu, 1979). An example of this is, while learning to drive, forming the association to press the brake pedal when a red traffic light appears. This ability to quickly determine an appropriate response is a very important aspect in video games as well, since the various onscreen stimuli require different responses from the player. Another related aspect is hand-eye coordination, which is the
ability to interact with items without directly being in contact with them, much like moving a computer cursor with a mouse. Tasks used to measure this are basic visual search tasks and other tasks that require fast responses to onscreen stimuli (Castel et al., 2005; Griffith, Voloschin, Gibb, & Bailey, 1983).

Video game research has been of interest for almost three decades. In a study performed in 1983, Griffith and colleagues compared experienced video game players (VGPs) and non-experienced video game players (NVGPs) on their ability to track a randomly moving dot of light around a rotary pursuit unit using a hand-held stylus. This unit contained a flat, opaque glass surface beneath which the light moved at varying speeds and trajectories. Significant differences in performance between experienced and non-experienced video game players were found, especially when the light moved at faster speeds. Overall, VGPs showed significantly better performance in their ability to react to the stimulus and produce the appropriate movement of the stylus. In 1983, the video games being produced were simplistic and non-realistic, similar to those in Figure 1A. Even though VGPs in this study were only exposed to these unsophisticated games, they still showed better performance in their ability to process visual information and translate it quickly into a specific hand movement. More recent studies have shown that this increase in processing speed and motor response can also result in improvements such as response mapping.

In 2005, Castel and colleagues sought to determine if VGPs’ faster processing speed would result in faster response times (RTs) in visual search tasks. Participants consisted of both NVGPs and VGPs who took part in both an easy and difficult visual search task. In both conditions, the number of distractor items was 4, 10, 18 or 26, and the target letter was
either a “b” or “d”. In the easy task, the object was to search for the target letter among “k” distractors. In the more difficult search task, the distractors consisted of different letters including “p”, “h” and “g”. The participant was required to press a key on the keyboard corresponding to the target letter present in the display. The more difficult version of the task especially allowed Castel, et al. to study how well participants could process visual stimuli and choose between two responses.

As expected, results showed that search slopes in the easy search task were significantly shallower than in the difficult search task. This meant that both VGPs and NVGPs were slower to respond in the difficult task than in the easy task as set size increased. VGPs showed identical search slopes to NVGPs, showing that both groups have similar search strategies and that neither group is more efficient. Even though VGPs used the same search strategies, they showed significantly faster reaction times than NVGPs in both difficulty levels and with any number of distractors. On average, VGPs were able to respond 200 ms faster than NVGPs, even on the most difficult search tasks. The general finding was that with only 12.9 hours of average video game play, the VGP group was able to produce a more effective association between the onscreen stimulus and the appropriate keyboard response; a task that is similar to responding to onscreen stimuli in a video game.

2.1.2 Executive Control

Executive control is concerned with how the cognitive system directs the allocation of attention (e.g., Baddeley, 1992) and is reflected in skills such as one’s multitasking and task switching ability. In video games, executive control is frequently used when alternating between different goals with varying priorities (e.g., navigate a route, avoid traps, evade detection, retrieve item), or sometimes to handle many priorities at once (e.g.,
defeat enemies, find healing items, escape current location, hide). In the laboratory, executive control is measured by paradigms evaluating divided attention, task switching, or attentional filtering (Greenfield, DeWinstanley, Kilpatrick, Kaye, 1994; Karle et al., 2010).

In a study designed to measure the effects of video game experience on the ability to divide attention, Greenfield and colleagues (1994) discovered that VGPs were better able to focus attention on more probable locations of target presentation while simultaneously ignoring locations where the target was unlikely to appear. The results showed that at locations where a target was very likely (80%) or very unlikely (10%), VGPs were significantly faster than NVGPs at responding to the target’s appearance, indicating that the attention of the VGPs was more focused on the target’s possible appearance location even when it was unlikely. When the target was given a 45% probability of appearing at either location, VGPs were still faster than NVGPs at responding to the target, indicating that their attention was more evenly dispersed across the entire display. This pattern of results shows that VGPs have widely dispersed attention but are still able to focus their attention on specific locations. The ability to switch between both dispersed and focused attention shows how high-level executive control over attention is improved by playing video games.

Castel and colleagues (2005) also believed that, because of the findings with respect to response mapping in VGPs (reviewed above), they might have some type of benefit in high-level executive control, which allows them to have more efficient control of attention. Karle and colleagues (2010) designed a study to test this assertion by comparing VGP and NVGP performance in a task-switching paradigm. This experiment required that participants change their responses depending on which cue was presented. Manipulating the time between the cue and the target appearance varied difficulty (with shorter times
being more difficult). The speed with which participants selected the appropriate response was used as a measurement of executive control because switching between tasks required a shift of selective attention, something that is controlled by the central executive (Baddeley, 1992). VGPs showed faster RTs than NVGPs even when the time between the cue and target was short. With a shorter time between the cue and the target stimulus, there was less time to process and select the appropriate response. The short RTs of VGPs indicated to Karle, et al. (2010) that both the processing and preparation of response were easily completed within the short time between the two displays in both conditions. Also, when compared to NVGPs, VGPs had a lower speed-accuracy tradeoff, indicating that their fast RTs were not due to a decrease in accuracy; it was more likely due to improved executive control over the focus of attention.

Executive control, which has commonly been measured by using divided attention tasks or a task switching paradigm, is one aspect of attention that is affected by the use of video games. It has been shown that video games improve the high-level executive control over attentional resource distribution and focus. This means that simply playing an action video game can improve the efficiency with which the central executive in working memory can allocate attention; one of the most sophisticated processes in the human attentional system.

2.1.3 Instantaneous Attentional Capacity

The capacity of visual attention can be discussed in terms of both instantaneous and sustained attention. First, literature concerning instantaneous allocation of attention is reviewed in this section and then literature regarding sustained attention is reviewed in 2.1.4. Instantaneous attentional capacity is a measure of the amount of information that can
be processed by the attentional system in a very short period of time. As mentioned above, one of the important skills used in video games is the ability to quickly react to onscreen stimuli. For example, in a video game, instantaneous attentional capacity may be used to quickly determine how many enemy characters are present in an environment, or to decide with a glance whether a room deserves further exploration. Examples of tasks used in the laboratory to measure this capacity are the enumeration task, the visual working memory (VWM) task, and the flanker task (Green & Bavelier, 2003; 2006b).

Shawn Green and Daphne Bavelier have focused much of their research on measuring differences in attentional capacity between VGPs and NVGPs. In their 2003 study, the flanker task was used to illustrate higher attentional capacity in VGPs than in NVGPs. The flanker task measures the ability to focus attentional processing to a single item while ignoring surrounding (i.e., “flanking”) irrelevant items. Performance in the flanker task is measured via the compatibility effect, which is the difference in RT for trials where distractor items are the same as the target (causing faster RTs) versus trials where distractor items are different than the target (causing slower RTs). The larger the compatibility effect, the more impact the irrelevant distractors had on processing the target item (both positively and negatively). Video games have been shown to lead to many benefits in the perception and attention of the player, but this is one case where video game experience did not lead to an improvement in the laboratory. VGPs who took part in this study had a higher compatibility effect than NVGPs, especially in trials that contained the most flanking items. Green and Bavelier (2006b) reasoned that VGPs’ higher attentional capacity was more than enough to process the target item and thus led to the additional processing of the irrelevant items as well, leading to a larger flanker effect.
The enumeration task is used to determine how many items can be counted in a very short time. In 2006, Green and Bavelier compared the enumeration performance of NVGPs who were either trained on the FPS game Medal of Honor or on the game Tetris, which requires accurate placement and rotation of block shapes as they fall from the top of the screen. The goal of Tetris is to arrange the blocks at the bottom so that there are no gaps (Figure 2). This game was considered to be a good control by Green and Bavelier because it did not contain any of the FPS game characteristics such as quick responses to the sudden appearance of objects, multiple fast moving objects to track, or multiple tasks to manage at a time. NVGPs were trained on either the FPS game Medal of Honor or Tetris for one hour per day over ten days.

The results of this study showed that participants trained on the FPS game were able to more quickly process items that only appeared on screen for 50 ms. Specifically, these participants were able to process up to five items with near perfect accuracy, while participants trained on Tetris were only able to process three items perfectly. This difference in the number of items that can be instantaneously processed shows that only ten hours of training on a FPS game can produce a quantifiable increase in attentional capacity that is not present after training on a non-FPS game.
Figure 2. An example screen of the video game “Tetris” showing a block falling from the top of the screen and the stacks of previously placed blocks at the bottom.

Video games require fast responses to onscreen stimuli, but before these responses can be performed, the stimuli must be processed by the visual system. A high instantaneous attentional capacity allows the player to process new visual information almost immediately. This quick processing also reaches into higher-level aspects of attention such as making decisions about whether information is relevant or not. A split second decision about the threat of an enemy character in a video game can mean the difference between continuing to play and starting the game over from the beginning. It is most likely this aspect of many FPS games that helps to improve the quick identification of relevant information and the overall speed with which visual information is processed.
2.1.4 Sustained Attentional Capacity

Sustained attentional capacity is the amount of information that can be maintained and processed by the attentional system over an extended period of time. In the laboratory, this is measured by testing observers’ ability to maintain a mental representation of a scene in a change detection task (e.g. Clark, Fleck, & Mitroff, 2011; Rensink, O’Regan, & Clark, 1997), to “track” items over a period of time in a multiple object tracking task Green & Bavelier, 2006b) or determine which of two stimuli appear first in a temporal judgment task (West, Stevens, Pun, & Pratt, 2008). In action video games, sustained attention may be used to keep representations of the virtual environment available for future processing. For example, this can help the player keep track of other game characters even when they are not currently visible, maintain focus fire on one of several enemies in a group of attackers, or remember escape routes and nearby locations in the game environment that provide cover or have power-ups.

Using a change detection task, Clark and colleagues (2011) tested the ability of both VGPs and NVGPs to keep a visual representation of a scene in working memory for comparison to a second scene. The first scene was separated from the second scene in time by a blank screen, and each scene was only shown for 250 ms. This display time was most likely selected because it limits the number of eye movements that can be made; a process that takes approximately 200 to 300 ms (Rayner, 1984). Since only one eye movement could be made during each scene presentation, the fixation area of the first display had to be kept in working memory so that a comparison could be made. In addition, previously searched locations might be kept in working memory to increase search efficiency by avoiding them on subsequent displays. The results of the study showed that VGPs
performed better than NVGPs in this task, finding changes faster and with higher accuracy. VGPs also used a more high-level strategy when searching for changes in an image by searching the image broadly and rarely returning to areas near a previously fixated location. This indicated that VGPs were able to process a wider visual area during a single fixation than NVGPs. The ability of VGPs to search the image using a more broad technique implies that their attention is constantly being updated with information regarding the absence of a target at a searched location. This, combined with their ability to search a wider area of the scene in a single fixation, gave VGPs an advantage in this task because NVGPs returned to already explored areas of the image since their sustained attentional capacity did not retain the previously searched locations.

The ability to track multiple items at a time reflects not only working memory capacity, but also sustained attentional capacity. In 2006, Green and Bavelier studied the effects of video game experience on performance in a multiple object tracking task. The ability to track more items at a time as they move randomly around the screen implies larger working memory capacity because the locations of the items and whether or not each item is a target must constantly be updated throughout the task (Pylyshyn & Storm, 1988). The results of a comparison between multiple object tracking performance in VGPs and NVGPs showed that VGPs were able to successfully track more items, with a significant difference between performance of the two groups when tracking three, four or five items. This advantage was present in all conditions except the easiest (track one item) and the most difficult (track seven items). In addition, VGPs showed at least 80% correct target identification when tracking up to five items, while NVGPs were only able to maintain this level of accuracy up to three items. The enhanced ability of VGPs to track items for a period
of time indicates that video games improve the ability to process information in parallel over time.

Using a temporal judgment task, West and colleagues (2008) showed that VGPs had higher attentional capture in response to exogenous visual cues. When asked to identify which of two targets seemed to appear first, VGPs were more affected by an irrelevant cue in their judgments of timing, indicating that an attentional cue had a stronger effect on them than on NVGPs. The irrelevant cue drew their attention to the location where the target was going to appear before it was presented. This gave a head start to visual processing at the cued location, while processing at the non-cued location proceeded only once the target appeared. Under such circumstances, if two items are presented simultaneously but attention has already been cued to the location of one item, it will appear is if the item appearing at the cued location was presented before the item at the uncued location, causing a temporal order illusion. For the two items to appear as if they were presented simultaneously under these circumstances, the item at the cued location must be presented slightly after the item at the uncued location. The time difference necessary to cancel out the attention cueing benefit estimates the processing time difference from that cue. VGPs needed more time to cancel out the temporal order illusion than NVPGs, indicating that the attentional cue provided a bigger advantage in attentional processing but also poorer judgment of the true presentation order of the items.

When playing a video game, the ability to start visual processing early offers a definite benefit by allowing the player to start making judgments about possible stimuli before they have even arrived (e.g., seeing an enemy’s shadow around a corner before they see you). In the case of this task, however, a detriment was observed because the speeded
processing of the target at the cued location made it seem to appear earlier. The increased amount of time between the two targets (i.e., poorer estimate of reality) in order for the VGPs to notice the difference is another example of the few times that playing video games does not necessarily produce “benefits” that transfer to the real world.

2.1.5 Spatial Resolution of Attention

Visual attention takes place in both the central visual field and the peripheral visual field. The spatial resolution of attention is a measure of the amount of space that must be present between items in order for them to be processed individually, leading to a behavioral response (Intriligator & Cavanagh, 2001). This aspect of visual attention is used in video games to help the player gather information from areas of the environment without the need to look away from the current focus, allow for quick interpretations of scenes, or assist with manipulating representations of the environment to determine correct paths through the game world. Some common laboratory tasks that measure spatial attention are the useful field of view task, the mental rotation task and the crowding task (Green & Bavelier, 2006c; Sims & Mayer, 2002).

Using a mental rotation task, Sims and Mayer (2002) showed that participants who were trained for 12 hours on the game Tetris showed significant improvements in mental rotation ability, but only on shapes that matched the Tetris shapes. The mental rotation task used in this study required participants to mentally rotate objects in three dimensions while the Tetris game only allowed rotation of shapes in two dimensions. These results indicated that there was only domain-specific transfer of training from Tetris directly to the mental rotation of similar looking shapes. This is an important finding because Tetris
experience appears unable to provide the broad transfer of training found in studies of FPS games.

In 2007, Green and Bavelier reported the results of a crowding task study that were quite surprising. When comparing performance between VGP and NVGP groups, it was discovered that VGPs had smaller crowding regions than NVGPs. This was shown by VGPs having better ability to separate a central target from peripheral items even when they were very close together. This meant that VGPs (or even NVGPs who were trained on an action video game for 30 hours) needed less empty space between visual information for it to be processed as separate. In order to successfully process the information as separate items, their vision must have higher spatial resolution (i.e., smaller receptive field sizes) and better visual acuity than NVGPs, particularly in the periphery. VGPs were better able to discriminate target items in both the periphery and central vision, implying that playing action video games alters fundamental aspects of the visual system. This means that besides just influencing the way that higher-level processes manipulate visual information (such as recognizing objects), video games also have the ability to change how low level aspects of perception and attention (such as detecting line orientation) gather this information in the first place.

To gain a better understanding of the spatial resolution of attention in VGPs, Green and Bavelier (2006a) compared VGP and NVGP groups on a useful field of view useful field of view-task. In this task, attention must be distributed across the entire display to successfully perform both the central identification task and the peripheral localization task. It was assumed that VGPs would out-perform NVGPs on this task when tested on eccentricities that matched the area utilized by the FPS training game. Results showed that
VGPs were, in fact, better able to locate a target using peripheral vision than NVGPs but also that VGPs did not experience a tradeoff of accuracy in the central task while performing better in the peripheral task. In most cases, an improvement in the peripheral task would be attributed to a shift of attention from the central to the peripheral targets, but VGPs were able to expand their field of view in such a way that no detriments were present. An even more surprising finding was that VGPs were also able to outperform NVGPs even in areas of their visual field that were beyond that covered by the video game screen. This means that the broad transfer of training seen in VGPs can extend not only to the area directly practiced in the game, but also to areas of the visual field that did not directly take part in the game. This transfer of training to portions of the visual field that were not directly trained is one of the most impressive findings in the current literature, implying that FPS video games can actually improve the visual system to an extent well beyond that which was directly trained.

2.2 Methodological Considerations and Precautions

As discussed previously, the goal of the current body of literature is to determine if there are differences between people who play video games and people who do not. There are two main experimental designs used to study these differences: cross-sectional and training. Here, the differences between the two designs, some example studies, and some weaknesses of each design will be discussed.

2.2.1 Cross-Sectional Studies (Correlational in Nature)

The majority of studies that measure effects of video games on attention and perception are cross-sectional in nature, as seen in Table 1 (e.g., Castel et al., 2005; Dye, Green, & Bavelier, 2009; Green & Bavelier, 2003; Karle et al., 2010). This means that groups
of participants with different levels of video game experience are compared with each other, representing the entire population of VGPs or NVGPs. These studies generally use surveys to determine the average number of hours per week spent playing video games and then separate participants into VGP and NVGP groups accordingly. The groups are then given a battery of basic perceptual and attentional laboratory tasks, and their performance is compared. These types of studies are helpful in determining if there are any differences between VGPs and NVGPs that could be correlated with hours of video game playing.

*Table 1.* Examples of the studies that employ the two most common types of experimental design in the video game literature (adapted from Boot, Blakely, and Simons, 2011).
A specific example of a cross-sectional study can be found in the first experiment performed by Green and Bavelier (2003). In this experiment, participants were asked to report their average video game use and were categorized as VGPs if this amount for the past six months was greater than one hour per day on at least four days per week. These participants also reported the games they played most frequently, which seemed to fall mostly into the “action” video game genre. The respondents were categorized as NVGPs if their reported video game use was little or none within the past six months. These groups then completed a flanker task (described above and in Appendix 1) to determine the amount of attentional resources available after processing a central task. This “left over” processing power – which is captured by the compatibility effect – was then compared between the two groups. It was hypothesized that VGPs would have a greater compatibility effect than NVGPs because of a higher efficiency in processing visual stimuli on which they had unknowingly been trained through their many hours of video game play. This hypothesis was supported with VGPs showing a fairly consistent compatibility effect between 10 and 25 ms and differing only slightly as the task difficulty increased. NVGPs’ compatibility effect steadily decreased as task difficulty increased. This means that on flanker task trials with more distractors, VGPs had a significantly higher compatibility effect, indicating that excess attentional resources ended up processing flanking distractors.

These cross-sectional studies are very informative and useful in building the foundation of this body of literature, but have the limitation of being unable to determine any sort of causation (Boot, Blakely, & Simons, 2011). Cross-sectional studies do not rule out a self-selection bias, which makes it nearly impossible to determine if VGPs show better
performance in experimental tasks because of their video game experience, or if they choose to play video games because their innate skills allow them to be more successful. This problem is mentioned in a number of articles (e.g., Green & Bavelier, 2003; 2007; Sims & Mayer, 2002) and taken into account in the design of later experiments, but there are other potential problems with this type of design that are not addressed in most studies.

The problem with recruiting VGPs into a study that tests their abilities on game-like perceptual and attentional tasks stems from what they expect the skills of an experienced VGP to be. If potential participants are directly asked for their average video game use during the recruitment stage of the study, they will anticipate that the study is testing the effects of video game usage. If these participants are familiar with the gaming literature cited here and on a number of video game and news websites (e.g. www.kotaku.com or www.msnbc.msn.com), this could support the expectation of being able to perform well because of their video game experience, which may then lead to more effort in the tasks and better performance (Boot et al., 2011).

One way around the majority of these problems is to use a different study design that focuses on the training of NVGPs and uses pre and post-tests to directly measure effects of specific video games. By using NVGPs, the potential problems with recruitment leading to expectancy to do well will be eliminated, and using a training paradigm will allow for interpretations of causation rather than simply correlation.

2.2.2 Training Studies (Causal in Nature)

Training studies essentially start with NVGPs and turn them into VGPs by having NVGPs train for a number of hours on a specific video game. In most cases, there are multiple groups of NVGPs that each receive training on a different type of game (Feng,
Spence, & Pratt, 2007; Green & Bavelier, 2003; Green & Bavelier, 2006b; Green & Bavelier, 2007; Green, Pouget, & Bavelier, 2010). Before and after this training, each group takes part in one or more perceptual and attentional tasks that are later used to determine if their abilities changed in any way during the training. Commonly, one group receives training on an action video game while the other groups receive training on a non-action game such as Tetris. The training regimen in these studies varies in length from seven to 50 hours over the course of two to 10 weeks.

In the third experiment of a study performed by Green and Bavelier (2006c), a training paradigm was used to evaluate the effects of action video game play compared to the effects of a visuo-motor game. Participants were categorized as NVGPs if they had little or no action video game experience within the past six months. Participants were randomly assigned to either the experimental or control group. Regardless of group, participants were given a useful field of view task (Appendix 1) before and after training on the video game.

The training regimen for each group consisted of 30 hours of game play. Training was divided into weekly training sessions that lasted from a minimum of five hours to a maximum of 8 hours with, at most, two hours of training per day. In the experimental group, participants played the game “Unreal Tournament” which is a fast paced FPS game in which the player must compete against other computer controlled characters in futuristic gladiator-style battles (Figure 3). Participants in the control condition played the game Tetris (Figure 2).
Figure 3. An illustration of the game play commonly seen in the Unreal Tournament series. Adapted from unrealtournament.com

Useful field of view performance from the pre- and post-test for each group were compared. Participants in the experimental group improved in their ability to localize the peripheral target at all eccentricities, including the 30-degree eccentricity that was beyond the visual field used in the training sessions. Participants in the control group did not change significantly. An additional finding in the experimental group was that this enhanced peripheral localization ability was not decreased by the addition of a central identification task, implying that there was no central vision cost associated with this peripheral vision improvement.

One potential problem with this study (and other video game training studies) is that a standard control group (i.e., a “no-training” group) is typically not used (e.g., Boot et al., 2008; Feng et al., 2007; Green & Bavelier, 2006b; Li et al., 2009). Furthermore, the control group that is used experiences some other sort of video game altogether (e.g.,
Tetris instead of Medal of Honor). Being exposed to a different video game is not entirely consistent with the concept of a control group (Boot, Blakely, and Simons, 2011). For proper control, two separate measures must be taken. In this dissertation, both types of control groups were used to ensure that any changes observed in the experimental groups could be attributed to the treatment, per se, and not to any other factors.

One type of control group would not receive any sort of “treatment” or training so that if any changes are found in the experimental group, they can be attributed directly to the treatment. One problem with this type of control is that they know that they are not in the experimental group, because they do not play any video games (receive any “pill”) and thus also do not experience any “side effects” of the “treatment”. In the case of video games, “side effects” might be things like increased motivation or intention to succeed on the experimental tasks because the subject knows they are part of a special “gamer” segment of the population.

A second type of control is closer to the classic “placebo” group used in drug studies. That group would not experience the “drug” (here, a video game), but would experience the equivalent to a “sugar pill” placebo. In properly controlled drug studies, placebo sugar pills have all of the “side effects” that come with the treatment drug, but lack the “active ingredient”. In this case, the “placebo” group would experience the game world, but would not receive the “active ingredient,” which is the specific aspect of the game being tested (i.e., friend vs. foe discrimination in Experiment 1, and broad attentional allocation in Experiment 2). Thus, participants in the “placebo” control groups in this dissertation were unaware that they were not in the experimental group.
32.3 Transfer of Training

One of the most interesting findings in this body of literature is that experience in video games can provide benefits that transfer broadly to many different aspects of human perception and attention, rather than just simply providing benefits within the video game. In most cases, experience provides very direct improvements that will only be evident in very similar situations or tasks. For example, Ball and colleagues (2002) showed that participants trained on a specific cognitive skill had increased performance on tasks related to that skill but performance on other unrelated tasks did not improve (Ball et al., 2002). In that study, elderly adults were provided with three different types of experience including memory training, reasoning training, and speed-of-processing training. Each of these groups was given a specific task related to these abilities: adults in the memory training group were taught mnemonics to assist with remembering lists of words or a shopping list, the reasoning training group practiced solving pattern recognition problems related to abstract reasoning tasks, and the speed-of-processing training group practiced visual search and divided attention tasks. Analyses comparing performance before and after the 10 intervention sessions found that improvements in each group were related directly to the type of training they experienced and did not transfer to everyday tasks such as the ability to use reasoning to check prescription drug dosage.

Dosher and Lu (1998) argued that specific strengthening of visual channels used to process information related to a training task and weakening of visual channels not related to a task are the defining characteristics of perceptual learning. This means that experience in a specific task should improve abilities in that task, but decrease abilities in unrelated tasks. In the case of video game play, however, the research literature has shown that
people not only improve abilities related to the game itself, but also abilities in other seemingly unrelated tasks (Basak, Boot, Voss, & Kramer, 2008; Sims & Mayer, 2002).

Basak, et al. (2008) analyzed the effects of a strategy game on cognitive decline in older adults. This study is similar to the Ball, et al. (2002) study, but rather than training the elderly adults on specific cognitive tasks, a strategy video game was used as the only form of training. In the experimental group, participants with no video game experience were trained for 23.5 hours on the real-time-strategy game Rise of Nations. Before, during and after this training regimen, a number of cognitive tasks were administered to detect any improvements in perception, attention, or cognition, which were then compared to a control group who received no training. It was found that the experimental group improved significantly in mental rotation, task switching, and visual working memory. If these improvements are categorized according to the organization used in this review, it can be seen that 23.5 hours of training on this game improved abilities in the spatial resolution of attention, executive control of attention, and the instantaneous capacity of attention. Comparing these results to those of Ball and colleagues (2002), an illustration of the diverse effects of video game play emerges. Training on a specific task or ability improves abilities directly related to the training, while video game training affects many diverse aspects of perception and attention.

The transfer of training from video games to other unrelated tasks is surprising because the video games used in the studies were not designed to train the participant on any particular cognitive skillset; they were simply designed as forms of entertainment. Utilizing the concept of perceptual learning, training in an action video game should only be able to improve the ability to succeed in that specific game, and while people who play
these games do become more successful at the game itself over time, they also improve on skills that are not directly required in the game.

As previously mentioned, Green and Bavelier (2006a) showed that training on a FPS video game expanded the player’s useful field of view to an area beyond that which was trained during game play. Also in 2006, Green and Bavelier showed that experienced VGPs were able to track two more items in a multiple object tracking task than NVGPs. In 2010, Karle and colleagues showed that VGPs were faster at switching between two tasks without the accuracy tradeoff shown in NVGPs. All of these studies provide evidence that playing video games can lead to a combination of perceptual and attentional improvements that are not found with other forms of training. It is this broad transfer of training that makes video games such an important domain to study.

These studies have laid the groundwork for research into video game training and the possible effects thereof, but what is it about these games that simultaneously train so many aspects of the visual system? With the knowledge gained from these previous studies, it is now possible to explore what aspects of these video games are leading to the cognitive and perceptual improvements. In the following experiments, specific aspects of FPS video games will be used as individual training regimens to answer this question.
CHAPTER 3

FRIEND VS. FOE DISCRIMINATION AND VISUAL INFORMATION PROCESSING

Video game training studies (as opposed to cross-sectional studies) allow one to make causal attributions about the role of video game play in visual system improvements, but the common result is that action video games are a “black box” that simply appears to work, but for unknown reasons. What is it about this genre of games that leads to improvements in fundamental aspects of human perception and attention? Why do these effects transfer to tasks that are not directly related to the game? Is there a way to deconstruct these video games to determine what specific aspects may lead to the improvements? These are the questions that the proposed studies will answer.

The main question of interest in the current study is what is it, specifically, about the action video game genre that leads to the benefits discussed above? Are there individual aspects of these games that play a larger role in these improvements than other aspects?

First, it must be determined which (if any) aspects of an action video game can be separated, and used for training. According to Green and Bavelier (2006a; 2006c), the characteristics of an action video game include fast motion, processing or tracking of multiple items simultaneously, efficient rejection of irrelevant information and objects, effective monitoring of the entire visual field, high temporal precision, and quick reaction to unexpected events. Therefore, to explore the impacts of these characteristics, Experiment 1 will focus on the video game aspect of efficiently rejecting irrelevant information and objects and Experiment 2 will focus on the effective monitoring of the entire visual field.
Second, the specific effects of training on one of these individual aspects must be measured and compared to a control group that has received no training. In the following experiments, one experimental group received video game training that contained the video game aspect being studied (the experimental group), while one group received training in the exact same video game world without the this specific aspect (the video game control or “placebo” group). Finally, participants in the third condition received no video game training at all (the no-training control group). This design allowed for comparisons between training on different aspects of action video games and also between training and control conditions.

3.1 Experiment 1 Introduction/Motivation

To determine if specific aspects of an action video game can lead to specific improvements in perception or attention, a readily available video game would not be sufficient because, by definition, it would contain all of the aspects that the design of this experiment attempts to separate. It is for this reason that all of the video game worlds in Experiment 1 and Experiment 2 were designed and created specifically for this study as a method of deconstructing and controlling the many aspects of action video games.

One consistent aspect of action video games is the need for the player to discriminate between friendly characters (friends) and non-friendly characters (foes). This can be a difficult task because of the fast pace of the game and number of stimuli being displayed. The player must make split-second decisions about how to react to given game characters, which are also called non-player characters (NPCs). If the player is to succeed and successfully navigate through the game, they must be accurate with these decisions and act upon them quickly. The player must eliminate foes before they eliminate the
player's character, and the player must not harm friends since this will usually result in some type of punishment (in some cases ending the current play-through entirely).

Experiment 1 was designed to determine if this sort of fast and dynamic discrimination between friend and foe NPCs is an aspect of action video games that enhances players’ ability to focus on relevant targets and filter out irrelevant distractors (Bavelier, Achtman, Mani, & Focker, 2011).

**EXPERIMENT 1**

The game worlds used as training in Experiment 1 were designed to be as close to a full action video game as possible. This means that there were lighting effects, realistic textures on surfaces, interaction possibilities between the player and the environment, and entities (such as trees and birds) that made the game world seem more lifelike.

The game world was designed to give the player some time to get used to the game controller, learn how to navigate the environment, practice using the in-game weapon and master one difficulty level before moving on to the next. As shown in pilot studies, this helped to decrease frustration and increase engagement in the game, which was especially important since the participants in this study were NVGPs. These inexperienced video game players were selected because the available video game training time was limited and participants with no experience in video game play have shown the capability of improving up to the level of experienced VGPs (e.g., Green & Bavelier, 2006b). Experienced video game players may have already reached the ceiling of the potential perceptual and attentional effects. Also, a training paradigm employing NVGPs was used to avoid many of the potential concerns detailed above that are commonly found in cross-sectional studies or studies that use VGPs exclusively.
Within the video game training world, participants in the experimental condition were exposed to an environment populated with friends that must be ignored and foes that must be focused upon, and participants in the video game control condition were exposed to the exact same environment, but populated only by foes. These two video game training conditions were combined with a third no-training control condition to complete the experimental design. Regardless of condition, all participants took part in three pre-test and three post-test tasks that were used to measure changes over the course of the training period.

The pre-/post-test sessions consisted of three tasks that were selected because they have been used previously in the video game literature and measure aspects of visual performance that were hypothesized to be affected by the video game training world. Task order was counterbalanced across participants and the experiment took approximately 30 minutes to complete. A short explanation of these tasks can be found below, with more detailed descriptions in Appendix 1.

The first task in the pre-/post-test was the flanker task (Eriksen & Eriksen, 1974). This task was used to measure how much of an effect irrelevant information had on the processing of relevant information. A central stimulus is presented that requires a rapid decision and response. The central stimulus is flanked by irrelevant stimuli that might either be compatible or incompatible with the correct response. When incompatible irrelevant stimuli are processed there is generally an increase in RT, whereas when compatible irrelevant stimuli are processed there is generally a decrease in RT. The difference between RTs on compatible and incompatible trials is the “compatibility effect”
and is the main measure of performance in this task (Eriksen & Eriksen, 1974; Green & Bavelier, 2003; 2006c)

The second task was the visual working memory (VWM) task. This task uses colored squares that could potentially change color between the first and second display to determine the number of items that can be held in an observer's visual working memory at a time (Luck & Vogel, 1997; Pashler, 1988). Participants tend to have near perfect performance up to their working memory capacity (typically about four items), and then steadily decreasing performance afterwards (Luck & Vogel, 1997).

The third task was the filter task, which measured how efficiently one allocated memory capacity by requiring the participant to focus attention on target items (two red rectangles) while ignoring irrelevant distractor items (between zero and six blue rectangles). If participants had perfect filtering ability, the number of distractors should not have an effect on their ability to detect a change in the target items. This allowed for the measurement of the amount of controlled access to visual working memory the participant had, or how easily irrelevant information was allowed to enter VWM (Ophir, Nass, & Wagner, 2009; Vogel, McCollough, & Machizawa, 2005).

The first hypothesis of Experiment 1 is that participants trained in the game world with both friends and foes will show an improvement in the ability to focus on relevant information and filter out irrelevant information. This improvement will be revealed by a smaller compatibility effect in the flanker task, which may be due to transfer of training from determining whether a NPC character needs to be attended to or not, to the discrimination between the relevant central arrow target and the surrounding irrelevant arrows in the task. This hypothesis is in contrast to the results that VGPs show higher
compatibility effects, on average, than NVGPs (Green and Bavelier, 2003). It is believed that the focused training on the friend vs. foe discrimination aspect of action video games will attenuate this effect. Also, since the NVGPs were inexperienced, they may be able to benefit from the attentional control improvements provided by playing this game without reaching the point of having the excess attention found in experienced VGPs. This hypothesis will be analyzed using the independent variable of training condition and the dependent variable of flanker compatibility.

The second hypothesis in this experiment is that any training in the video game world (whether in the experimental condition or video game control condition) will improve VWM capacity over the no-training condition. Furthermore, training in the friend vs. foe discrimination condition will improve VWM capacity more than training in the foes only condition. This hypothesis will be evaluated by using the independent variable of training condition, and the dependent variable of VWM capacity change as calculated from the participant’s performance in the VWM task in the pre-/post-test.

The third hypothesis is that performance on the filter task will improve more in participants trained in the friend vs. foe discrimination game world than in participants trained in the foe only game world. This will be tested by, again, using the independent variable of training condition and the dependent variable of filter task performance.

Finally, it is hypothesized that participants in either the experimental condition or the video game control condition will improve in video game ability, allowing them to reach more difficult game levels as the training time proceeds. To evaluate this hypothesis, final level completed (or the number of times the game world is completed) will be recorded for
each training day. These will then be compared for each participant to determine if the
game is engaging enough to hold interest for the entire training regimen.

Table 2. Summaries of each hypothesis for Experiment 1 including specific effects on each
dependent measurement.

| Hypothesis 1 | The effect of irrelevant information (the flanker compatibility effect) will
decrease more when trained on the friends and foes condition compared to
the foes only condition or the no-training condition due to focused training
on friend vs. foe discrimination. |
|--------------|----------------------------------------------------------------------------------|
| Hypothesis 2 | Training in either the friends and foes or foes only condition will improve
performance in the VWM task more than the no-training condition, but the
two video game training conditions will show the same benefits. |
| Hypothesis 3 | The ability to filter out irrelevant information will improve in the friend
and foe condition than in either the foe only or no-training conditions. |
| Hypothesis 4 | Performance in the training game worlds in both the friends and foes and
foes only conditions will improve throughout each training session |

3.2 Method

3.2.1 Participants

Participants were 45 college undergraduate and graduate psychology students and
were between the ages of 18 and 59 (M: 26.8). They were recruited through an online
survey about media multitasking preferences that also happened to determine the number
of hours of video games played per week. Questions pertaining to video game usage were
combined with questions from another study to eliminate any possibility of participant
expectation bias. Participants were responding to a survey about media multitasking and
their preferences for multitasking during work, so questions about the number of hours
they played video games per week were well disguised. Boot and colleagues (2011)
described how participants in video game research much not be aware of the experience
requirement to help avoid possible confounding expectation biases. In this study the issue
of expectation bias was avoided in two ways; first, only NVGPs were recruited and second, the participants were unaware of the video game aspect until they were formally invited to participate in the study. All participants gave informed consent and were awarded course credit after completing the study. The study was approved by the WSU IRB.

The survey questions are shown in detail in Appendix 2, but generally asked the participant for the average number of hours per week spent playing both console/handheld games (XBOX, Playstation, Nintendo, iPhone, etc.) and computer games (PC, Online, Downloaded, etc.). Also, the different genres of games played were collected. The genres included Action, Simulation, Driving, Puzzle/Card, Role Playing, Adventure, Strategy, Sports, and Fighting. In addition, there was an option to manually type in a game that was believed to not fit into any of these categories, or to select “I don’t play video games”. Examples of each genre were provided to assist with selections. At the end of the survey, participants were asked to enter their email addresses if they were interested in being contacted for further research opportunities. This was used in conjunction with the video game responses to recruit participants.

To be recruited, the participant must have reported zero hours of game play time on both console/handheld and computer options. To ensure that there was no confusion associated with these questions, responses to the game genres question was also used in selecting possible participants. The genres used to eliminate potential participants were the Adventure and Action styles because these game types were most similar to the games used in the training portion of the study and it was important that participants did not have experience in similar types of games. If participants indicated zero hours of game play time in an average week, reported not playing Action (FPS or TPS) and Adventure video game
types, and selected the “I don’t play video games” option in the game genres question, they were sent a formal email inviting them to take part in the study.

3.3 Apparatus

3.3.1 Pre-/Post-Test Tasks:

The pre-/post-test tasks for Experiment 1 took place on a 2-GHz Mac Pro computer driving a 17-in. (diagonal) Dell M991 CRT monitor at a resolution of 1,400 x 1,050 pixels. The tasks were programmed using MATLAB (version 2010a) and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Responses were gathered with an Apple USB extended keyboard.

3.3.2 Video Game Training Levels

The video game training levels were run on a Mac Mini computer with an Intel Core 2 Duo 2.53 GHz processor running Windows 7. A ViewSonic HD monitor with 1920 x 1080 resolution was used to display the levels.

The video game worlds were built on the Source game engine created by Valve Corporation in 2004. The worlds were created using the Source Software Developer Kit (SDK) and the Hammer Editor, which were both also produced by Valve Corporation (Morris, & Bernier, 2010; Newell, & Harrington, 2010). This software was selected because it allowed for the development and implementation of incredibly diverse environments, computer controlled artificial intelligence, realistic lighting effects, ambient sound, and Boolean logic controllers that allowed the player to interact with the game world.
3.4 Stimuli

3.4.1 Pre-/Post-Test Tasks

The flanker task used in this study was similar in concept to the one used by Green and Bavelier (2003), but differed in terms of actual stimuli and presentation. The task consisted of a fixation point followed by an array of arrows (Figure 4). Each arrow subtended 2.98° x 1.19° of visual angle. The central target arrow was surrounded by frame corners and pointed either leftwards or rightwards. In addition to the central arrow, there were either two or 14 leftwards or rightwards facing distractor arrows either flanking the target arrow horizontally, or surrounding the target arrow on all sides. This entire display appeared at a random location on the computer screen and remained on the screen until the participant responded.

In 50% of the trials, the distractor arrows flanking the target arrow pointed the same direction as the target arrow. In the other 50%, the distractor arrows pointed the opposite direction. This division was the same in both the two and 14 distractor set sizes and the ordering of the trials was randomized. This created a 2 by 2 matrix of difficulty (Figure 4). The participant pressed an arrow key on the keyboard to indicate the direction of the target arrow as quickly as possible while ignoring the directions of the distractor arrows. Audio feedback was provided after each response indicating correct or incorrect, and a practice block was used to acquainst the participant with the task.

RTs from these trials were used to estimate the flanker compatibility effect, which is a combined measure of the negative influence of inconsistent visual information and the positive influence of consistent visual information. When arrows pointing in the opposite direction flank the target arrow, responses are slowed to the extent that the distracting
arrows are processed along with the target. On the other hand, when flanking arrows point in the same direction as the target, responses are speeded for the same reason. Thus, the difference between RTs on trials with inconsistent versus consistent distracting arrows is a measure of how much influence flanking stimuli have on target processing, and by extension a measure of the selectivity of attentional processing.

Figure 4. Illustration of the flanker task used in the pre-/post-tests and the organization of trials used in the task.

The VWM task was similar to that used by Luck and Vogel (1997). The trial presentation had two arrays displayed one after another and separated by a blank screen.
The first array was shown for 90 ms, followed by a blank interval for 877 ms, and then the second array was shown for 2000 ms or until the participant responded. In each array there were four, eight or 12 squares that subtended 0.85° x 0.85° of visual angle each and were displayed in one of seven randomly chosen colors (red, green, blue, violet, yellow, white or black; see Figure 5). The participant’s task was to determine if any of the squares changed color from the first array to the second array, which occurred on 50% of the trials. Each set size was shown 40 times, in random order. Participants pressed either the QUOTE key to indicate “Change Present” or the A key to indicate “Change Absent”. Response feedback was given after every trial via written text.

This task measures the number of items that can be maintained in VWM for a short time. When the number of items being maintained during the blank interval is fewer than the observer’s VWM capacity, they should perform at ceiling when comparing their mental representation of the first array to the second array. However, if the number of items in the first array exceeds the observer’s VWM capacity, some item representations will be lost during the blank interval. When the second array appears, the observer will be able to answer correctly for any item representations remaining in VWM, but will guess on any others. Thus, once the set size of the arrays surpasses the VWM capacity of the observer, performance declines steadily.
The filter task was similar to the task used by Vogel, et al. (2005) and Ophir, Nass, and Wagner (2009). In each trial, participants saw two arrays of rectangles. The first array was presented for 90 ms, and was separated from the second array by a blank screen for 877 ms. The second array was presented for approximately 2000 ms or until the participant entered a response. Each rectangle subtended a visual angle of 0.85° x 1.05°. Each trial began with two red target rectangles, and zero, two, four, or six blue rectangles, which served only as distractors. The participant was instructed to ignore all blue rectangles. The orientation of all rectangles was randomly selected to be between 0 and 179 degrees (Figure 6).
Figure 6. An illustration of the set sizes used in the filter task.

On 50% of the trials, one of the red target rectangles changed orientation by 30 degrees in the second display. In this case, the participant was instructed to respond with “Change Present” indicated by a press of the “QUOTE” key, or “Change Absent” indicated by a press of the “A” key. Feedback text was provided after each response. The task began with a practice block demonstrating each set size of 0, 2, 4, or 6 distractors. The experimental block consisted of 20 randomly arranged trials in each of these set sizes.

Performance on this task estimates how well an observer controls access to VWM, and more specifically, whether irrelevant information is filtered from VWM or not. The core of this task is maintaining a representation of the orientation of two red rectangles from the first array during the blank interval, and then determining whether either of the
orientations changed in the second array. Performance on this core task should be quite good since VWM capacity is typically estimated to be about four items and the observer only needs to maintain two. In this task, irrelevant blue rectangles are sometimes also displayed, but if the observer maintains proper control of access to VWM, then the addition of blue rectangles should not affect performance (e.g., Luck & Vogel, 1997). However, if access to VWM is not well controlled, then the blue rectangles will enter VWM and lower performance on the task.

3.4.2 Video Game Training Worlds

There was one experimental condition and one video game control condition in this study. The experimental condition contained both friend and foe NPCs, and the video game control condition contained only foes. In a third no-training control condition, participants came in for the pre-test on day one, played no video games for days two and three, then returned on day four to take the post-test. The two video game training worlds for the experimental and video game control conditions were completely identical except for the experimental aspect being studied; in this case, the type of NPCs that inhabited the world. Each game level within these worlds was built using the same design, which introduced the player to the mechanics of the game and then slowly increased difficulty. Pilot studies indicated that this slow increase in difficulty was vital to the study because it limited the amount of frustration felt by the NVGP participants and increased participant engagement.

The first area was designed to be a tutorial in basic use of the controller for navigation. Players had to successfully navigate through a series of low walls to get to the entrance of the training arena (Figure 7). The second room introduced players to the NPCs found within the training rooms with whom the player would be interacting. An example of
the friendly character was placed in a room with a green background and an example of the foe character was placed in a room with a red background (Figure 8). The third room was considered a practice room for firing the character’s primary weapon (Figure 9). Here, the player had to kill two of the enemy NPCs (bathed in red light) before the exit door would open (friends were impossible to target). The final practice room was a duplicate of the actual training rooms, but with only one of each NPC (Figure 10). See tinyurl.com/ChrisDissertation for videos of the practice rooms and training levels.

*Figure 7.* The first practice room designed to teach the player how to use the controller to move the character through the game world.
Figure 8. The second practice room designed to teach the player about the friend and foe NPCs inhabiting the game world.

Figure 9. The third practice room designed to teach the player how to use the virtual weapon within the game to eliminate only foe NPCs.
Figure 10. The final practice room designed to provide the player with practice in a simplified version of the following training rooms.

3.4.3 Design of Game Levels (Practice)

The navigation practice room contained some obstacles that required the player to practice using the controller to navigate around to reach the exit. These obstacles required the use of both left and right motion and left and right rotation, which taught the player how to use both controller analog sticks (Figure 7).

Once the player successfully navigated through the obstacles, they moved on to the example NPC room (Figure 8). This room contained an example of the characters that would be seen in the following rooms. The NPCs appeared to be contained behind a gate so that the player did not feel the need to interact with them. The NPCs reacted to the player in an appropriate manner, such as the foe character drawing a weapon and the friend character making a pleasant comment. Text instructions about what action to take when
each character was encountered (i.e. do not harm this character) were also displayed onscreen while the player was looking at the NPC.

Once the player successfully moved through this room, the virtual weapon was picked up and the door to the next practice room opened. In this room, a stationary example of each NPC was seen (Figure 9). The goal was to eliminate the foes, which would cause the exit door to open. This room was designed to help the player get used to the method of eliminating the foes that was used in the upcoming actual training rooms. To eliminate an enemy character, the player pressed the appropriate controller button while the targeting indicator was on the NPC. Each press of the controller button fired a bullet from the virtual weapon, and each NPC required between three to six bullets before being eliminated.

In the final practice room, the player interacted with NPCs that were capable of moving and attacking (or simply moving in the case of the friend NPCs). When the player was ready, they guided their character to fall into the room that contained the NPCs (Figure 10). This drop at the entrance to the room did not harm the player's health but ensured that the player was not able to backtrack through the world, away from the enemies. This simplified navigation for the player and also avoided problems with experiment length and planned difficulty increases. In this room, the player eliminated the foe and avoided harming the friend if he or she was in the “Friends and Foes” experimental condition, or simply eliminated the two foes if in the “Foes Only” video game control condition.

If a friend was hit, the lights in the room went dark for three seconds and a message stating, “Do not hurt your friend” appeared. This was intended to be a form of punishment that would lead the player to correctly undertake the task of only eliminating the foes. In
this room, the characters utilized artificial intelligence that allowed them to be interactive and immediately run towards the player. The friends simply attempted to maintain close contact with the player while the foes attempted to attack the player with a short-range weapon similar to a club. Once all enemy characters were eliminated, the exit door opened and the player was able to move to the actual training rooms. The training rooms were exactly the same as this final practice room, but with increasing difficulty levels.

3.4.4 Design of Game Levels (Training)

The training levels consisted of four rooms that had to be cleared before the player could access a more difficult level. Each of the rooms in a level was kept at a consistent difficulty by allowing only a specific number of NPCs to appear. The four rooms had to be cleared of foe NPCs without the player's character being killed. If this did occur, the player started over at the beginning of the current difficulty level. This ensured that a participant received additional training at the difficulty level that was at their threshold before moving on to even more challenging rooms. After completing each level, the player's character was provided with items to repair any damage taken in the previous four rooms. This allowed the player to begin each new difficulty level with a fully replenished character. This process continued until the participant completed all 16 rooms, after which there was a final room with a “goal”. At this point, the participant was asked to start the levels over from the beginning. This process continued until the training time for that session was reached. See Figure 11 for a visualization of the number of friend and foe NPCs encountered in each level and each video game training condition.
Figure 11. A depiction of the number of friend and foe NPCs inhabiting rooms in each game level and for each video game training condition. The green figures represent Friend NPCs and the red figures represent Foe NPCs.

At the end of each day of training, the most difficult level that the participant reached was recorded to assess whether the participant performed better than on previous training days. This was a method of testing whether the game was engaging enough to keep the participant interested. During the final day, the participant only performed the post-test tasks. This separate final day was decided upon to eliminate the possibility of improvements simply because of physiological reactions to the stressful and exciting game play. This has been mentioned as a possibility by Green, Li, and Bavelier (2009), and
discussed in greater detail in a study by Carnagey and colleagues (2007) where violent action video games were shown to increase measures of physiological excitement such as heart rate and Galvanic skin response. In a review of the literature on violent video games, a number of studies found these games to have similar effects on aggressive behavior and physiological responses (e.g., Carnagey, Anderson, & Bushman, 2007) though in some studies, violent video games were found to have no effects (Dill & Dill, 1998).

3.5 Procedure

The overall design of the study was a four day long experiment with one pre-test session, one post-test session and two hours of video game training, overall. Day one consisted of a half hour of pre-test tasks, and a half hour of training in the video game world. Days two and three consisted of 45 minutes of training in the video game world. Day four consisted of a half hour of post-test tasks that were the same as the pre-test tasks but in a different order. See Figure 12 for an illustration of the experimental schedule.

![Figure 12](image_url)

*Figure 12*. The training and testing schedule used for Experiment 1. Top: Schedule for the friends vs. foes and foes only condition. Bottom: Schedule for the no-training condition.
On the first day, participants were required to read and sign an informed consent document. Once this was completed, the participant performed the three pre-test tasks in a counterbalanced order so that each possible order of tasks was accounted for across participants. After completing these tasks, the participant was taken to a different room where the game training session was explained. Before starting the training session, the experimenter explained the use of the game controller, the information portrayed on the Heads Up Display (HUD), and gave some basic tips about navigating through the game world. Figure 13 shows an instruction page that was present at all times during the training phase. This instruction page helped show the player the functionality of the controller buttons. The experimenter stayed with participants as they played through the practice rooms on day one. After the practice rooms were completed, the experimenter asked for questions, and then left the participant. A digital timer was used to notify the experimenter when the training session was completed. At this time, the experimenter notified the participant, reminded them of their schedule for the next day, and thanked them.

*Figure 13*. The illustration page used to help the player understand the functionality of the game controller. This was visible at all times during training.
On days two and three, participants were taken directly to the video game training room where they started playing at the beginning of the game world. After answering any questions participants had, they were left to play the video game for 45 minutes. Again, a digital timer was used to notify the experimenter when the training session was completed. Occasionally during the training sessions, a participant reached the goal of the game world (i.e., cleared all of the game levels) before the training session was completed. In this case, the experimenter reset the game, and the participant played through the world again from the beginning. In these rare occurrences, the experimenter recorded the number of times the goal was reached in each session as a measure of participant engagement rather than simply recording the final level reached at the end of each session.

On the final day, the participants only took part in the post-test tasks. These tasks were identical to the pre-test tasks, but were counterbalanced so that no participant experienced the post-test tasks in the same order as they did in the pre-test. After the post-test tasks were completed, the participants were debriefed, thanked for their time, and given course credit for participating in the experiment.

3.6 Results

Prior to performing statistical analyses, trials with RTs lower than 300 ms or higher than 2000 ms were removed from the analysis. In total, 27 trials were removed, which made up fewer than .2% of trials, overall. (White, Brown, Ratcliffe, in press). A 2x3x2 (Time x Condition x Set Size) mixed ANOVA was performed on the flanker compatibility effect data to determine whether set size had an impact on performance in the flanker task. This analysis failed to detect a main effect of set size, \( p = .205 \), and therefore these data were collapsed across variations in set size. A simplified 2 x 3 (Time x Condition) mixed ANOVA
on flanker compatibility data failed to detect a significant main effect of time, \((p = .086)\), or training condition \((p = .972)\). Also, no significant interaction between training condition and time \((p = .407)\) was found. Figure 14 shows the change in the flanker compatibility effect from pre-test to post-test in each condition.

*Figure 14.* The flanker compatibility effect at pre-test and post-test. No significant performance differences between groups. Error bars represent standard error of the mean.
The effects of video game training on VWM capacity were analyzed using a 2x3 (Time x Condition) mixed ANOVA on the dependent variable of average VWM capacity. Results of the analyses indicated that there was neither a significant main effect of time ($p = .448$) nor a significant interaction between training condition and time in terms of VWM capacity ($p = .198$). Analysis of the between subjects effects showed no main effect of condition on VWM capacity ($p = .898$). The change in VWM capacity from pre-test to post-test for each condition is shown in Figure 15.
Figure 15. VWM capacity at pre-test and post-test. No significant differences between performance in the three groups were found. Error bars represent standard error of the mean.

To determine if a main effect of set size was present in the filtering capacity results, a 2x3x3 (Time x Condition x Set Size) mixed ANOVA was performed on average filtering capacity as the dependent variable. No main effect of set size ($p = .893$) was found, so a new mixed ANOVA on average filtering capacity was performed to analyze effects of condition and time on filtering capacity.
After collapsing set size, the new 2 x 3 (Time x Condition) mixed ANOVA on the average filtering capacity dependent variable showed a significant main effect of condition on filtering capacity, $F(2, 132) = 6.51, p < .01$, partial $\eta^2 = .09$. However, no main effect of time ($p = .219$), and no significant interaction between training condition and time ($p = .588$) were present.

To further analyze the main effect of condition on filtering capacity, a post-hoc Tukey test was performed to determine which conditions, in particular, were significantly different. Results indicated that participants in the group required to make a distinction between friends and foes had a reliably higher filtering capacity than participants who were not, $p < .01$, or who received no-training, $p < .05$ (see Figure 16). This was not evident when analyzed with training time however, which implies that participants in the Friends and Foes condition had a higher filtering capacity even before beginning the experiment.
Figure 16. Post-test filtering capacity scores in the friends and foes condition appear to show more increase than any other conditions. Error bars represent standard error of the mean.

To determine whether average game performance over time, a 3 x 2 (Time x Condition) mixed ANOVA was performed on data reflecting highest game level achieved per day. This ANOVA detected a significant main effect of time $F(2, 56) = 20.4, p < .001$, partial $\eta^2 = .602$ and a significant main effect of condition $F(1, 28) = 4.45, p < .05$, partial $\eta^2$. 
2 = .137, but no interaction between time and condition (p = .30). These results are illustrated in Figure 17, which shows the increase in performance across the training phase for each condition, but no real difference in the amount of improvement between the groups.

Three paired t-tests were performed on the results in each condition to determine whether the change in performance was significant. T-tests performed on the results from the friends and foes condition showed significant increases in performance from Day 1 to Day 3 \( t(14) = 5.492, p < .001 \), from Day 1 to Day 2 \( t(14) = 3.055, p < .01 \), and from Day 2 to Day 3 \( t(14) = 2.418, p < .05 \). Results of the t-tests on the foes only condition performance showed significant improvement between Day 1 and Day 3, \( t(14) = 3.551, p < .01 \), and significant improvement between Day 1 and Day 2, \( t(14) = 3.637, p < .01 \). There was no significant improvement from Day 2 to Day 3 (\( p > .05 \)).
Figure 17. Participants in the friends and foes and foes only conditions increased in game performance significantly at each training day. Participants in the foes only condition increased significantly from the first to second day, but not on the third day. Error bars represent standard error of the mean.

Finally, a 3 x 2 (Time x Condition) mixed ANOVA was used to analyze the average number of times the game was completed by each group during the training phase of the experiment. This ANOVA detected a main effect of time $F(2, 56) = 20.47, p < .001$, partial $\eta^2 = .251$, but no interaction of time and condition ($p = .33$) nor a main effect of condition ($p = .167$). These results are presented in Figure 18, which shows that game performance increases as a function of time but that training condition does not have a differential effect.

Again, three paired t-tests were performed on the number of times the game was completed to determine whether the change in performance as training time progressed was significant. Results of the t-tests on the results from the friends and foes condition
showed no significant change in performance from Day 1 to Day 3, from Day 1 to Day 2, or from Day 2 to Day 3. Results of the t-tests on the foes only condition performance showed significant improvement between Day 1 and Day 3, $t(14) = 3.44, p < .01$, but no significant improvement from Day 1 to Day 2 or from Day 2 to Day 3 (both $p > .05$).

*Figure 18.* Participants in the friends and foes and foes only conditions did not show significant improvement in the number of times the game was completed on any training day. Participants in the foes only condition showed significant increase from the first to the third day, but not between any other training days. Error bars represent standard error of the mean.
3.7 Discussion

Results of the flanker task indicated that training condition did not have a significant effect on whether the compatibility effect changed over time. Recall that Hypothesis 1 anticipated that participants in the friends and foes condition would experience a larger decrease in the flanker compatibility effect than those in either of the other two conditions because the discrimination between friend and foe characters is an aspect of FPS video games that forces the player to select which characters require focused attention and which do not. This forced selection allows the player to practice allocating attention to relevant objects (foes) and ignoring irrelevant objects (friends). The results from these analyses do not support Hypothesis 1.

Since training time was limited to two hours, it is worth looking at trends in the results to determine if training had any marginal effects that could provide further insight about the relationship between friend vs. foe discrimination and the flanker compatibility effect. Figure 14 shows the amount of change in the flanker compatibility effect found in each condition. Trends show that participants in the friends and foes condition experienced a larger average decrease in the flanker compatibility effect than participants in either the foes only or the no-training condition.

It is important to look at the scores at both the pre-test and post-test to determine if these results are due to differences between the groups that were evident prior to training, or after training (Figure 14). The flanker compatibility effect values at the pre-test and post-test for each condition shows a lack of significant differences between conditions.

No statistically significant effects were found in VWM capacity, either between groups or over time, indicating that a comparable change in VWM capacity was found in all
three conditions, rather than just in the two video game training conditions as hypothesized. This result fails to support Hypothesis 2. However, there is something interesting about how Hypothesis 2 failed, which is illustrated in Figure 15. Participants in both the friends and foes condition and the no-training condition show trends towards similar amounts of VWM capacity increase, but participants in the foes only condition showed a trend towards VWM capacity decrease of almost the same amount. While it is interesting that the trends of these data may show differences in the change in VWM capacity with regard to the type of training that participants experienced, there is no statistically significant difference between groups.

Again, it is important to determine if group differences prior to training played a role in the slight decrease in VWM capacity in the foes only condition. In Figure 15, it is evident that there were no real differences between groups at either the pre-test or the post-test, but the decrease in performance is still evident. VWM did not receive any transfer of training from this video game aspect, as indicated by the lack of statistically significant results. Evidently, the discrimination between friends and foes does not utilize VWM enough to provide any sort of improvement in capacity.

Hypothesis 3 anticipated more improvement in filtering capacity for participants in the friends and foes condition than for participants in the other two conditions. Results from the filter task show a main effect of condition, which post-hoc tests revealed to be mainly due to participants in the friends and foes condition having a higher average filtering capacity than participants in either the foes only condition or the no-training condition (Figure 16). This result does not provide support for Hypothesis 3, because no interaction of training condition by time was observed. Players in none of the three
conditions showed a statistical difference in their ability to keep distracting information from entering VWM. In the friends and foes condition, perhaps no difference in performance was found because even though the friend characters were designed to be irrelevant, the player was still required to allocate some attention to successfully avoid them. Filtering capacity may not have been activated at all since every item was relevant and required processing. In other words, access to the participant’s VWM was not well controlled in either game training condition because in the foes only condition, all NPCs were relevant because they were the targets that required action, but in the friends and foes condition, the friends were also relevant because they required attention so that they could be avoided.

Hypothesis 4 predicted that performance in each of the two game training worlds would increase as training progressed. This would be a sign that the game levels were engaging and challenging enough to keep participants involved in the training, and that learning was taking place. Figure 17 shows the average participant progress through the game world by illustrating the furthest level reached by the end of the time on each day of training. This graph, and the results of the ANOVA and the t-tests, indicate that both of the game worlds showed significant improvement in furthest game level reached as the training phase progressed. The only exception is that participants in the foes only condition did not show significant improvement between Days 2 and 3. This tempers support for Hypothesis 4 by adding the qualification that participants in the foes only condition may have received a slightly unequal training difficulty that could have resulted in a less engaging experience (or some other difference). Figure 18 shows that the average number of game completions in each condition did increase throughout the training phase, and the
AVOVA indicated that there was no difference between the rates at which this increase occurred. The t-tests however, indicated that there was not a significant difference between performance on any day except for between Days 1 and 3 in the foes only condition. This equivalent (but not statistically significant) improvement provides further support for Hypothesis 4 by showing that participants both game training conditions improved their performance on the game as the training phase progressed. Overall, the difficulty of the two conditions may need to be adjusted in further research, but support for Hypothesis 4 is still present.

This potential for a lack of difficulty in the foes only condition was anticipated from pilot studies and accounted for by adding more foes to each game level than were experienced in the friends and foes condition (Figure 11). The potential of the foes only condition to result in lower performance because of a lack of engagement is a valid point, but a different interpretation also presents itself. Figure 18 shows that participants in the foes only condition spent most of their training time in levels 3 and 4. According to Figure 11, these levels contain more foe NPCs than the same levels in the friends and foes condition. So while these participants may have found the game easier to complete, they actually experienced more focused training because they were required to eliminate additional foes. Under this interpretation, participants in the foes only condition should have experienced additional improvements in task performance even though their training may have been less engaging.

Although this interpretation is plausible, the potential lack of engagement could be a limitation of Experiment 1. A simple way to eliminate this is to add more foe NPCs to each training level in the foes only condition. If the total number of foe NPCs in this condition
were equal to the total combined number of friend and foe NPCs in the other training condition, it would ensure that participants in all training conditions would experience the exact same number of visual stimuli in each level. Alternatively the number of foe NPCs in the foes only condition could be lowered so the same number of foes in each level of this condition appear as each respective level in the friends and foes condition. This would provide a consistent number of foe characters to eliminate in each training condition and could lead to more consistent engagement. The arrangement of the number of friends and foes in Experiment 1 was considered a compromise between these two possibilities.

3.7.1 Experiment 1 Limitations

While the game world was designed to eliminate as many extraneous video game aspects as possible so that the training would be focused on friend vs. foe discrimination, the player was still required to navigate through the game world while eliminating foes. In some ways, this helped the training session feel more like playing a complete video game, potentially leading to higher external validity, but in other ways this could have diluted any effects provided solely by the intended experimental training aspect.

To determine if this inclusion of manual navigation had any actual effect on the results, a further study should be performed to compare the current video game training level with an identical game level without the navigation aspect. In this proposed study, the first experimental condition would be identical to the friends and foes condition from this experiment. The second experimental condition would train participants in the exact same game world, but the game character would be placed on a moving platform such that the participant would only be required to rotate their view and not to also move the character. If these two conditions result in similar effects on the flanker, VWM and filter tasks, it will
show that navigation did not dilute the effects found in this experiment, but if the two experimental conditions show different results, it may be concluded that navigation is an aspect of FPS games that should be tested separately from the others and provide stronger effects than the ones detailed here.

Finally, the most obvious limitation of this study was that participants were only trained for two hours in the video game world. This was due to the necessity of using classroom credit points in exchange for participation. A straightforward extension of this study would add several more levels of difficulty to the game world and recruit a paid subject pool to participate in the experiment for a longer period of time. If participants could complete 10 hours of training across 2-3 weeks in these custom-designed video game worlds, several of these marginal effects might have time to bloom to significance. This first study pioneers the approach of using custom-designed video game levels for identifying specific attentional and perceptual benefits of video game play – many other studies with better access to resources will surely follow.
FOCUSED VS. DISPERSED ATTENTION AND VISUAL INFORMATION PROCESSING

A frequently encountered characteristic of FPS video games is the visual perspective of the player. Since the player’s view of the world is limited to the view of the character in the game, information about the virtual world must be maintained even when the perspective of the game character does not allow the entire game world to be visible onscreen. Video game worlds are constantly changing with new areas to explore or new enemies to battle, often appearing without notice. Players must use onscreen cues and maintain a mental map of the game world so that they can quickly navigate through it or anticipate the appearance of enemies coming from offscreen.

4.1 Experiment 2 Introduction/Motivation

A successful FPS video game player must not only understand where they are in the world, but also be aware of the locations of enemy NPCs. This experiment examines whether a game world with enemies at many locations affects perception and attention differently than a game world with enemies at a single location.

Keeping track of an entire game world relies heavily on indicators built into action video games. If an enemy NPC attacks the player from a location that is not visible onscreen, a peripheral portion of the screen becomes highlighted, indicating to the player where they should look to find the attacker (Figure 19). Such indicators relieve some attentional load by helping the player to know when it is important to focus attention to the periphery. These indicators may also serve as exogenous attention cues, automatically summoning the players’ attention to the periphery (Castel, et al., 2005; Posner, Cohen, 1984). Green and Bavelier (2006a) showed that action video games improve useful field of
view (UFOV) task performance and expand peripheral vision to areas beyond that trained by the video game. Whether or not this improvement is due to the exogenous cues and the requirement of keeping track of the game world is the main research question in Experiment 2.

*Figure 19.* An illustration of peripheral indicators used to indicate damage originating from offscreen (red parallelograms on the left and right side of the screen). Adapted from www.lowpings.net
EXPERIMENT 2

In this experiment, the effects of whether enemies are grouped together or spread out during action video game play are studied, without confounding effects from other game aspects. As in Experiment 1, custom designed game worlds were created, recruited participants who were all NVGPs, and trained them how to use the game controller and about the other information present on the screen before beginning the actual experimental training sessions.

Analogous to our design in Experiment 1, this experiment had a video game experimental condition, a video game control condition, and a no-training control condition. In the experimental condition, participants were placed into a game world where enemy NPCs were distributed throughout an entire arena. In the video game control condition, participants played through a game world where enemy NPCs always came out of a single tunnel in a game arena. In the no-training control condition, no video game training occurred. Again, regardless of condition, all participants took part in three pre-test and post-test tasks that were used to assess changes over the course of the training period.

As in Experiment 1, the pre-/post-test sessions consisted of three tasks that were counterbalanced for each participant and took approximately 30 minutes to complete. A short explanation of the UFOV task can be found below, with more detailed descriptions in the method section of Experiment 1 and Appendix 1.

The flanker task and the VWM task used in Experiment 1 were used in Experiment 2. They were identical to the tasks described previously. In addition to these, a UFOV task was added that required the participant to complete a simultaneous central letter identification task and a peripheral localization task. This design is similar to that used by
Ball, Beard, Roenker, Miller, and Griggs (1988) and Green and Bavelier (2003; 2006c), and was selected for use here because of its proven ability to detect changes in video game training studies.

The first hypothesis of Experiment 2 is that participants who are trained in the game world with a wide focus of attention will experience more positive effects in the UFOV task than those trained in the game world with a more centralized focus of attention. Specifically, these participants should be able to localize peripheral targets at greater eccentricities from the central fixation point. The independent variable of training condition and the dependent variable of average UFOV target display duration for each eccentricity will be used to evaluate this hypothesis.

The second hypothesis is that those participants who train in the video game world will improve their performance in the VWM task more than those participants who receive no video game training. This hypothesis will be evaluated using the independent variable of training condition, and the dependent variable of VWM capacity as calculated from the participant’s performance on the VWM task.

Third, it is hypothesized that performance on the flanker task will not differ significantly between the experimental group and the video game control group. Since the training worlds used to train both of these groups only contain enemy NPCs, the player’s ability to discriminate between relevant and irrelevant information should not be affected. This would be reflected in the flanker task compatibility effect and will be evaluated using the independent variable of training condition and the dependent variable of compatibility effect.
Finally, it is hypothesized that participants in both video game training conditions will improve in their abilities to play the game, which will allow them to reach more difficult game levels as the training time proceeds. To evaluate this hypothesis, the furthest enemy NPC wave reached and the number of times all waves are completed will again be recorded for each participant on each training day. This will indicate whether each participant was engaged in the game enough to improve the necessary skills to reach more advanced levels.

Table 3. Summaries of the hypothesis for Experiment 2, including specific effects for each dependent measurement.

<table>
<thead>
<tr>
<th>Hypothesis 1</th>
<th>Training in the multiple enemy NPC location condition will improve peripheral target localization at larger eccentricities in the UFOV task more than training in the single enemy NPC location condition or the no-training baseline condition.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypothesis 2</td>
<td>Training in either video game world condition will improve performance on the VWM task compared to the no-training baseline condition.</td>
</tr>
<tr>
<td>Hypothesis 3</td>
<td>The flanker compatibility effect will not differ significantly between experimental and video game control conditions.</td>
</tr>
<tr>
<td>Hypothesis 4</td>
<td>Video game performance will improve over time, with participants in both experimental and video game control conditions reaching more advanced levels.</td>
</tr>
</tbody>
</table>

4.1 Method

4.1.1 Participants

Participants were 27 college undergraduate and graduate psychology students, and members of the community and were between the ages of 18 and 59 (M: 30.93). They were recruited using the same online media multitasking survey method as Experiment 1 (Appendix 2). To review, participants were covertly recruited from a screening survey for another study. As before, expectation bias was avoided by only recruiting NVGPs who
reported zero hours of console/handheld and computer game play and reported having not played action or adventure game genres. To further reinforce our minimization of expectation biases, the participants were not informed of the inclusion of video games in the experiment until the training sessions began. All participants signed an informed consent document and were awarded course credit after completing the study. The study was also approved by the WSU IRB.

4.2 Apparatus

4.2.1 Pre-/Post-Test Tasks

The pre- and post-test tasks for Experiment 2 took place on the same 2-GHz Mac Pro computer and the same 17-in. (diagonal) Dell M991 CRT monitor at a resolution of 1,400 x 1,050 pixels used in Experiment 1. The tasks were programmed using MATLAB (version 2010a) and the Psychophysics Toolbox (Brainard, 1997; Pelli, 1997). Responses were gathered with an Apple USB extended keyboard.

4.2.2 Video Game Training Levels

The video game training levels were run on the same equipment used in Experiment 1: a Mac Mini computer with an Intel Core 2 Duo 2.53 GHz processor running Windows 7, and a ViewSonic HD monitor with resolution of 1920 x 1080. The video game worlds were built using the Source game engine, the Source Software Developer Kit (SDK) and the Hammer Editor (Morris, & Bernier, 2010; Newell, & Harrington, 2010).

4.3 Stimuli

4.3.1 Pre-/Post-Test Tasks

As mentioned above, both the Flanker task and the VWM task from Experiment 1 were used in the Experiment 2 pre-/post-test. These tasks were counterbalanced with a
UFOV task for each participant. The UFOV task was similar to the task used by Ball and colleagues (1988) and Green and Bavelier (2006c).

The UFOV task began with ten practice trials to acquaint the participant with the procedure. Each trial consisted of a central fixation point subtending .9° x .9° of visual angle, and surrounded by four “spokes” of five squares, each subtending 1.19° x 1.19° of visual angle (Figure 20). These spokes were numbered 1 through 4 and arranged at diagonals centered at the fixation point with each box corresponding to 3.28°, 6.56°, 9.53°, 12.78°, and 16.01° of eccentricity, respectively. During the stimuli phase, one of four capital letters (E, F, H, or I) appeared at the central fixation point at a random orientation (45, 95, 135, 180, 225, 275, 315, or 360 degrees). The central letters subtend a visual angle of .13° x .6°. At the same time, one of the 16 peripheral squares was filled with a high luminance cue, lighter than the dark gray background. This display was presented onscreen for a short amount of time that varied depending on the staircase recommendation for that trial to probe the participant’s threshold for each eccentricity. The stimuli display time started at 200 ms and was adjusted in response to participant performance in 13.33 ms steps (i.e., the refresh rate of the monitor), based on recommendations from the QUEST algorithm (Watson & Pelli, 1983). Each peripheral eccentricity was cued 32 times throughout the entire task, and the QUEST algorithm’s best estimate of the subject’s display threshold at each eccentricity was recorded at the end of the task. The QUEST algorithm uses Bayesian estimation methods to quickly and accurately determine perceptual thresholds (Farrell & Pelli, 1999; King-Smith, Grigsby, Vingrys, Benes, & Supowit, 1994; Nachmias, 1981; Pelli, 1987; Pelli, & Farrell, 1994).
Figure 20. Illustration of the UFOV task showing the stimuli phase and the response phase. To correctly respond to this trial, the participant would enter “I” and “1” on the keyboard, followed by “spacebar”.

In each trial, the participant identified the letter present in the central location by pressing the appropriate keyboard key (E, F, H, or I). Then, the participant identified the location of the peripheral target by reporting the spoke on which the target appeared by pressing the appropriate key (1, 2, 3, or 4). The participant was not asked to identify the exact location of the peripheral target because, according to Ball and colleagues (1988), when participants correctly identified the spoke where the peripheral target appeared, they also correctly identified the eccentricity at which it was present 90% of the time. Responses were dynamically highlighted on the screen as it was entered so adjustments could be made if necessary before locking in the final response. The participant’s response was not recorded until they pressed the space bar to indicate the response was complete. Visual feedback was given by highlighting correct responses in green and incorrect responses in red. Response time for each trial was recorded, but only trials in which both the central task and the peripheral task counted as correct for the QUEST staircases calculating threshold exposure RT for each eccentricity. This allowed the QUEST staircase
algorithm to rapidly estimate average, standard deviation, and mode RT separately for each eccentricity, for each participant. In addition, the UFOV task records proportion correct for both central and peripheral targets in each trial, which is the dependent variable that will be used in the analyses.

4.3.2 Video Game Training Worlds

There was one experimental condition and two control conditions in this study. Both the experimental condition and the video game control condition contained only enemy NPCs, but in the video game control condition, the NPCs only appeared from a single location. In the experimental condition, the enemies appeared from numerous locations around the player’s character. In a similar, controlled design to Experiment 1, the two video game training worlds were identical except for the locations at which enemy NPCs appeared around the character. The game world in the experimental and video game control conditions consisted of only one very large room. The player’s character was located on the top of a pedestal and was unable to walk in any direction. The player’s view could be rotated or moved up or down to facilitate aiming at the doorways that opened into the room. Initially, a single enemy NPC appeared at the central doorway, but the number of enemy NPCs appearing in the room was steadily increased in such a way that early waves were much easier than later waves.

This design was used to maintain similarities with the UFOV task, which required participants to focus in the center of the screen while still allocating attention to the periphery. When an enemy is targeted in the game world, the player must allocate attentional resources to ensure that the enemy does not move out of the targeting reticle. During this process, other enemies may appear on-screen or begin to fire upon the player
from off-screen, activating the peripheral damage indicators. When this occurs, the player must maintain focus on the targeted NPC, but divert some attentional resources to the new visual information elsewhere on the screen. It is this focus of attention at the center of the screen while attention is also being allocated to the periphery that links the game world so closely with the UFOV task.

Before the first wave of enemy NPCs began, onscreen text was displayed to indicate to the player how to succeed in the game. The difference between the two experimental conditions was that the locations of the appearance of the enemy NPCs. See Figure 21 and Figure 22 for examples of the training room, the different video game training conditions and the enemy NPC waves. Also, tinyurl.com/ChrisDissertation/ contains example videos of the video game practice rooms and training levels used in this experiment.

![Single Door Condition](image)

*Figure 21.* In the video game control condition NPCs only appeared at a single location with the number of NPCs at that location increasing.
Figure 22. In the experimental condition, enemy NPCs appeared at multiple locations around the room (notice the enemy in the upper right). Only a single NPC appeared in each doorway at a time. Also notice the peripheral damage indicator on the right side of the screen.

4.3.3 Design of Game Levels

The game world in this experiment was designed to allow players to focus on localizing (aiming) and eliminating enemy NPCs without the need for navigation. Since the character was unable to move from the central pedestal, the only goal was to rotate and aim quickly and accurately enough to eliminate the enemy NPCs before they had a chance to overwhelm the player. There were three floors within the octagonal shaped room that made up the game world. Each wall contained a door that led to a location where an enemy NPC could appear. When an enemy NPC appeared, it navigated to the door opening and began firing at the player. The enemy NPCs did not move from the level on which they appeared, but had the ability to move from one doorway to another or hide behind a wall for a short time. This helped to keep the game more engaging and interesting for the player and also helped to increase difficulty of later enemy NPC waves.
As the enemy NPCs began to appear, the player gained access to the virtual weapon used to eliminate the NPCs. Each NPC required only one successful hit to be eliminated, and after eliminating a pre-determined number of enemy NPCs, the difficulty level increased and more NPCs began to appear. Also, at pre-determined time intervals, a supply of bullets for the virtual weapon and a supply of health for the character were both dropped. This allowed the player to maintain enough health and ammunition to continue the training and reach the more difficult levels of the game.

In the experimental condition, as the player advanced to higher difficulty levels, enemy NPCs would begin to appear from doorways further away from the first “active” doorway. This meant that as the player continued through the game, the number of “active” doorways would consistently increase so that by the end of the game, all 24 doorways were producing a single NPC at a time. The maximum number of NPCs that the player needed to eliminate in this condition was 348 in total. This provided the player with motivation to allocate attention to areas not displayed on screen and also allowed peripheral damage indicators to appear (Figures 23 and 26).

The training game world used in the video game control condition was essentially identical to the world used in the experimental condition, with the exception of where enemy NPCs appeared as the player progressed through the game. In this condition, enemy NPCs only appeared from a single central doorway, but the number of enemies that appeared in that doorway was increased similarly to the experimental condition so that by the end of the final level, the participant also had to have eliminated 348 NPCs total. At the beginning of this condition, only one enemy NPC appeared in this doorway, but as the player advanced, the number of enemies increased until the difficulty was approximately
the same as the experimental condition. See Figure 23 for an illustration of the number of enemy NPCs in each wave and the locations of the “active” doorways.
Figure 23. Illustration showing enemy NPC location for each wave in both the experimental and video game control conditions. Also showing the number of enemies in each wave.
4.4 Procedure

The overall experimental design was identical to Experiment 1; a pre-test and 30 minutes of video game training on Day 1, 45 minutes of training on Days 2 and 3, and only the post-test on Day 4 (see Figure 12). The only slight change was the addition of a test for visual color limitation prior to the beginning of the study (Dvorine, 1955). Even though the colors used in the VWM task were not equiluminant and therefore unlikely to cause difficulty for participants with color-limited vision, the Dvorine plates were used as an additional safeguard in this study. Before the video game training began, the experimenter explained the use of the controller and the HUD, as was done in Experiment 1. In the game world of this experiment, there was no need for dedicated practice rooms since the player did not engage in any complex navigation or NPC discrimination. Aiming practice was built in to the training session so that the first few minutes of game play acted as the practice for the remainder of the session. The experimenter was present during the first few minutes of the first level (the practice portion) to answer any questions and help the player become comfortable with the controls and the concept. After the practice portion, the experimenter left the participant in the training room for the remainder of the training time.

4.5 Results

Using the same method as in Experiment 1, trials with RTs lower than 300 ms or higher than 2000 ms were removed from the analysis. In total, 20 trials were removed, which made up fewer than .2% of total number of trials. (White, Brown, Ratcliff, in press). Next, a 2x3x2 (Time x Condition x Set Size) mixed ANOVA was performed on the flanker compatibility effect dependent variable to determine whether performance in the flanker task was affected by set size. This analysis detected a main effect of set size, $F(1, 24) =$
11.06, $p < .01$, $\eta_p^2 = .315$, and therefore set size was not collapsed during subsequent analyses. A pairwise comparison between the two set sizes indicated that the larger set size (14 distractor arrows) resulted in a longer RT than the smaller set size (2 distractor arrows), $(p < .01)$. The ANOVA did not detect a main effect of training condition ($p = .196$), a main effect of time ($p = .81$), a significant interaction between training condition and time ($p = .893$), an interaction between set size and condition ($p = .641$), an interaction between time and set size ($p = .576$), or a three-way interaction between time, set size and condition ($p = .76$).

The effects of video game training on VWM capacity were analyzed using a 2x3 (Time x Condition) mixed ANOVA. The results of this ANOVA indicated that there was a significant main effect of time for VWM capacity, $F(1, 78) = 12.69$, $p < .001$, $\eta_p^2 = .14$, as well as a significant interaction between training condition and time $F(2, 78) = 4.22$, $p < .05$, $\eta_p^2 = .098$. Figure 24 shows the change in VWM capacity in each condition over time. Analyses of the between subjects effects showed that there was no main effect of condition on VWM capacity ($p = .248$).

To further explore the interaction of training condition by time, VWM scores before and after training were compared via t-test for the single door condition, the multiple doors condition and the no-training condition (see Figure 24). These planned comparisons revealed that participants’ visual working memory capacity significantly improved in the multiple doors condition, $t(26) = 4.01$, $p < .001$, but not in the single door condition or the no-training condition (both $p > .1$).
Figure 24. VWM capacity at pre-test and post-test. Participants in the multiple doors condition showed a significant improvement. Error bars represent standard error of the mean.

A 2x3x5x5 (Time x Condition x Eccentricity x Display Time Bin) mixed ANOVA was performed on the dependent variable of proportion that both stimuli were responded to correctly to evaluate the effects of video game training type on UFOV performance. Before performing the ANOVA, trials with display times that were above 200 ms were removed because of the potential for eye movements within that time period (Arnold & Tinker,
1939; Bahill & Stark, 1979). If these trials had remained in the analysis, the results would no longer be usable as a measure of spatial attention. Once these display times were removed, the remaining display times were grouped into bins to allow for analysis of proportion correct change at each different display time. According to Mauchly’s test, the assumption of sphericity was violated with regard to display time, \( \chi^2(9) = 45.30, p < .001 \). Therefore the degrees of freedom were corrected using Greenhouse-Geisser estimates of sphericity (\( \varepsilon = .69 \)). With this correction, the ANOVA detected a main effect of display time bin, \( F(2.74, 168) = 102.145, p < .001, \eta_p^2 = .709 \). The ANOVA did not detect any other significant effects or interactions (all \( p > .05 \)). These results are shown in Figure 25.
Figure 25. UFOV proportion correct change from pre-test to post-test in the three conditions. **a:** Results of the multiple doors condition at each display time. **b:** Results of the single door condition at each display time **c:** Results of the no-training condition at each display time. Error bars represent standard error of the mean.
Finally, a 3 x 2 (Time x Condition) mixed ANOVA was performed on the cumulative number of enemies eliminated to detect any differences between performance in either video game training world over the three training sessions. While the game performance analysis does give some insight into the difficulty and engagement differences between conditions, this ANOVA utilized the average total number of enemies eliminated per day in each video game condition to better show performance differences between the groups. This may provide a better representation of change in game performance since participants in the single door condition experienced a lower number of total enemy waves and consistently performed at ceiling. This ANOVA resulted in a significant interaction between time and condition $F(1.45, 23.14) = 10.43, p < .01, \eta_p^2 = .395$ a significant main effect of time $F(2, 32) = 5.75, p < .05, \eta_p^2 = .264$, and a significant main effect of condition $F(1, 16) = 77.81, p < .001, \eta_p^2 = .829$. These results are illustrated in Figure 26, which shows the dramatic difference in average game completions between training conditions. Three paired t-tests were performed on the results in each condition to determine whether the changes in performance were significant. T-tests on the results from the multiple doors condition showed no significant decrease in performance from Day 1 to Day 3, from Day 2 to Day 3, or from Day 1 to Day 2 (all $p > .05$). Results of the t-tests on the single door condition results showed significant improvement between Day 1 and Day 3, $t(8) = 4.762, p < .001$. Also, significant improvement between Day 1 and Day 2, $t(8) = 3.757, p < .05$. There was no significant improvement from Day 2 to Day 3 ($p > .05$).
Figure 26. Average number of total enemies eliminated no each day of training. Participants in the single door condition did show an increase in performance here, while participants in the multiple doors condition does not show an increase in performance. Error bars represent standard error of the mean.

4.6 Discussion

The first hypothesis in Experiment 2 was that participants in the multiple doors condition would improve more at peripheral eccentricities than participants in the single door condition. Participants in the multiple door condition were required to locate enemies at numerous locations surrounding their game character and were also exposed to
peripheral damage indicators (Figures 19 & 22), which may have provided them with exogenous attentional activation at peripheral portions of the screen.

The results of Experiment 2 showed only a main effect of display time. This effect simply indicates that participant’s performance changed as the stimuli was on screen for different amounts of time. Since there were no interactions between condition and eccentricity, there is no statistical support for Hypothesis 1. Figure 25 shows the change in proportion correct for both the peripheral and central target from pre-test to post-test with regard to display time. In these graphs, it is evident that participants in all conditions experienced no significant change in proportion correct at any eccentricity.

A possible explanation for the lack of statistical support of this hypothesis could be that the game training worlds did not tap into the instantaneous spatial aspect of attention that is tested by the UFOV task. In the task, the participant must very quickly spread their attention to the periphery while still focusing attention at the center of the screen. In the game world, the enemies appear constantly, so there is potentially never a need to divide attention; the player can simply move their focus slightly and successfully defeat another enemy.

Hypothesis 2 stated that training in either the multiple doors condition or the single door condition would increase performance on the VWM task. Results showed that improvements in VWM capacity significantly interacted with time and condition, implying that performance in the conditions changed at different rates from pre-test to post-test. Participants in the multiple doors condition showed increases in their VWM capacity by approximately 1.4 items, while participants in the single door condition and the no-training condition showed increases of only .3 and .2 items, respectively. This result does not
support Hypothesis 2 because participants in each of the video game conditions did not show similar change in VWM capacity. Only those participants who practiced in the video game world requiring dispersed attention showed a significant increase in VWM capacity.

This result is surprising because the inclusion of multiple enemy locations was not expected to have a differential effect on VWM capacity, especially after only two hours of training. Regardless of training condition, participants were exposed to the same total number of enemy NPCs before completing the game, and it was assumed that simply changing the locations of the enemies would not show such an effect on VWM. These results could simply be indicative of differences in strategy in participants in the different conditions rather than fundamental changes in VWM capacity. Perhaps participants in the multiple doors condition not only processed visual information from the NPCs, but also information from the peripheral damage indicators, and other on-screen information. This possible difference in strategy may show a change in how the central executive allocates attention between the different aspects of working memory rather than a change in VWM itself (Baddeley, 1992).

The constant appearance of the peripheral damage indicators during the more difficult waves in the multiple doors condition could also have contributed to the improvements in processing at the peripheral eccentricities for the multiple doors condition. These indicators repeatedly drew attention to the edges of the screen every time the player took damage from a NPC from a peripheral location. This taxing task does not occur in the single door condition; the participant is only required to focus on a single doorway that becomes increasingly salient as the difficulty increases, leading to the improved performance in the center-most eccentricities in the UFOV task. While the single
door condition can occasionally display peripheral damage indicators if the player has rotated the character away from the initial viewpoint, they are not displayed nearly as often as in the multiple doors condition under natural gameplay. This could explain the lack of improvement (and possible the decrease in performance) at the most peripheral eccentricities.

Figure 24 shows group differences before training and after training. The groups seem to increase towards a similar point and participants in the multiple doors condition seem to score lower at the pre-test. However, the slope of the increase in the multiple doors condition is much more steep than that of any other group, indicating that although they may have started at a lower performance level, they increased to such an extent as to end up at a similar level of performance as participants in the other conditions.

The third hypothesis anticipated that the average flanker compatibility effect would not differ significantly between conditions. This was supported by results showing only significant effects of set size on performance, indicating that training type did not have a differential effect on the flanker compatibility effect. The lack of difference between performance in the three groups supports the idea that allocating visual attention to the entire game world did not have an effect on identifying and focusing on relevant visual information. This could be because in both the multiple doors and single door conditions, there were no irrelevant or distracting visual items since all characters in the game level were enemies, and required attention from the player.

The final hypothesis for Experiment 2 was that participants in either of the training conditions would improve performance in the game levels as the overall training time increased. Figure 26 shows the cumulative number of enemies eliminated for participants
in the multiple doors condition and the single door condition on each day of training. The results of the ANOVA on average cumulative number of enemies defeated detected a significant main effect of condition. Participants in the single door condition showed an increase in the total number of enemies eliminated as training time progressed but participants in the multiple doors condition did not show an average increase. This partially supports Hypothesis 4, but the overall result is that the game training levels used in the multiple doors condition were not engaging enough to provide motivation for the participant to improve throughout the training phase.

One explanation for this could be that the game world used in the multiple doors condition was too monotonous and did not allow for much engagement in the game. With the seemingly endless waves of enemies, the participants could have felt that attempting to reach the next more difficult level was pointless, leading to a drop in performance. Another potential explanation could be that, since these participants were NVGPs, they simply overly engaged in the game and became overwhelmed because of the sheer number of enemies that attacked the player's character at a time.

4.6.1 Experiment 2 Limitations

The lack of performance increase in the video game training level used in the multiple doors condition implied a lack of participant engagement. This could have contributed to the large amount of variance found in some of the results from the multiple doors condition and to the lack of significant differences between each condition in terms of performance at different eccentricities in the UFOV task. In future studies, this lack of engagement could be eliminated by adding feedback to the game levels such that the participant would be congratulated after successfully completing a wave of enemy
characters. The game level is currently programmed to move directly from the current wave to a more difficult wave with the only notification to the player being an increase in the number of enemies. Providing momentary textual and visual feedback throughout the training session may be a way to sustain engagement.

As mentioned previously, the possibility of an eye movement in trials with display times greater than 200 ms also affected the analysis of the results. This is another potential limitation of Experiment 2. If an eye movement was made, the participant could have potentially moved their field of view, rather than using both central and peripheral vision. Since this activity does not use divided attention, the current UFOV task may need to be altered in future studies. The best way to do this would be to alter the limits used by the QUEST algorithm, so that display times greater than 200 ms are not allowed. Not only would this allow for measurement of central and peripheral attention allocation, it would also allow for the use of the QUEST estimate in the analyses.

An interesting future study would be to add manual navigation to both the experimental and video game control conditions in this experiment to determine if this would have any dilution effect on the current significant results. As mentioned previously, the lack of significant results in Experiment 1 could be due to the combination of friend vs. foe discrimination and manual navigation through the game world. In addition to a future study that removes this navigation aspect from Experiment 1, it is suggested to add manual navigation to Experiment 2 by enlarging the pedestal on which the game character is positioned, allowing the player to control character with both control sticks. Weaker effects on VWM capacity and UFOV performance could be interpreted as additional evidence that
manual navigation through the game world limits the amount of beneficial visual training provided by these games.

**GENERAL DISCUSSION**

This dissertation was designed to answer two questions. First, can different aspects of FPS video games be separated and used as a training regimen in an experimental design? Second, do two of these specific aspects play a role in some of the perceptual and cognitive improvements found in recent research? Until now video game researchers have found it sufficient to determine that video games provide some benefits for the player and that the FPS type of game is more beneficial than any other. The method used in this dissertation was developed as a way to add specificity to this body of research and determine what it is about these games that leads to such diverse benefits. This method is unique because it allows the numerous experiences found in FPS video games to be focused on individually by the experimenter. This has allowed for some interesting findings that help to explain some of the general results in previous literature (e.g. Green & Bavelier, 2006a).

Both of the experiments in this dissertation utilize a completely new and customizable method for determining what aspects of FPS video games lead to attentional and perceptual improvements in the player. The method has allowed us to determine that training on only a single aspect of an FPS video game (in this dissertation either friend vs. foe discrimination or focused vs. dispersed attentional allocation) can produce unique results. Even with only two hours of training in these custom built video game levels, some significant improvements in the player’s cognitive and perceptual abilities are present; abilities that correspond with training on a very specific video game aspect.
A good example of this can be found in Experiment 2, where significant improvements in VWM capacity were found primarily in participants that were trained for only two hours in the dispersed attention aspect of FPS video games. Also in Experiment 2, trends toward beneficial changes in UFOV performance at the most peripheral eccentricities were associated with dispersed attention. Trends in Experiment 1 showed that two hours of training on friend vs. foe discrimination led to both decreases in the flanker compatibility effect and increases in filtering capacity.

The short training time used in this dissertation can be considered as both a limitation of the studies and a potential method that could be used in future studies. In terms of potential for future studies, if trends can be found with only two hours of video game training when the training is focused on a single aspect of a video game, perhaps more results could be found while using significantly less training time than has been required in the past.

On the other hand, some of the trends in the data that did not reach significance might turn into reliable findings once a longer training period is instituted. Participants showed such varying amounts of performance change that it was difficult to find any significance in many of the statistical analyses. This was most likely due to the short training time, which could be remedied by merely increasing the training length in each condition. Since numerous studies have shown significant results with longer training phases, it is encouraging to think that slightly increased training times could potentially decrease the amount of variance between participants found in this dissertation, (Feng, et al., 2007; Green & Bavelier, 2003; Green & Bavelier, 2006a; Green & Bavelier, 2006b). One caution when considering the extension of training time as a simple future version of the
current study is that adding to the length of the training time could make the current game levels unusable since they were custom built to take approximately 45 minutes to complete (and many participants routinely cleared the entire game world during the later phases of training). Simply increasing the time that participants are exposed to the game worlds may not be enough to truly eliminate this limitation since this may lead to much lower engagement during training once the game worlds become too repetitive.

The small number of participants in each condition, while not necessarily a limitation, could be adjusted in future studies. The majority of research in this field uses an average of approximately 11 participants per condition (e.g. Green & Bavelier, 2003). So although the number of participants used in this study is appropriate, it could be beneficial to perform these studies with more participants in an attempt to decrease the amount of variance and potentially increase the power of any statistical analyses. Power analyses for Experiments 1 and 2 showed that, in the statistical analyses that were not already significant, 45 additional participants, at minimum, would need to be run in order to achieve significance at the .05 level. To increase the sample size by that amount, the recruitment criteria for NVGP participants should be re-evaluated. The requirements for NVGP participants in the current study were very strict: no experience playing FPS video games, so an example of a more liberal criteria would be to allow people to participate if they had not played a FPS game within the past 6 months rather than limiting the participant pool to people who had never played such a game. Removing the strict recruitment guidelines could lead to weaker effects of video game training, and so could be used in conjunction with the increased training time mentioned above to help balance this issue.
The interesting results found in these two experiments show that there is much more to explore in terms of video games and their effect on perception and attention. There are a number of experiments that could be built directly from the training and testing regimens used in this dissertation. First, the trends towards improvement in the outermost eccentricities for participants in the multiple doors condition of Experiment 2 may have partially been due to the peripheral damage indicators that notify the player of offscreen enemies (Figures 23 and 26). An interesting future experiment could use the multiple doors condition training level for both experimental conditions, but in one condition the indicators would be removed completely. This would be a way to determine whether the increased VWM capacity and the benefits found at more peripheral UFOV locations were due to keeping information about offscreen enemies in working memory, or simply due to activation of peripheral vision due to the very salient indicators appearing at the edges of the screen.

Another future experiment could be to use a very controlled game environment to compare the effects of a first person viewpoint to a third person viewpoint and what effects these perspectives have on transfer of training. This study would be simple to complete by utilizing the game worlds created for Experiment 1 for each condition and adjusting the player's perspective appropriately using commands built into the game engine. One condition would be implemented as it is currently, with the user's perspective being the same as the character's while the other condition would have the user's perspective come from outside the character (e.g., as if from a security camera in the corner of the room). This would be an interesting way of determining if it is the content of the game itself, or the perspective of the player that has a bigger impact on the observed benefits. If participants
in the first person perspective condition show improvements that are not found in the third person perspective condition, this would demonstrate that it is the similarity between the user’s and character’s perspective of the game world, and the perspective they have when navigating that world, that leads to the transfer of benefits from video game training. Perhaps the usage of a first person viewpoint is why action video games are so effective as training in previous studies.

CONCLUSIONS

Action video games can provide players with benefits far beyond simple response mapping and hand-eye coordination. Benefits can range from improvements in peripheral vision and the spatial resolution of attention to increases in task switching and change detection ability. Many of these benefits can then lead to increases in performance in the real world through unprecedented broad transfer of training. Research has sought to determine whether the benefits observed in long-term action video game players are due to self-selection or not and what types of effects these games have on non-experienced players. Training studies have shown that novice players can reach levels of perceptual and attentional benefits found in experienced players simply by playing action or FPS video game for a few hours. This dissertation has revealed that these video games not only provide benefits to the player, but that certain aspects of the games may lead to specific improvements in laboratory tasks over other aspects.

In this dissertation, specific aspects of FPS video games were able to be separated and used as individual training regimens that provided players with unique benefits. In Experiment 1, it was determined through improvements in the flanker compatibility effect, that friends vs. foe discrimination is an aspect of FPS video games that has beneficial effects
on the player’s ability to discriminate and focus on relevant visual information. In Experiment 2, results showed that the dispersed attention aspect of video games provides the player with a significant benefit in the number of items that can be held in VWM, as well as a marginal benefit when required to allocate attention to peripheral locations. In contrast, focused attention to a single location onscreen only marginally improves attention allocation to central locations without providing a benefit in VWM capacity.

More generally, this dissertation shows that there is much more to learn about the benefits of video games. Future research will be able to determine if other aspects of video games can have specific effects on the player by using the methods described here. If more links between single aspects of video games and specific effects on visual performance are found, they could be used to design video games that lead to specific benefits when played for only a few hours. While not everyone enjoys playing action video games, the fact that they could be designed to provide specific benefits to fundamental aspects of human attention and perception in such a short time period is promising and worthy of further investigation.
REFERENCES


APPENDIX 1

TASKS USED IN GAME STUDIES

Change Detection:

This task is used to measure the efficiency with which the formation and comparison of two scenes can be made. This is commonly thought of as a measurement of visual attention and even top-down, or active control, of attention (Clark et al., 2011; Rensink et al., 1997). The main concept of this task is to identify the change in two scenes that are flashed onscreen for a short time, with a blank screen appearing between the two images. The second scene will be almost completely identical to the first, but will have one or more changes, such as the addition a new object, an object that changes locations, or an object that has been changed in some way (e.g., color). The three displays repeat until the participant is able to identify the change. In some variations, the participant must also indicate the level of certainty with which they responded (K. Clark et al., 2011).

Proportion of correct change identification and response time (RT), or number of repetitions needed to identify the change, is generally recorded. These measurements can be used to determine how effectively and efficiently visual attention and visual working memory can be used to record and compare images.

Contrast Sensitivity:

A contrast sensitivity task is used to measure the ability to discriminate between different levels of contrast, generally using Gabor patches consisting of the same spatial frequency but slightly different luminance levels. Gabor patches contain alternating bands of high and low luminance. The higher contrast sensitivity a person has, the better able
they are at identifying whether two Gabor patches are identical or differ slightly in overall luminance (Li et al., 2009; Polat & Sagi, 1993). This task generally begins with the presentation of a target Gabor patch. Then after a fixation cross and a blank screen interval, the first patch is presented for a short duration (e.g., 90 ms). This is followed by another blank screen and the second Gabor patch for a short duration. The task of the participant is to identify which of the two stimuli contained the target (e.g., “brighter”) Gabor patch (Polat & Sagi, 1993).

The results of this task are used to determine how different the contrast of a Gabor patch must be before a participant is able to reliably identify it as different. The closer this threshold is to the contrast ratio of the target Gabor patch, the higher contrast sensitivity the participant has.

Crowding Task:

This task is used to measure the effects of crowding in the periphery and thus the spatial resolution of the visual system (Green & Bavelier, 2007; Tripathy & Cavanagh, 2002). There are a number of variations on this task, but one example requires the participant to identify the orientation of a “T” shape when two other “T” shapes flank it vertically. This identification is done with the stimulus presented at different eccentricities from the central point of the screen (0, 10 and 25 degrees, for example). The size of the “T” shapes is also adjusted according to eccentricity with larger stimuli being used at greater eccentricities. In addition, a staircase is used to determine the distance between the three “T” shapes in each trial, which is later used to estimate the crowding threshold. After viewing a fixation dot for 150 ms, the stimulus set is shown on screen for 100 ms. After the
stimuli are removed from the screen, the participant must indicate as accurately as possible whether the orientation of the central “T” shape was right side up or upside down with no concern for speed (Green & Bavelier, 2007).

The distance between the “T” shapes on the final ten trials is averaged to determine the crowding threshold or the smallest distance at which the participant can discriminate between the shapes at a given eccentricity. A smaller distance between the shapes at this crowding threshold indicates that the participant has a smaller crowding region and therefore higher spatial resolution.

**Enumeration:**

An enumeration task is used to measure the number of items that can be attended to in a short period of time (Green & Bavelier, 2006b). Typically, this task begins with a fixation cross for 500 ms, after which a number of objects (usually between one and 12 squares) are presented on the screen for a short duration (e.g., 50 ms). After the squares have disappeared, the participant must report how many items were on the screen.

Quantifying a smaller number of items requires a different strategy than quantifying a larger number. Results of this task commonly show that when the display contains more than about four items, RT slows more rapidly than with fewer than four items. This may be due to participants using a faster, non-verbal form of counting for the smaller set sizes and a slower, verbal form of counting for larger set sizes (Gallistel & Gelman, 1992). With smaller set sizes, the number of onscreen items can be immediately identified using parallel processing called “subitizing”, while with larger set sizes, the items must be counted serially (Kaufman, Lord, Reese, & Volkmann, 1949).
Filter Task:

The filter task is designed to measure the control of what information is allowed into visual working memory, and more specifically, how effectively irrelevant visual information is blocked (Ophir et al., 2009; Trick & Pylyshyn, 1994; Vogel et al., 2005). The task is composed of three main screens that appear consecutively (Figure 27). The first screen contains an array of two, four, six, or eight rectangles at random orientations. Two of these rectangles are always red and considered targets and the remaining rectangles are blue and considered distractors. The next screen is blank and is followed by another array of rectangles that is either completely identical to the first or identical with the exception that one of the red rectangles has changed orientation. The task of the participant after this third screen disappears is to quickly and accurately identify whether or not there was a change in the red rectangles while ignoring the blue rectangles (Ophir et al., 2009).

Figure 27. Illustration showing the general design of a filter task with the memory array and the comparison or test array. One of the red rectangles has changed orientations in the test array.

Since the blue rectangles should never be identified as relevant information, performance in the 4, 6 and 8 rectangle conditions should be the same as the 2 (target only)
rectangle condition. Working memory capacity is calculated by subtracting incorrect identifications of change from correct identifications of change and multiplying by the number of items on screen (i.e., \((HITS - FA) \times \text{SET_SIZE}\)). Capacity for the two rectangle condition is subtracted from the other conditions to determine the effect that a greater number of distractor rectangles has on processing the target rectangles (Ophir et al., 2009).

**Flanker Task:**

The flanker task measures the amount of distraction caused by irrelevant stimuli while processing relevant stimuli. There are a number of variations on the standard flanker task, but in general terms, the task requires a participant to identify a target item, which is usually a shape or an arrow, while ignoring distractor items that are either the same as or different than the target shape. When the target and distractor items are the same, the trial is categorized as “compatible” and in most cases RTs are fast. When the target and the distractor items are different, the trial is categorized as “incompatible” and RTs are slow. The number of distracting items is also manipulated, with more items creating more influence on the RT (either positive or negative). These two manipulations combine to create a task with four possible trial types: easy and compatible, difficult and compatible, easy and incompatible, and difficult and incompatible (Figure 28).

The major dependent variable of the flanker task is the compatibility effect and is calculated by subtracting RT on compatible trials from RT on incompatible trials for each difficulty level (Eriksen & Eriksen, 1974; Green & Bavelier, 2003; 2006c). The result is a measure of how much of an effect irrelevant information has on RT to relevant information
and is interpreted as the amount of “left-over” attentional resources a person has in a task of the given difficulty.

Figure 28. Illustration showing one version of the flanker task. In this design, the participant must indicate whether a square or diamond appeared in one of the circles. Adapted from Green and Bavelier (2003).

**Mental Rotation:**

This task assesses high-level spatial attention by having the observer decide whether two pictures of a simple three-dimensional (3D) block object are the same or different. Alternatively, a criterion block may be displayed and the observer has to pick which of four blocks match it. The criterion and test blocks differ in terms of their angle of rotation. Typical results are that RT to identify the matching block increases linearly with the 3D angular difference between criterion block and test block (Shepard & Metzler, 1971). The shallower the RT x angle function, the more efficient the observer is at mental rotation. In Figure 29, the criterion set of blocks can be found in the left circle for each group. In-group A, the objects are the same but rotated. In group B the objects are different.
(mirror images of each other; Feng et al., 2007; Shepard & Metzler, 1971; Terlecki & Newcombe, 2005; Vandenberg & Kuse, 1978).

![Figure 29](image)

**Figure 29.** Illustration showing the design of a mental rotation task. The comparison shape on the right in 19A can be created by rotating the criterion shape on the left. In 19B, the shapes are not the same.

**Multiple Object Tracking:**

A multiple object tracking (MOT) task is commonly used to measure the fidelity of sustained visual attention, and the number of identical items that can be held in visual working memory at a time (Green & Bavelier, 2006b; Pylyshyn & Storm, 1988).

In this task, a number of identical items (usually between four and 10 circles) appear on screen and typically half of them are visually cued in some way (e.g., flashed several times before the trial begins). These items then return to their original attributes so that the items are indistinguishable. All of the items then move randomly around the screen for a set amount of time, which is usually between five and 20 seconds. During the motion phase, the items rebound off the edge of the screen and will either bounce off other disks or pass through them. When the items stop moving, the participant must identify the originally cued targets either by clicking on them or by answering yes or no to an indicated item using the keyboard. Proportion correct is recorded for each set size, and is interpreted
as the number of items that can be tracked or attended to simultaneously (Green & Bavelier, 2006b).

**Task Switching:**

A task switching paradigm is used to measure the effectiveness and efficiency with which executive control directs attention to multiple tasks over time (Boot et al., 2008; Karle et al., 2010; Pashler, 2000). In a common form of this task, participants must switch between identifying whether a number is even or odd, or higher or lower than five. In each trial, a single number is shown on the screen for a short time (usually around 1500 ms), but is preceded by an informative visual cue. This cue is most often a change in background color or a colored outline around where the target number will appear, and indicates to the participant whether they will be identifying the following number as even or odd, or as higher or lower than five. Each of the possible task responses is mapped to a keyboard key, and the participant must quickly decide which key to press after the number is shown. RT and accuracy are recorded and used to measure efficiency of executive control for task switching. Typically, RTs to items after a switch in task are longer than RTs to items when there is no switch (regardless of task), and the difference in RT between switch and no-switch trials is reported as a measure of task switching efficiency.

**Temporal Order Judgment Task:**

A temporal order judgment task is used to measure how quickly an exogenous attention cue can be processed. It has been shown that such exogenous visual cues can draw attention and thus speed up the processing of a later appearing item shown in the
same location (Shore, Spence, & Klein, 2001; West et al., 2008). In this task, the cue, which is usually a salient outline appearing for 45 ms, is used to draw attention to a specific location immediately before two items appear on screen. Each of these items is separated by a short time known as the stimulus onset asynchrony (SOA) and the participant must identify which of the two items appeared first. This SOA begins at 192 ms, and is adjusted based on correct or incorrect judgments of temporal ordering; if the trial was responded to correctly, the SOA decreases by 12 ms, and if the trial was responded to incorrectly, the SOA increases by 12 ms.

Most often, items that appear in the same location as the exogenous attention cue are identified as appearing earlier than the other item. This is called visual prior entry and is believed to occur because attention has already been drawn to the location, which helps to speed processing of the item. This additional processing speed leads to the perception that the item appeared first (Shore et al., 2001). The measurements taken from these trials are used to determine the amount of time required between the appearance of the two items for them to appear to the participant as arriving simultaneously. This is a good indication of how effectively exogenous cues are used to direct attention across time (West et al., 2008).

**Useful Field of View (UFOV):**

The UFOV task measures the ability to detect, locate, or identify an item in the periphery while simultaneously correctly identifying an item at fixation. Since attention must be allocated to both the central fixation as well as the periphery, this task measures
the spatial distribution of attention over the entire visual field (Edwards et al., 2005; Feng et al., 2007; Green et al., 2009).

There are a number of variations of this task, but generally, “spokes” of squares are arranged in a radial pattern with each square on the spokes at a different eccentricity (e.g., 10, 20, 30 and 40 degrees) from the center of the screen (Figure 30). Most often, there is an identification task that appears at the central point. This involves identification of a letter, number or shape and ensures that the participant continues to fixate at the central point during the trial. At the same time, a target is flashed in one of the peripheral squares. For each of these trials, the participant must identify the central target and indicate the location of the peripheral target. The timing of the target display is usually staircased so that performance on the central target identification task is maintained at approximately 75% correct. This display time threshold is then plotted as a function of eccentricity.

Figure 30. Illustration showing one version of the UFOV task. The participant must identify the central item as well as indicate where the peripheral item appeared.
Visual Search:

There are many varieties of visual search tasks, but one that is used most commonly in the gaming literature is described here. Visual search tasks are used to identify how efficiently visual attention can be applied to a scene, and also to determine the effectiveness of top down or bottom up processing (Castel et al., 2005; Chisholm, Hickey, Theeuwes, & Kingston, 2010; Theeuwes, 1991; Wolfe, 1998).

Generally, a visual search task requires a participant to find a target item among some number of distractor items. One specific example of this is displaying an array of identical items onscreen with one item being different in some single dimension. This is often a difference in the color or orientation of the target item, with difficulty of the task being adjusted by the number of distracting items and the similarity of the distractors to the target. The display appears and the participant must report whether the target was present or absent by pressing the appropriate keyboard key (Wolfe, 1994). In visual search tasks with RT as the dependent measure, search displays are typically visible until the participant responds.

Another specific example of a commonly used visual search task was developed by Theeuwes (1991), and begins with a central fixation point surrounded by five, seven, or nine shapes arranged in a circular formation. Only one of these items is unique in shape, which indicates to the participant that it is the target. The distractor items each contain a line segment that is tilted ±22.5 degrees from either horizontal or vertical, with the line segment inside the target shape being exactly horizontal or vertical. The task is to identify the orientation of the line inside the target item (i.e., “horizontal” or “vertical”) as quickly and accurately as possible. In some trials, an additional distractor element will be present
such as a different shape or color applied to one of the non-target items. In this case, the participant must differentiate from the non-informative elements to find the target (Theeuwes, 1991). Accuracy and RT are gathered from the participant’s responses and used to calculate a measure of search speed. A more efficient or effective search strategy will be evident in a faster search speed and/or lower increases in RT as a function of set size (i.e., lower RT x set size slope).

**Visual Working Memory:**

The visual working memory (VWM) task is used to measure the number of items that can be held in visual working memory simultaneously. In the classic version of this task by Luck and Vogel (1997), a number of small colored squares appear on screen for 100 ms and are followed by a 900 ms blank screen. Next, a test array of the same colored squares appears for 2,000 ms or until response. On half of the trials, one of the squares changes color, and the participant must indicate, as quickly and accurately as possible, whether any of the squares have changed color, or whether the display is identical to the first. The number of squares in each trial ranges from one to 12. RT and accuracy are recorded and used to determine the average number of items that can be processed at a time by the participant. This is commonly calculated by subtracting the number of incorrectly identified no-change trials from the number of correctly identified change trials and multiplying the result by the number of items in the set (i.e., \([HITS - FA]*Set\ Size\)).
APPENDIX 2

QUESTIONS IN RECRUITMENT SURVEY

1. How many hours per week do you play video games on a console, mobile phone, or handheld device (XBOX 360, Playstation 3, Wii, DS, iPhone, etc.), on average?

2. On average, how many hours per week do you play video games on a computer (Web based, downloaded, purchased software, etc.)?

3. Which of the following genres of video games do you play the most? Check ALL the boxes that apply. The parentheses give examples of each type.

- Action (Halo, Call of Duty, etc.)
- Simulation (The Sims, Spore, etc.)
- Driving (Forza, Test Drive, etc.)
- Puzzle/Card (Tetris, Poker, etc.)
- Role Playing (Mass Effect, Fable, World of Warcraft, etc.)
- Adventure (Myst, Resident Evil, etc.)
- Strategy (Civilization, Warcraft, etc.)
- Sports (Madden, NBA 2K11, etc.)
- Fighting (Soul Caliber, WWE, etc.)
- I do not play video games

Other (please specify): ____________________________