COGNITIVE TRAINING WITH VIDEO GAMES:

The Role of Target Presentation Rate and

Maximum Target Eccentricity

by

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Abstract

Action video games have been shown to improve the visual cognitive abilities of those who played them for as little as ten hours when compared to those who played a control non-action video game for the same period (Green & Bavelier, 2003). The purpose of the current study was to examine which specific traits of action video games are responsible for which specific changes in visual cognition occurring while playing action video games. To test this, the visual cognitive abilities of participants were measured using a battery of five tasks before and after ten hours of practice with one of four versions of a simplified action video game. The battery was chosen to measure different aspects of the visual cognitive system. The Useful Field of View task measures the amount of visual angle the participant can actively attend to at any given time, the spatial limit of visual attention. The Attentional Blink task measures the ability to monitor one location over time, the temporal flexibility of visual attention. The Flanker task measures interference of a task-irrelevant object on a primary task, and is thought to provide an indirect measure of attentional capacity. The Visual Reaction Time task was intended to be a measure of visual apprehension speed and response generation. The Visual Search task was intended to measure the ability to find and identify a target amongst distractors. Participants were randomly assigned to one of four training conditions in a 2X2 factorial design manipulating the rate at which targets appeared and the maximum eccentricity at which the targets appeared during training. The paradigm

provided evidence that faster target training rates caused a marginal improvement over the slow rates in the Useful Field of View task from pre-training to post-training. Training with the fast target rate caused greater improvement than the slow rate on the Attentional Blink at only lag 2 and and a reversed effect at lag 6. All groups improved from pre-training to post-training on the Useful Field of View, Attentional Blink and Visual Search tasks. However, there was no differential effect for the narrow and wide training eccentricities.

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Chapter 1: General Introduction and Overview

Interest in how action video games affect attentional capacity and cognitive skills has been generated recently with the increasing popularity of these games in our society (Green & Bavelier, 2003), especially among the younger generations (Trick et al., 2005). Action video games are typically defined as any game with at least one and often all of the following traits: rapid responses are required, multiple objects must be apprehended simultaneously or in quick succession, multiple objects must be tracked, and large visual areas must be monitored continuously. These traits that define action video games can be seen in many of the tasks that researchers studying attention have explored for many years. For example, researchers have used a variety of experimental paradigms including reaction time (RT), attentional blink (AB), multiple object tracking (MOT), useful field of view (UFOV), dual attention, and selective attention tasks to examine the processes underlying attentional control (Klemmer, 1956; Raymond, Shapiro & Arnell 1992; Pylyshyn & Storm, 1988; Ball et al., 1988). The similarity between action video games and attentional experimental paradigms has led some researchers to examine the extent that playing action video games might alter or improve attentional capabilities (e.g., Green & Bavelier, 2003, 2006a, 2006b; Boot et al., 2008). The current study utilized a simplified action video game in order to investigate which aspects of the games are influencing which aspects of the visuo-cognitive system. The impact of the factors of target presentation rate and maximum target eccentricity during training on RT, AB, UFOV, attentional capacity and visual search was investigated. In addition to exploring the effects of two key factors of video game training on a battery of visual cognitive skills, the current study also provided an opportunity to examine whether a simplified version of the action video game can provide the same benefits that have been previously shown with action video-game training. The long-term goal is that use of a simplified action video game will lead to more effective designs for action video-game training tasks that can be then used to enhance the visual cognitive skills of those who play them. The current design may also lead to further understanding of the visual cognitive system and its plasticity.

Chapter 2: Literature Review

2.1: Practice

Practice or learning effects have been studied since the earliest days of psychology as a discipline (Thorndike, 1913). As people practice a task they almost always improve although there are clearly limits on both the scope and extent of the improvement (Newell & Rosenbloom, 1981). Furthermore, it is often suggested that the relationship between amount of practice and reaction time can be fit with a power law function (Fitts & Posner 1967; Welford, 1968), and while the exact nature of the learning curve has long been under question (Restle & Greeno, 1970; Mazur & Hastie, 1978; Heathcote, Brown & Mewhort, 2000) most generally agree that the largest benefits of practice occur early in training and that the benefit per practice exemplar decreases as more practice occurs. This suggests that if there are beneficial effects of playing action video games, that the largest benefit would be seen during their first few sessions playing those games. It then follows that the same amount of practice with these action video games would cause far less improvement for a seasoned action game player than it would for a novice. For this reason, the group that is most likely to show practice effects within a limited amount of training time, and the group which has been focused on most in terms of training studies in this area of research are those who rarely play action video games.

2.2: Complex Skill Acquisition

Although there has been an increased interest in the potential effects of playing action video games on attentional processes over the past few years, research examining changes in attentional capacity, and other cognitive skills through video game training, can be traced back to Amir Mane and Emanuel Donchin (1989). They designed the game Space Fortress as a means to study complex skill and its acquisition. The game consisted of a two-dimensional, zero-friction environment where participants maneuvered a spacecraft around the screen while attempting to orient their craft to shoot toward either the “fortress” in the middle of the screen or “mines” which would appear at random locations approximately every four seconds. They were required to hit these objects as often as possible with their limited ammunition. They also had to control the direction of their spacecraft's movement in order to avoid being “shot” by the fortress or running into mines. The task was designed to require the participant to engage in actions that are representative of real-life tasks, to incorporate dimensions of difficulty that can be changed in order to study particular skills and their acquisition, and to keep the task interesting and challenging for participants over long durations of practice. The Space Fortress game was used extensively through the 1990's by many researchers (e.g. Fabiani et al., 1989; Shebilske et al., 1992; Donchin. 1995) to study many questions about “complex skill and how it develops”, including optimality of training strategies (Gopher, Weil, & Seigel 1989), how well visual attentional skills would predict performance on this complex game (Arthur et al., 1993), and even how well the game could be used as a predictor of intelligence (Rabbitt et al., 1989). Perhaps the most interesting results of training on the Space Fortress game came out of two studies that showed the skills learned during training with this game could transfer to almost completely different, real-life tasks such as flying of actual military aircraft (Gopher, Weil, & Bareket, 1994; Hart & Battiste, 1992). There are few commonalities between the tasks required while playing Space Fortress and the tasks required for real flight other than they both required dividing and shifting attention and likely some overlap between 2D and 3D flight control skill. This research showed for the first time that practice on a complex video game could improve performance not only on the practiced video game task, but could also generalize to improved performance on other tasks. This generalized learning suggests that the improvements in performance were not only due to specialized learning of stimuli-response pairings associated with the specific game, but were more likely caused by changes in the general cognitive processes required by the video game, leading to the possibility of improved performance on any other task that relies on the same cognitive processes.

2.3: Generalized Benefits of Video Game Practice

Because the early research examining the relation between video games and cognitive processes mostly relied on the Space Fortress game, there was some consistency in the paradigm making it easier to interpret and compare these studies than if multiple different games had been used. On the other hand, because the research focused on many different theoretical questions it was hard, if not impossible, to construct a meaningful meta-analysis. Very few studies, other than those involving the impact of training on piloting skill, investigated the generalization of Space Fortress training to other skills. In fact, most studies used improvements on the Space Fortress game as their only measure of improvements through training (Gopher, Weil, & Seigel 1989; Fabiani et al., 1989; Shebilske et al., 1992; Donchin. 1995). Green and Bavelier (2003) were the first to systematically examine the effects of action video game training on different visual processing mechanisms. They used the amount of improvement on standard visual attention tests as their measure of how much visual attention training occurred and abandoned the controlled dimensions of the Space Fortress game in favour of more current action video games. They selected participants that had little previous experience with action video games in order to capture the earliest range of the learning curve where, as outlined earlier, there should be the greatest improvement per unit of training experience. Participants were then randomly assigned to one of two training groups: (1) action video game group, and (2) non-action video game control group. Participants in both groups completed three cognitive tasks (UFOV, AB and an enumeration task) during a pre-training session and again during a post-training session.

These three cognitive tasks were chosen by Green and Bavelier (2003) because together they provide an estimate of an individual's attentional capacity and their ability to allocate attention spatially and temporally.

The amount of visual angle one can process briefly-presented information from without moving the eyes or head is thought to provide a measure of the spatial extent of visual attention. Participants were asked to detect a target appearing on the screen at different eccentricities and report its position relative to fixation. The Useful Field of View (UFOV) task measures the likelihood that a participant is able to detect a target at a given eccentricity, and therefore provides a measure of the breadth to which attention can be allocated. Because the target is large enough to be clearly visible at longer durations (over a second), even at the largest eccentricities, it is unlikely that the decrease in performance with increasing eccentricity on the UFOV task is attributable to the decrease in visual acuity with increased eccentricity (Frisen & Glansholm, 1975). The presentation of stimuli during the UFOV task however happens quickly enough that you must be attending to the area where the target appears to accurately detect it (Ball & Owsley, 1992).

The measure of temporally distributed attention Green and Bavelier (2003) used was the attentional blink (AB) task, which is a measure of a participant's ability to detect two masked targets that are presented briefly in close temporal succession. Participants typically have a deficit in detecting the second target if the targets are presented within approximately 500 ms of each other. This is often thought of as an attentional refractory period caused by the apprehension of the first target. The most common paradigm to measure the attentional blink utilizes a rapid serial visual presentation (RSVP) stream of letters and or numbers presented at 10 Hz. The targets are distinguished from the distractors in the RSVP stream by colour or by identity. The two targets appear with various numbers of intervening items in the stream. The participants are asked to identify or simply detect the targets and their AB score is their second target apprehension ability when the first target is correctly identified. The deficit in second target apprehension does not appear to be caused by perceptual, memory or response limitations and has been labeled the attentional blink period. This task requires very little spatially distributed attention but rather measures the participant's ability to attend to a specific location over time. This is thought to be a measure of how well we are able to allocate attention over time and how much temporal cost there is to attending to the first target (Shapiro, Arnell & Raymond, 1997).

Green and Bavelier (2003) used the enumeration task to measure the capacity of attention. In the enumeration task, a set of target squares are briefly presented on the screen and then masked. The participants are asked to report the number of targets that were presented (Trick & Pylyshyn, 1993). There are thought to be two processes by which people could enumerate items. The first being subitization, a process thought to be pre-attentive such that the number of items presented are rapidly apprehended in parallel. The second being counting, a likely serial process requiring attention. Their accuracy at this task as a function of the number of targets presented, is considered to be a measure of attentional capacity.

During the training phase of the Green and Bavelier (2003) study, participants in both groups played a video game for 10 hours within a 10 day period. The only difference between the two groups was that those in the action video-game group played a current action video game called Medal of Honor, while those in the non-action video game control group played a non-action video game (Tetris). The effect of training for each attentional measure was assessed by the change in performance from pre-training to post-training. For several cognitive measures, participants in the action video-game group showed a greater training effect than those in the non-action video game control group. Specifically, training with action video games led to a wider useful field of view, a reduced attentional blink as well as an increased ability to enumerate items. They have since used this training action game versus non-action game paradigm to examine more carefully the causal role of action video game playing on enumeration ability (Green & Bavelier, 2006b). They found that the increased enumeration ability might not be caused by an actual increase in subitization ability– more likely, the increased ability is attributable to an increase in the speed of serial counting of the number of items presented, a process which is thought to require attention (Trick & Pylyshyn, 1993). The Green and Bavelier (2006b) study also provided evidence that action video game training can also increase the multiple object tracking capacity of participants. Based on this combination of results, Green & Bavelier suggested that action video game playing may affect performance on these tasks by altering visual short-term memory skills.

Training with action video games has also been shown to improve spatial rotation abilities more than training with a control game, a 3-D puzzle game called “Ballance” (Feng, Spence & Pratt, 2007). Furthermore, they showed that the spatial rotation ability deficit traditionally found for females relative to males might be reduced or eliminated through such training. This training might then have some applied benefit in that spatial skill, including spatial rotation ability, has been shown to be correlated with performance in mathematics and science courses (Delgado & Prieto, 2004). This work stemmed in part from earlier work that showed practice with the more obviously related spatial skill game of Tetris (a game where the player must rotate a series of falling 2-D objects to fit with other static 2-D objects which have already fallen) improved adolescents’ spatial abilities on a variety of tasks compared to an untrained group (Okagaki & Fresch, 1994).

A correlation study comparing self-reported action video game players with self-reported non-action video game players suggests that action video-game experience might be responsible for better performance on visual search tasks (Castel, Pratt & Drummond, 2005), although they suggest that the improved search performance might not be attributable to an improvement in attentional processing, but rather to an improvement in response control. They based this conclusion on the finding that the slope of the reaction time versus set size function did not significantly differ for action video game players and non-players meaning that both groups likely searched through the items at the same speed and a second finding that amount of action video game playing doesn't seem to correlate with the magnitude of inhibition of return (IOR). IOR is thought to be one mechanism that allows for increased efficiency of visual search by biasing attention away from previously searched locations (see

Klein, 2000, for a review).

Other correlation studies of self-reported action video-game players and non-video game players have examined executive control using a task switching paradigm (Karle, Watter & Shedden, 2010). Task switching refers to the process of switching from one task to another task. In essence, each task has a set of stimulus-response rules, and so task switching can be thought of as the switching of one set of stimulus-response rules for a second set. The cost of task switching is then typically measured as the reaction time (RT) difference between a condition in which the second task is preceded by the same task (Repeat condition) and a condition in which the second task is preceded by a different task (Switch condition). The task-switching procedure and the measured switch cost is frequently used as a measure of cognitive flexibility. Karle et al. showed that action video-game players had smaller switch costs than non-video game players suggesting that playing action video games was associated with greater cognitive flexibility. However, they also found that the reduced switch costs of action video game players disappeared as the proactive interference between the two tasks increased. Proactive interference is the cost of a prior event on the processing of a new event and is increased as the two tasks have more overlapping stimuli and rules. According to Karle et al., video-game players seem to exhibit less of a switching cost when changing between tasks than non-video game players unless the similarity of the two tasks is increased.

2.4: Low Level Perceptual Benefits of Action Video Games

There is also recent training research by Green and Bavelier (2007) that suggests playing action video games might also impact visual spatial resolution. They provided evidence that those trained on action video games, versus those trained with a control game, were able to tolerate more target crowding without task interference. Target crowding occurs when there are only small distances between a target and distractor such that the identity of the distractor interferes with the participant's ability to identify the target. Although this may not be the typical task used to measure spatial resolution, the ability to reduce the effect of distractor crowding through training certainly illustrate changes in the visual processing system. Further evidence that training, albeit intensive training, can improve lower level visual functioning comes from a study which showed that contrast sensitivity could be increased significantly by playing 50 hours of an action video game (Call of Duty and Unreal Tournament 2004) over 9 weeks compared to those who played a control game (The Sims 2) for the same duration over the same period (Li, Polat, Makous & Bavelier, 2009). The size of this contrast sensitivity enhancement was anything but trivial with ~50% improvement in just 9 weeks. Previous research had shown that practice can improve contrast sensitivity to this degree, but only when participants performed thousands of trials on a contrast detection task with the same stimuli used during both training and test phases (Huang, Zhou & Lu, 2008). Therefore, the amount of generalization of contrast detection ability to novel stimuli remains unknown (Li et al., 2009).

2.5: Open Questions

Despite the increase in research examining the impact of action video game playing on cognitive processing, many questions remain. Two examples include: How long do the attentional benefits derived from playing action video games persist after training? How much training is optimal? While these questions are of significant interest, there is a critical issue that should be addressed first.

The term “action” in action video games is ambiguously defined and therefore the traits or components that comprise an action video game are unclear. More critically for any training study, it is not clear how the components of an action video game differ from a non-action control game. Therefore, in a video game training study, it is difficult to know which aspects of action video game training actually lead to improved attentional performance. Furthermore, because it is unclear as to which components of an action video game differ from the control game, there is no way to link training of specific game components with specific cognitive skills.

While there is a long-term benefit to classifying action games along different task dimensions, rather than into action and non-action categories, the current study takes a different approach to explore different task dimensions. Rather than using a standard action video game for training and trying to find an appropriate non-action video game to use as a control, I have developed a simplified video game in which I can systematically manipulate various properties of the game with the goal being to link the training of specific game properties with specific cognitive changes.

Previous research examining action video game training cannot easily address the question of which aspects of action video games produce cognitive changes because the action video games used in these studies are exceedingly complex and differ in multiple ways from the non-action video games used as controls. First, action video games typically require monitoring of multiple objects, while the control game (e.g., Tetris) requires monitoring of a single object. Second, action video games are rendered in a 3-D environment that the player travels through while the background in the control game is a 2-D static image. This means that the player in the action video game is also constantly changing his or her viewpoint, whereas it is static in the control game. This also means that the action video game likely also places increased demands on the working memory system as it is useful if the player can remember the spatial organization of previously-viewed doors, halls, objects, and enemies, which is likely greater than the working memory demands required by the control game. These are just some of the ways that action video games differ from the control games used in recent studies. Because of the multiple differences between action video games and the control games, it is impossible to discern which aspects of action video games are the key factor(s) in causing changes in attentional processing. Therefore, if we want to increase our understanding of which aspects of action video games produce which cognitive changes, it will be necessary to gain better experimental control over the action video games.

Chapter 3: Goal of the Current Study

3.1: Components of Action Video Games Explored

The goal of this study was to explore which components of the action video game experience are beneficial to enhancing which visual cognitive abilities. This was achieved by having different groups of participants play different versions of a simplified action video game during a ten hour training phase and assessing the change in their cognitive abilities from pre-training to post-training. Although there may be numerous components of the action video game experience that could possibly contribute to visuo-cognitive changes, this study focused on two components: (1) the rate at which targets were presented and, therefore, the rate at which targets must be identified to perform optimally, and (2) the maximum eccentricity with which the targets could appear from the center of the screen and, therefore, the area that was monitored for targets. Due to the inherent complexity of the space fortress task, although rate of target asteroid presentation was one of the controllable dimensions of the game, no studies were published isolating the rate of presentation as a manipulated variable. The target presentation rate manipulation explores the question of whether the number of exemplars of practice the person has had experience with is important for causing the cognitive changes previously observed in action video game play. The maximum eccentricity at which targets are presented has never been explicitly explored during training. Green and Bavelier (2003) however, noted that the attentional benefits they observed in self-selected action video game players extended beyond the eccentricities that these video game players reported to have likely experienced during typical game play. The maximum eccentricity of targets manipulation investigates the question of whether practice at wider eccentricities helps broaden spatial attention, or if practice at narrow eccentricities is generalizable to a larger visual field. By directly manipulating these two components in a simplified version of a current action video game, much in the same way that the dimensions of Space Fortress can be manipulated, greater control was achieved over the visual training the participants experienced compared to previous studies that used qualitatively different games for the experimental group (e.g., Medal of Honor) and the control group (e.g., Tetris).

The experimental design then consisted of the manipulation of two components of the video game in a 2x2 between-subjects factorial design: (1) Rate of Target Presentation (slow, fast) and (2) Maximum Target Eccentricity (narrow, wide). The simplified video game has the following advantages: First, we can control the rate of target presentation and the maximum eccentricity with which they occur. Therefore, training with a control game (e.g., Tetris) that is qualitatively different from the action video game (as done in previous research) is no longer necessary. We are simply able to train different groups with the same game that is manipulated to be more "action" or less "action" along the two task dimensions of target presentation rate and maximum target eccentricity. Second, this design has the potential to show that training of attentional abilities can be done without many of the features found in current video games (e.g., violence, realistic 3-D environments). Third, this design also allows for an examination of the relative contributions of training of two video game components (rate of target presentation, and maximum target eccentricity) to several visuo-cognitive measures.

In the simplified action video game used in the current study, the rate of target presentation for the fast-rate groups was set to be approximately the same as that found in the action video game Medal of Honor (first-person shooter used in previous research). Using this target rate, it will be possible to determine whether training in the simplified video game yields similar changes in attentional ability as those observed during action video-game training in previous studies (Green & Bavelier, 2003). The slow-rate groups were trained with targets appearing at a quarter of the frequency of the fast-rate groups. Similarly, the wide-eccentricity groups used approximately the same maximum eccentricity of target appearance as is found in the action video-game condition of previous studies. The narrow-eccentricity groups were trained with targets appearing at a maximum eccentricity that was one-third of that used for the wide-eccentricity groups. If rate of target presentation and maximum target eccentricity are key components underlying the benefits of action video games, then the fast-rate groups and the wide-eccentricity groups will show benefits in cognitive ability as seen in previous studies (Green & Bavelier, 2003). Furthermore, participants in the wide-eccentricity and fast-rate groups should show similar benefits to that observed in previous studies because their training task is most similar to action video games previously studied.

During both a pre-training and a post-training testing session, the participants completed five tasks: useful field of view task, attentional blink task, flanker task, simple reaction time task, and a visual search task.

3.2: Useful Field of View Task

The useful field of view task provides a measure of visuo-spatial attentional ability by measuring the extent to which a visual stimulus can be detected at a given eccentricity (Ball et al., 1988). Performance on the useful field of view task is important in that it has been found to be a predictor of accident rates in aging populations (Owsley et al., 1998; Clay et al., 2005). It is suggested to be a measure of the maximum amount of visual scene that you can attend to and have awareness of. If the maximum eccentricity of target presentation during training underlies the cognitive benefits found in previous video game training studies, the wide-eccentricity groups should produce greater cognitive benefits than the narrow eccentricity groups. Specifically, those in the wide-eccentricity groups should show a wider useful field of view than those in the narrow-eccentricity groups due to the fact that the wide-eccentricity conditions are more similar to the action video games which have previously showed these training effects (Green & Bavelier, 2003). It was not expected that the rate of target presentation would impact performance on the useful field of view task.

3.3: Attentional Blink Task

The attentional blink task provides a measure of the visuo-temporal ability of the attentional system by measuring the ability of a participant to identify the second of two targets within a rapid serial visual presentation stream of stimuli (Shapiro, Arnell & Raymond, 1997). Typically, participants show a reduced ability to identify the second target if it is presented between approximately 200 and 500 ms after the first target. The amount that second target detection is reduced by the presence of the first target is thought to be a measure of the temporal resolution of attention. If the rate of target presentation underlies the cognitive benefits found in previous studies, the fast-rate groups should produce greater cognitive benefits than the slow-rate groups. Specifically, training with a fast-rate should lead to a greater reduction in the “attentional blink”, due to the fact that the faster rate would be more similar to the action video games which have previously produced these results (Green & Bavelier, 2003). The maximum eccentricity of the target presentations were not expected to have any effect on performance on the “attentional blink” task.

3.4: Flanker Task

The flanker task was used as a measure of attentional capacity (Lavie & Cox, 1997). Although Green and Bavelier (2003) report enumeration alone for the results of their training study, they use two measures of attentional capacity to compare self selected action video-game players and non-action video game players. They used the enumeration task, but in conjunction they used a flanker task that aims to measure attentional capacity by measuring the amount of automatic processing that is done on a task-irrelevant distractor. Previous research has shown that participants with larger attentional capacities are more likely to involuntarily use their excess capacity to process an irrelevant distractor (e.g., Maylor & Lavie, 1998). It is argued that the amount of interference that is caused by the identity of the task-irrelevant distractor is related to the extent that the irrelevant distractor is processed. The assumption then becomes, the more attentional processing capacity a participant has, the more processing is done of the irrelevant distractor. The more processing of the irrelevant distractor, the more interference to the primary task. If the rate of target presentation or the maximum eccentricity of target presentations underly the cognitive benefits found in previous studies for attentional capacity, then the fast-rate groups and the wide maximum eccentricity groups should produce greater cognitive benefits on the flanker task than the slow-rate groups and the narrow maximum eccentricity groups. This expectation that training with a fast-rate and wide-eccentricity would lead to an increased attentional capacity is based on the fact that the faster rate and wide-eccentricity training are more similar to the action video games which have previously produced these training effects (Green & Bavelier, 2003).

3.5: Visual Reaction-Time Task

The Visual Reaction-Time Task is a deceptively simple paradigm of flashing a stimulus at fixation and having the participant respond via key press, but it actually can be influenced by many factors. Perhaps the most interesting of these factors was explored by Klemmer (1956) when he investigated the role of variable versus fixed foreperiod in the simple visual reaction time paradigm. He studied the differences in responding during trials that appeared at predictable intervals versus those that appeared at unpredictable intervals. Based on this research, he described the act of responding to a stimulus of unknown timing as the act of balancing preparatory systems and response restraint systems. I expected that those in the fast rate conditions would show greater improvement on the reaction time task from pre-training to post-training compared to those in the slow rate conditions because the video game requires fast responses similar to those required on the reaction-time task (see e.g., Thorndike, 1913). Specifically, the reaction-time task was similar to the training task in that, in both, a target appears and the participant must make a response as quickly as possible. It was not expected that the eccentricity of the targets during training would have any effect on the reaction time measure because the stimulus was only presented at fixation.

3.6: Visual-Search Task

Finally, the visual-search task was used as a generalized measure of visual cognition and motor response performance, as it is not identical to any one aspect of the training game, but likely shares overlapping visual cognitive and response control skills that might be improved through playing the game. With the visual-search task, efficiency of the visual search process is indexed by the slope of the reaction time versus set size function, whereas the efficiency of the response system is thought to be reflected in the Y-intercept of the same function (Wolfe, 1994). Although there is no causal evidence that suggests that action video-game playing causes improvement in visual-search abilities, if the rate of target presentation is responsible for the correlation differences between action video-game players and non-action video game players (Castel, Pratt & Drummond, 2005), then the fast-rate conditions should exhibit a larger reduction in the intercept of the visual search-time function from pre-training to post-training due to faster processing and responding when the target is found. Again, although there is no evidence that action video-game playing causes improvement in visual-search abilities, correlation data suggests that such a training effect is possible (Castel, Pratt, & Drummond, 2005). Therefore, if maximum eccentricity of target presentation during training does influence visual-search capabilities, then participants in the wide-eccentricity conditions should exhibit a greater reduction in the intercept of the visual search time per item function from pre-training to post-training indicating faster fixed processing time once the target is found, benefiting all searches equally, regardless of the number of items present. Specifically, in addition to causing a reduction in search time, if there is any benefit to visual search processes due to the wider maximum eccentricity of target presentations then it should cause a decrease in the slope of the reaction time versus set size function.

3.7: Summary of Experimental Generalizations

In summary, the largest benefits should occur for those participants that were trained with a fast target-presentation rate and a wide maximum target eccentricity. The results are expected not only because this condition most closely resembles the action video-games which have previously produced these results but also because this condition required detection and responding to the most targets, and provided practice monitoring the largest visual area. Although specific predictions are made here, it is important to note that they are made cautiously and that this study was designed primarily to be exploratory. With the use of a simplified action video game and the systematic manipulation of two components of that game, and with a range of cognitive measures assessed before and after training, it is anticipated that the current study will provide a solid initial step towards our understanding of how playing action video games influences visuo-cognitive processes.

Chapter 4: Method

4.1: Participants

A total of 27 participants with normal or corrected-to-normal vision were recruited for this study. These participants were recruited based on a prescreening questionnaire in which they each reported currently playing less than an hour a week of video games, and never playing more than four hours a week in the past. Four participants were asked to withdraw because they were at chance on the pre-training UFOV task and therefore their improvement on the task could not be measured. Three participants withdrew from the study after only the first few sessions. The remaining 20 participants were randomly assigned to one of the four conditions (5 participants per condition): (1) Slow Rate, Narrow Eccentricity, (2) Slow Rate, Wide Eccentricity, (3) Fast Rate, Narrow Eccentricity, (4) Fast Rate, Wide Eccentricity.

It would have been interesting to include participants with a wide range of previous video game experience and to examine how the effect of training varies as a function of previous video game experience. However, in this first study I decided to include only those individuals who have less than average (based on the prescreening questionnaire) action video game experience because, based on the practice literature, those with the least video game experience would benefit the most from training. Participants were compensated $112 for their time ($7 a session), and those who completed the study were entered into a draw for a one in nine chance of an additional $100. Participants were also told after their first session playing the simplified action video game that there was a performance bonus of $20 given to the top half of participants, based on their improvement in ability to quickly respond to the targets in the game. All participants were given the performance bonus regardless of actual performance.

4.2: Apparatus

The participants viewed the training and testing tasks on a 17" CRT monitor at a distance of 50 cm with the exception that the viewing distance for the useful field of view task was set at 28 cm (to allow for testing at larger eccentricities). A chin rest was used to ensure that participants maintained the appropriate viewing distance during both training and testing. Testing and training was conducted using a PC computer with a standard mouse and English "qwerty" keyboard. All systems used were Intel Core 2 Duo Q7500 machines with Nvidia GeForce 8600 GTS graphics cards that powered the monitors at a refresh rate of 60hz. All testing and training procedures were written in Matlab and utilized the psychophysics toolbox for screen presentations. Psychophysics toolbox is a set of free functions for Matlab which help to accurately present visual and auditory stimuli (Brainard, 1997; Pelli, 1997). All but the simple reaction-time task were run in MS Windows XP operating system; the simple reaction-time test was run in Ubuntu Linux 8.04.

4.3: Procedure

There were three components to this experiment that were completed in the following order: (1) pre-training testing, (2) training, and (3) post-training testing. The pre- and post-training tests were identical and were divided into three sessions. During the first session, the participants completed a useful field of view task (280 trials - 45 minutes to complete). During the second session, two tasks were completed in the following order: attentional blink task (260 trials – 30 minutes to complete), followed by a flanker task (200 trials – 20 minutes to complete). The third session consisted of two tasks in this order: simple reaction-time task (300 trials – 15 minutes to complete), visual-search task (280 trials – 40 minutes to complete). Participants completed ten hours (ten sessions of one hour each) of training in their designated conditions, over no greater than a two week period. They then completed the post-training test measures in the same order they completed them pre-training.

4.4: Testing Procedures

4.4.1: Useful Field of View Task

The useful field of view task was a slight modification of the task used by Green and Bavelier (2003). The participants were instructed to maintain fixation in the centre of the screen throughout the trials. The participants viewed a black fixation cross on a white background which subtended 1^0X1^0 of visual angle for 1 second. The fixation was replaced with eight spokes of black outlined boxes

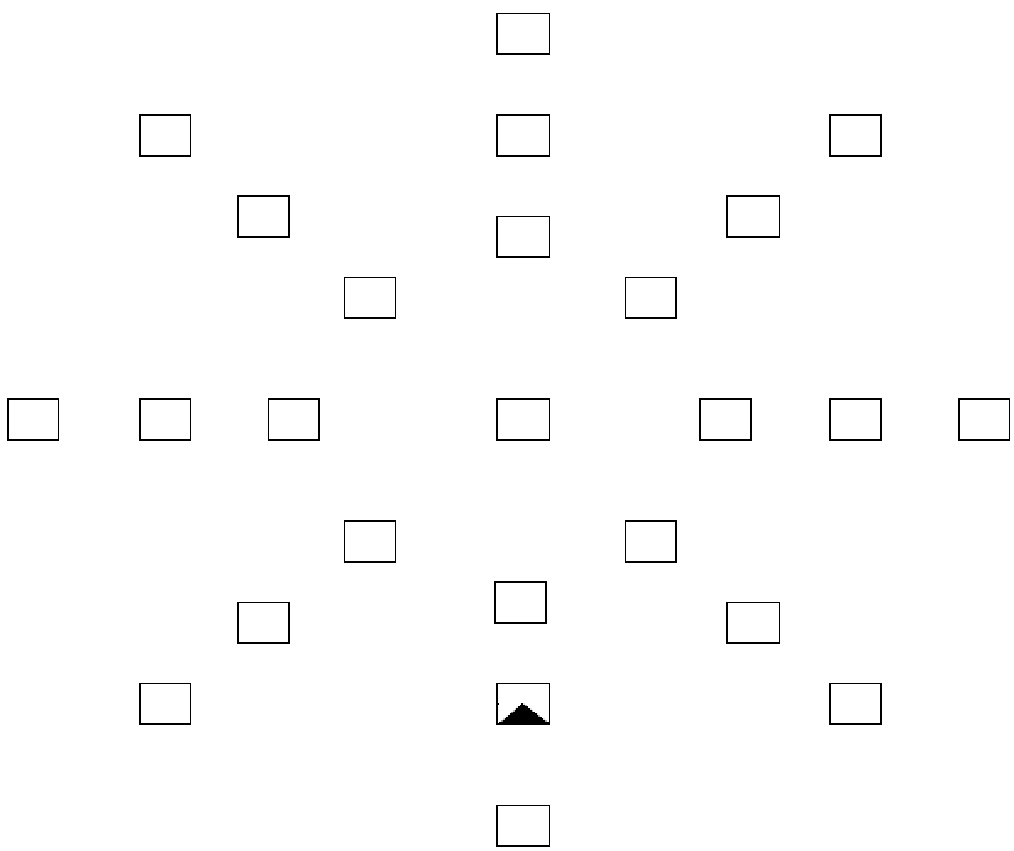

Figure 1: The brief presentation of boxes at eight different orientations during the useful field of view task at each of three eccentricities (8^0, 15^0, 22^0). The target triangle, shown here directly below the centre of the display at the 15^0 eccentricity, appeared in any one of the boxes. The participant was asked to respond as to the orientation of the target relative to the centre of the display.

extending from the centre to the edges of the screen with each of the spokes separated by a 45^0 angle (see Figure 1). Two of the spokes pointed straight to the centre of the top and bottom of the screen. Each of the boxes comprising these spokes subtended a visual angle of 3^0X3^0. Each spoke had one box at each of three eccentricities 8^0 , 15^0, and 22^0. Only one spoke contained a box with a target in it on each trial. The target was a solid black triangle which appeared within a box and subtended a slightly smaller visual angle than the box itself. The spokes of boxes and the target were presented for 16 ms, followed by a mask which covered the entire screen. The mask was comprised of 100 randomly drawn circles and rectangles in three shades of grey. The participant's task was to identify which spoke contained the target using a key press after the mask was shown. The dependent measure was the participant's accuracy rate for correctly detecting the target spoke at each eccentricity. The useful field of view task provided a measure of the accuracy of each participant to detect the presentation of a target at a given eccentricity.

4.4.2: Attentional Blink

The attentional blink task used was the same as that used by Green and Bavelier (2003) with slight timing differences to match our screen's refresh rate. The participant was instructed to maintain fixation in the centre throughout the trials. The participant viewed a grey background with a black fixation cross in the centre subtending 1^0X1^0 of visual angle. The participant then saw a stream of uppercase-black letters appear one after another in the centre of the screen. Each letter in the stream was presented for 16 ms and was followed by a blank grey screen for 84 ms before the next letter in the stream appeared. Each of the letters subtended a visual angle of 4^0X4^0. The participant’s primary task was to monitor the stream of seven to fifteen black letters for a white letter. The white letter was the target letter and was presented on every trial. The participant was instructed to remember which letter appeared in white. The secondary task for the participant was to monitor the stream of black letters appearing after the target letter to determine if a letter 'X' appeared within the subsequent eight letters. An 'X' followed the white letter on 50% of trials. The participants were asked to respond using a keyboard which letter they saw in white. They were then asked if they saw an 'X' or not, again using a keyboard to respond (“y” for yes,“n” for no). The dependent measure on this task was the accuracy on the secondary task and how it changed as a function of the location of the 'X' in the stream relative to the target letter. Only trials in which the participant correctly responded on the primary task were included in the analysis.

4.4.3: Flanker Task

The flanker task was a slight variation of the flanker task used by Green and Bavelier (2003). The participants viewed a black fixation cross on a white background for 200 ms. Six black circles each

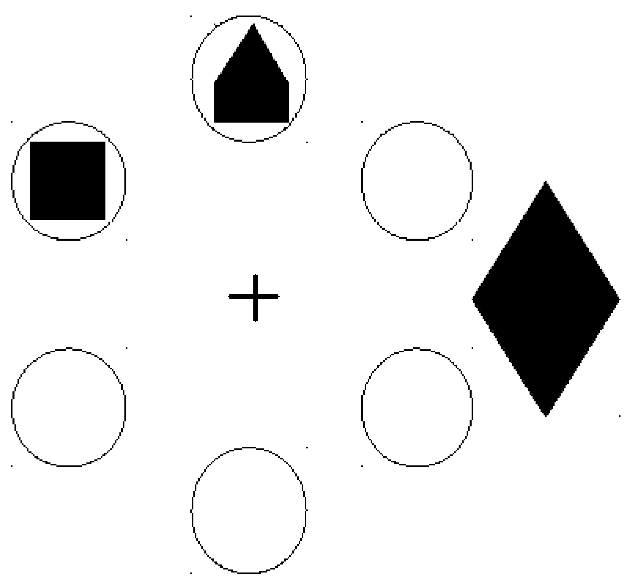

Figure 2. The low load condition of the flanker task is shown here, as only two of the six circles contain possible targets. This is an example of an incongruent trial as the large task-irrelevant distractor on the right does not match the identity of the search target (i.e., the square shown in the top left circle).

subtending a visual angle of 4^0X4^0 were then simultaneously presented. The circles were presented at the two, four, six, eight, ten, and twelve o'clock positions all at an eccentricity of 10^0. One of the circles was filled with a black target (either a square or a diamond) which subtended approximately the same area as the circle. In the low-load condition, one of the remaining circles was filled with a black distractor. In the high-load condition, all five of the remaining circles were filled with black distractors. In both the low- and high-load conditions, each distractor shared features with both squares and diamonds (e.g. the top of a diamond with the bottom of a square) and each distractor subtended roughly the same area as the circles. There was also a large task-irrelevant flanker (either a black square or a black diamond) which subtended a visual angle of 8^0X8^0 located just outside the circle of circles on either the left or right side (see Figure 2). The circles, target, distractor(s), and flanker were presented simultaneously and remained on the screen until a response was made. The participant was instructed to maintain fixation in the centre of the screen and respond using a key press as to whether the target in the circle was a diamond or a square. It was a 2x2 design with target -flanker congruency as one factor and perceptual load as the other. This produced four conditions: (1) incongruent flanker, low load, (2) congruent flanker, low load, (3) incongruent flanker, high load, (4) congruent flanker, high load. Previous research has suggested that the congruency effect can be used as an index of attentional capacity. For example, using a similar task design, Maylor & Lavie (1998) showed that young adults showed a larger congruency effect than older adults. The interpretation was that young adults have a larger attentional capacity than was needed for finding the search target and that the excess attentional capacity was involuntarily used to process the irrelevant flanker. In contrast, the older adults were suggested to have reduced attentional capacity and therefore did not process the irrelevant flanker and therefore do not show a congruency effect. Therefore, if training with a video game leads to increased attentional capacity this should be evident by an increase in the congruency effect.

4.4.4: Visual Response-Time Task

This task was a modified version of Klemmer's (1956) variable foreperiod, simple visual response-time task. The participants viewed a black fixation cross (subtending 1^0X1^0 of visual angle) centred on a white background. The cross turned into a black square (subtending 3^0X3^0 of visual angle) after a variable length foreperiod of 1, 1.5, or 2 seconds. The participants were asked to respond by pressing the space bar as soon as they noticed the fixation change to a solid square. The participants were instructed to maintain fixation in the centre of the screen throughout the trials. The latency between the presentation of the square and the keypress was recorded and used as an index of simple visual response speed.

4.4.5: Visual Search

The visual search task was a variation of traditional visual-search paradigms (Castel, Pratt & Drummond, 2005). Participants were asked to start each trial fixating on a black fixation cross subtending 1^0X1^0 of visual angle on a white background. When the fixation cross disappeared after 1 second, the search array was presented and the participants were free to move their eyes anywhere they chose. Each search array consisted of either 32 items (easy-search condition) or 64 items (hard-search condition). Each search array only had one target item and a target item was present on every trial. The non-target (distractor) items consisted of the letters “p” and “q” and the target item was either a “b” or a “d”. The items were all black letters, and each subtended 1^0X1^0 of visual angle. The search items appeared at least 5^0 of visual angle from the centre of the screen and appeared at most 20^o of visual angle from the center of the screen. Each of the search items had at least 1^0 of visual angle separating them from the other search items. The display was presented until the participant made their response.

4.5: The Simplified Action Video Game

The simplified action video game was presented on a white screen. Light grey targets (subtending 3^0X3^0 of visual angle) were presented at random intervals with an average frequency which matched the assigned rate condition at a random location within the boundaries of the eccentricity condition. The participant's task was to move the mouse to each target and to make a mouse click as quickly as possible on the target. For Rate of Presentation, the fast groups were trained with targets appearing at approximately the same rate as occurs in the Medal of Honor action video game (20 targets per minute), and the slow groups were trained with targets appearing at a quarter of that rate (5 targets per minute). For Visual Field Width, the wide groups were trained with targets that were presented anywhere within an eccentricity of 16^0 from the center of the screen, having a maximum eccentricity roughly equivalent to that used for standard action video games, and the narrow groups were trained with targets presented at a maximum eccentricity that was a bit less than one third that of the wide group (approximately 5^0 from the center of the screen).

One concern was that because the training task given to these four groups would differ in difficulty, there would also likely be differences in motivation or effort. To try to equate motivation for the four groups, task success was equated during training by adjusting the duration of time that targets were presented, so that the success rate of target responding would be approximately 60% for each of the four conditions. Target presentation duration was adjusted to try and keep task performance for each participant at approximately the same level (60%) as was found during a pilot training project using a typical action video game, Quake Arena. All participants started at the same target duration on the first session (1.5 s). For each participant, the target duration was adjusted to attempt to establish and maintain a 60% success rate for all of the sessions. Specifically, during a training session, the target duration was adjusted based on the participant's performance on the previous 5 minute block. This was done by taking the percent success from the previous block and subtracting that success rate from the desired 60%. This difference was then scaled by the current duration and a fixed constant then added to the current duration in order to calculate the new target duration. Target duration for each new session was calculated based on performance on the last 5 minute block of the previous session. Task improvement on the simplified action video game was measured by the decrease in target duration from the first session to the last session while maintaining a 60% success rate.

Chapter 5: Results

The current study manipulated two components of a simplified video game (Rate of Target Presentation and Maximum Target Eccentricity) to determine whether either component produced changes in cognitive processing. An alpha level of .05 was used for all statistical tests. For any of the cognitive measures, if it was clear that the participant did not understand the task, then their pre-training and post-training scores for that measure were excluded. Furthermore, if a participant was at, or below, chance on a cognitive measure, then their pre-training and post-training scores for that measure were excluded.

5.1: Useful Field of View Task

The useful-field-of-view task measured participant's accuracy at detecting a target at three separate eccentricities (8^0, 15^0, 22^0). Three participants were excluded from this data set (n = 17) because they were at chance on even the narrowest eccentricities of this measure. Detecting a target at

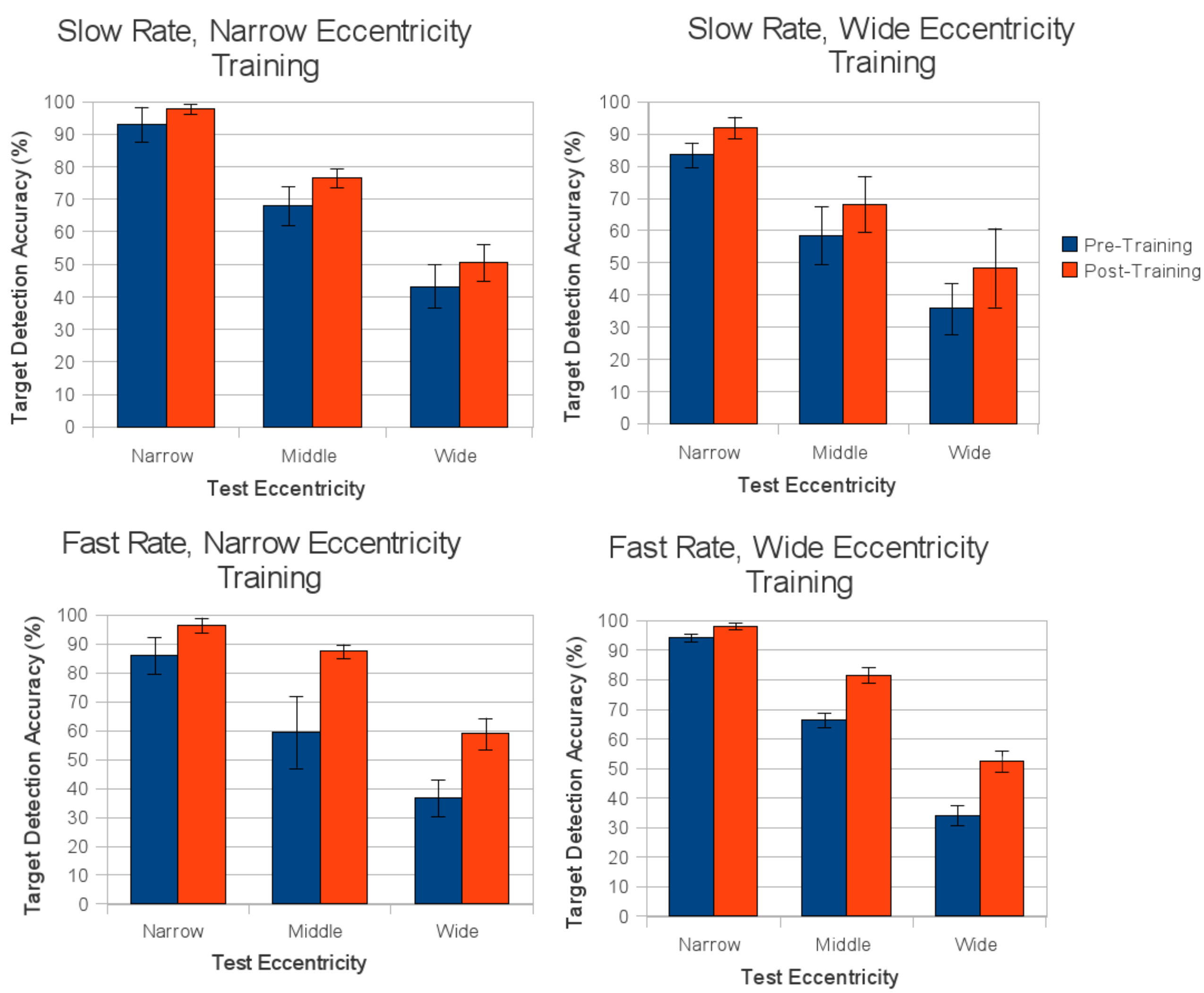

Figure 3. Mean scores and standard errors for each of the four separate training conditions on the Useful Field of View Task at each test eccentricity pre-training and post-training.

the narrowest eccentricity proved to be too easy with participants performing at ceiling, subsequently the near eccentricity scores were removed from the analysis.

Figure 3 shows target detection accuracy as a function of target eccentricity during testing pre-training and post-training for each condition. As shown in Figure 3, participants were worse at detecting targets at the widest test eccentricity (M = 44.91 %, SD = 10.29 %) than they were at the middle test eccentricity (M = 70.97%, SD = 11.74%), $F(1,13) = 302.79$, $MS_e = .004$, $p < .001$, $\eta^2 = .96$. The advantage is consistent with previous literature on the UFOV which suggests that our UFOV deteriorates as a function of eccentricity. Also shown in Figure 3, all training conditions improved from pre- (M = 50.26%, SD = 11.87%) to post training (M = 65.62%, SD = 12.47%), $F(1,13) = 30.32$, $MS_e = .013$, $p < .001$, $\eta^2 = .7$. The data confirm that the simplified action video game training is sufficient to

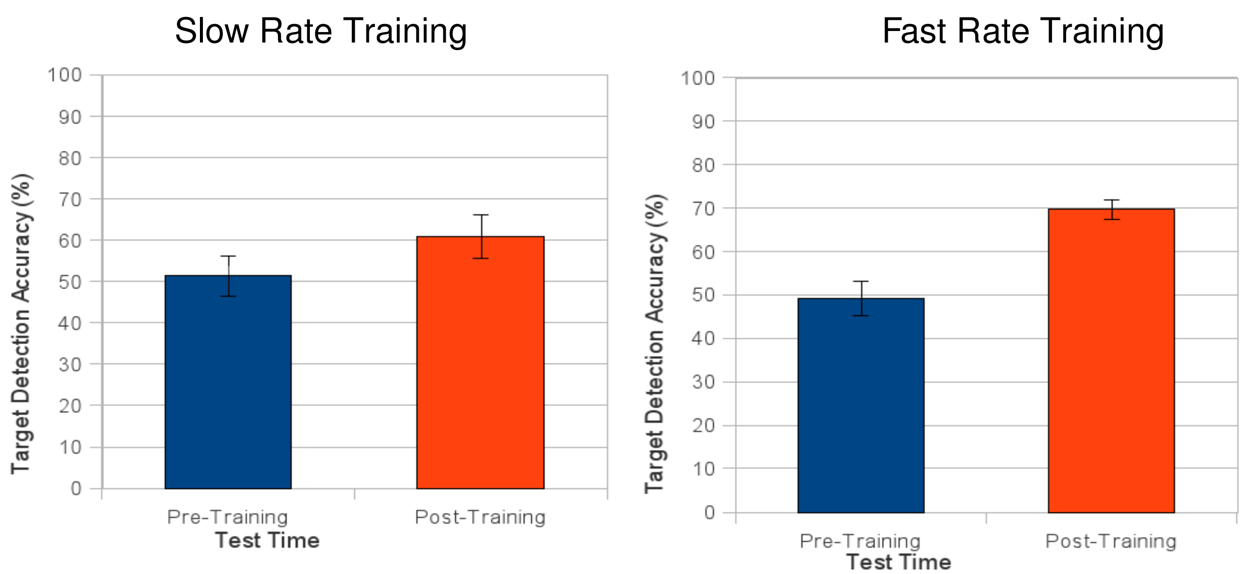

Figure 4. In the UFOV task, the slow rate training conditions produced no evidence of improvement from pre- to post training whereas the fast rate conditions improved significantly from pre- to post training. The combined accuracy collapsed across the middle and wide test eccentricities is shown here.

show benefit from pre- to post training.

Figure 4 shows overall accuracy for detecting targets at the middle and wide test eccentricities as a function of test time for participants in the fast- and slow-rate conditions separately. As is shown in Figure 4, those in the fast-rate condition improved marginally more than those in the slow rate, $F(1, 13) = 4.229$, $MS_e = .013$, $p = .06$, $\eta^2 = .25$. It was not predicted that training rate would affect the amount of improvement at the UFOV task and may reflect either the nature of the UFOV task itself or of the benefit of the faster training rate. There was no evidence that the eccentricity of training had any impact on the improvement on the UFOV task, $F < 1$. None of the remaining effects or interactions were significant.

5.2: Attentional Blink Task

The attentional blink task measured participants' accuracy detecting a second target after the presentation of a first and primary target as a function of the lag between the targets. Only one of the participants was excluded from this data set ($n = 19$) due to computer failure. Only trials where the first target was correctly identified were included in the analysis.

Figure 5 shows accuracy of detecting the second target as a function of lag for both pre- and post training. As is shown in Figure 5, second target detection varied as a function of lag, $F(7, 9) = 23.31$, $MS_e = .01$, $p < .001$, $\eta^2 = .95$, across all conditions and test times. The shape of the function is consistent with previous research. Also shown in Figure 5, participants across all conditions and lags improved from pre-training ($M = 77.57\%$, $SD = 7.26\%$) to post-training ($M = 81.04\%$, $SD = 8.7\%$),

$F(1,15) = 6.8$, $MS_e = .01$, $p < .05$, $\eta^2 = .31$. The improvement confirms that the simplified action video game training is sufficient to lead to improvement from pre-training to post training on the attentional blink task.

Figure 6 shows second target detection accuracy by lag, and pre- and post-training for the fast- and slow-rate conditions. As shown in Figure 6, participants in the fast rate conditions showed a different pattern of post-training advantage than those in the the slow-rate conditions, $F(7, 9) = 4.75$, $Ms_e = .005$, $p < .05$, $\eta^2 = .79$. At lag 2, those in the fast-rate conditions show a reduced attentional blink

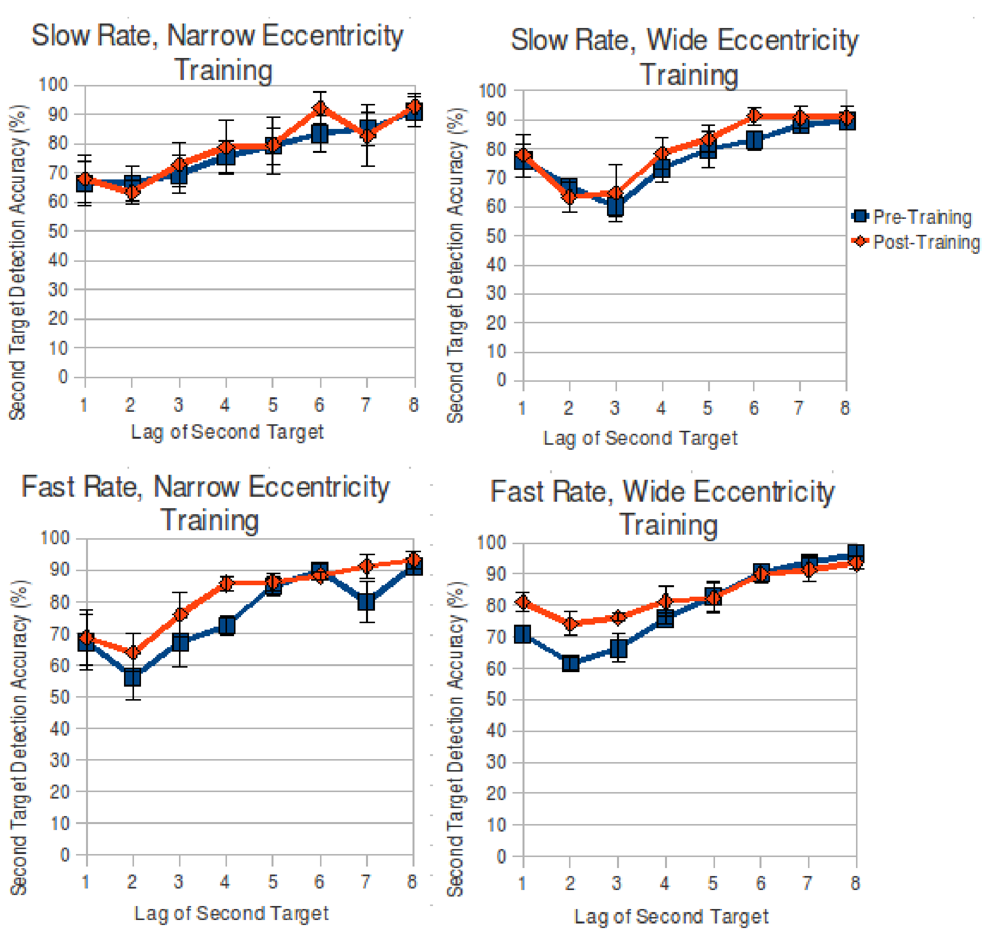

Figure 5: The means and standard errors for the second target detection accuracy during the Attentional Blink task pre-training and post-training are shown here for each training condition.

over those in the slow-rate conditions, $F(1, 16) = 8.77$, $MS_e = .039$, $p < .01$, $\eta^2 = .35$. At lag 6, those in the slow-rate training conditions showed a greater reduction in attentional blink than those in the fast-rate training conditions, $F(1, 16) = 10.05$, $MS_e = .021$, $p < .01$, $\eta^2 = .39$. The additional improvement shown by those in the fast-rate conditions at lag 2 confirms that faster target appearance rate during training produces increased ability to deploy attention in time. The improvement shown by those in the slow rate conditions at lag 6 was unexpected. There was no evidence that the eccentricity of training had any impact on the improvement on the AB task, F < 1. None of the remaining effects and interactions were significant.

5.3: Flanker Task

The flanker task measured the interference produced by a task-irrelevant distractor on a search

Figure 6. The pre-training and post-training second target detection rates during the Attentional Blink task are shown here for the slow rate and fast rate training conditions separately.

task. Interference was defined as the response time difference between congruent (target and flanker are the same shape) and incongruent (target and flanker are different shapes) conditions. Five participants were excluded from the analysis (n = 15), two due to computer error, and three due to abnormally high error rates.

Table 1 reports the mean response times for the Flanker task as a function of Training Condition, Perceptual Load, and Test Time. As is shown in Table 1, interference did not vary as a function of Test Time, Perceptual Load, or Training Condition, Fs < 1.

Figure 7 shows the cost of an incompatible distractor as a function of Perceptual load both pre-training and post-training. As is shown in Figure 7, Participants showed a higher incompatibility cost post-training than pre-training in the high load condition and a lower cost post-training than pre-training in the low-load condition, $F(1, 11) = 6.29$, $MS_e = 2239.64$, $p < .05$, $\eta^2 = .36$. This difference was unexpected. None of the remaining effects and interactions were significant.

5.4: Visual Reaction Time Task

The visual reaction time task measured the participants' latency to depress a key when a visual stimulus was presented. Four participants were removed from the data set (n = 16) for producing much higher rates of premature responding than the rest of the participants.

		Slow Rate, Narrow Eccentricity Training		Fast Rate, Narrow Eccentricity Training		Slow Rate, Wide Eccentricity Training		Fast Rate, Wide Eccentricity Training	
		Low Load	High Load	Low Load	High Load	Low Load	High Load	Low Load	High Load
Pre-Training	Incongruent	809 (49)	1035 (63)	730 (73)	872 (103)	652 (31)	836 (91)	773 (47)	1003 (72)
	Congruent	761 (26)	988 (69)	654 (43)	894 (102)	652 (55)	869 (60)	782 (58)	1006 (65)
Post-Training	Incongruent	692 (36)	905 (112)	599 (34)	755 (69)	619 (22)	743 (35)	665 (18)	838 (51)
	Congruent	710 (56)	866 (107)	574 (42)	705 (60)	622 (45)	714 (33)	663 (35)	824 (48)

Table 1. The mean response times for the Flanker task are shown in milliseconds for each of the four training conditions in each of the four Flanker task conditions pre- and post training.

Figure 8 shows the mean response times pre-and post training for each condition. As is shown in Figure 8, there was a marginal advantage in response times post-training over response times pre-training, $F(1, 13) = 3.10$, $MS_e = .002$, $p = .10$, $MS_e = .004$, $\eta^2 = .21$. This confirms that the simplified action video game training is sufficient to lead to improvement from pre-training to post-training on the visual reaction time task. Neither rate of target presentation nor target eccentricity during training produced evidence differing training effects on the RT task, Fs < 1. None of the remaining effects and interactions were significant.

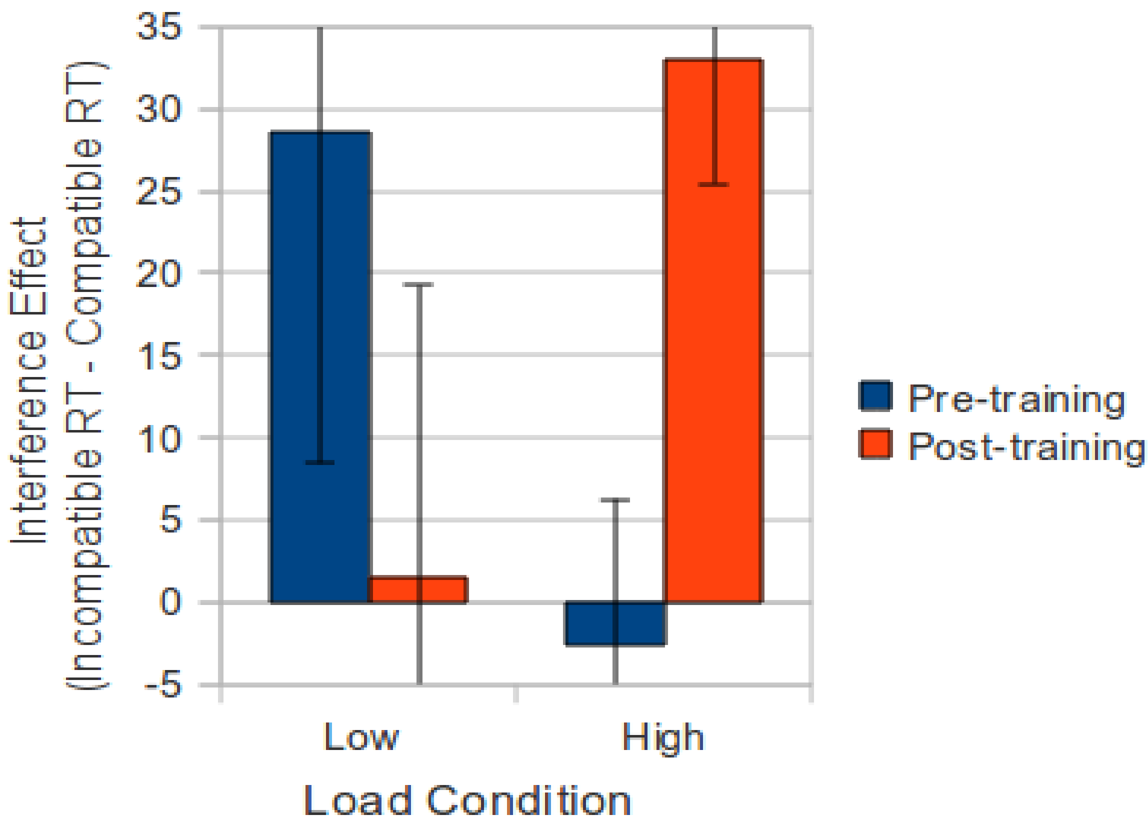

Figure 7. *The interference scores for the Flanker task are plotted above by subtracting the response times of the incongruent trials from the response times of the congruent trials. Interference scores are a measure of irrelevant item distraction.*

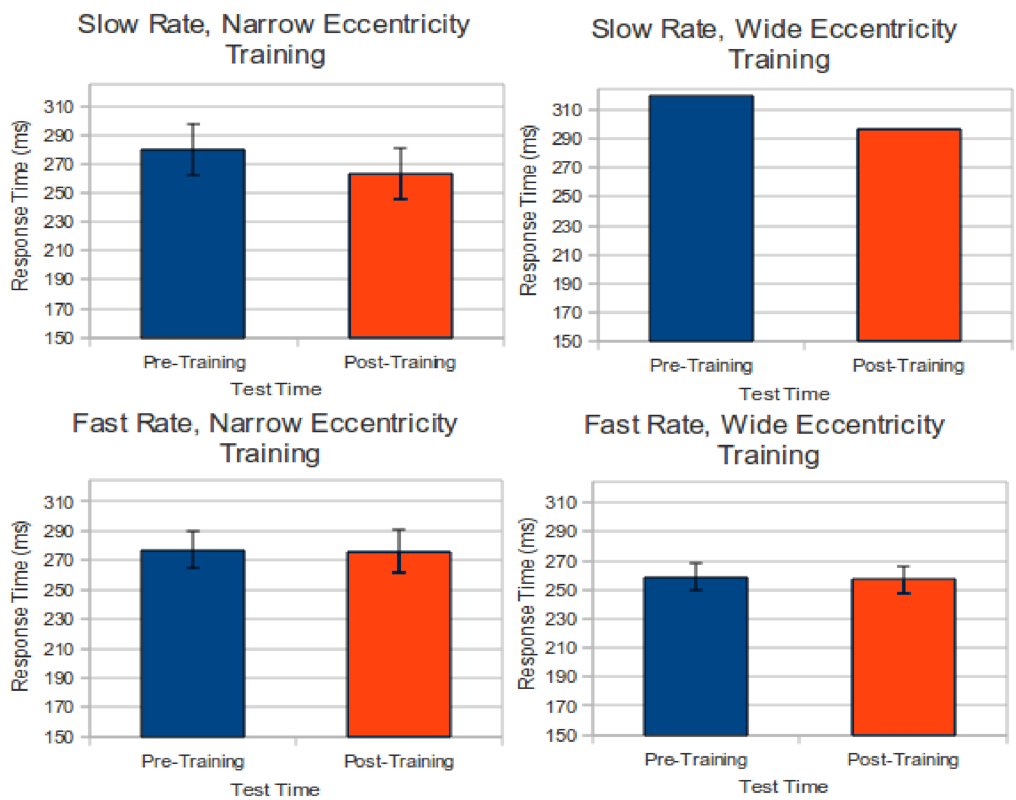

Figure 8. The mean response times and their standard errors for each of the four training conditions pre-training and post-training on the Reaction Time task are shown above.

5.5: Visual Search Task

The visual search task measured participants' latency to find and identify a target amongst distractors. Two participants were excluded from this data set (n = 18) for having accuracy rates which were much lower than all other participants.

Figure 9 shows response times as a function of Test Time and Search Difficulty for each Training Condition. As is shown in Figure 9, there was an advantage for the easy search condition (*M* = 2759.91 ms, *SD* = 532.81) compared to the hard search condition (*M* = 4268.41 ms, *SD* = 699.24)

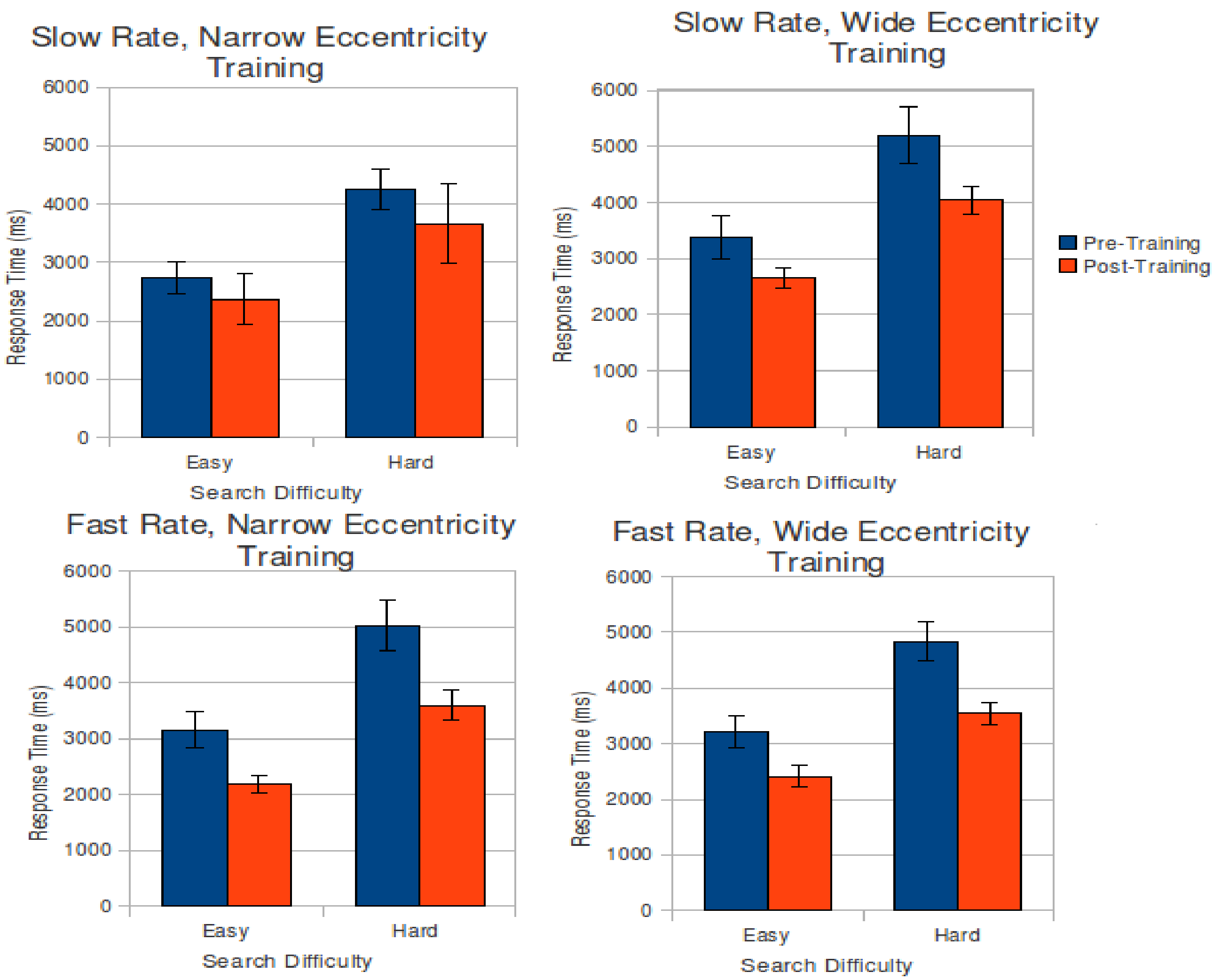

Figure 9. The mean response times and standard errors on the Visual Search task for all four training conditions pre-training and post-training are shown here.

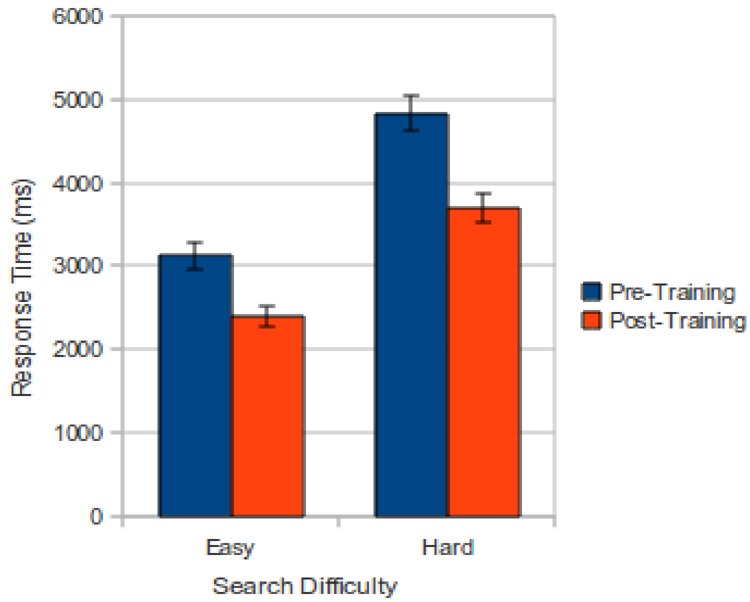

Figure 10. *The response times for the Visual Search task pre-training and post-training are shown here.*

across all Training Conditions, $F(1, 14) = 488.81$, $MS_e = 82699.46$, $p < .001$, $\eta^2 = .97$. The pattern of search times increasing as a function of increasing distracting items present is consistent with previous research. Also, as shown in Figure 9, participants in all Training conditions showed an advantage post-training (M = 3045.47 ms, SD = 611.61) compared to pre-training (M = 3982.86 ms,, SD = 755.63), $F(1, 14) = 34.68$, $MS_e = 428204.37$, $p < .001$, $\eta^2 = .71$. The advantage shown post-training confirms that the simplified action video game training is sufficient to lead to improvement from pre- to post-training on the visual-search task.

Figure 10 shows response times collapsed across training conditions as a function of Test Time and Search Difficulty. As is shown in Figure 10, there was a greater improvement pre-training to post-training in the hard search condition (1111 ms) than in the easy search condition (718 ms), $F(1, 14)$ =

9.71, MS_e = 71017.56, $p < .01$, $\eta^2 = .41$. The result confirms that improvement on the visual search task was not due solely to faster target processing once the target is found, but rather, it also reflects increased search ability. Neither rate of target presentation nor target eccentricity during training produced evidence differing training effects on the Visual Search task, $F(1,14) = 1.85$, MS_e = 71017.56, $p = .2$, $\eta^2 = .12$ and $F < 1$ respectively. None of the remaining effects and interactions were significant.

5.6: Training Task

Although the training was the independent variable in the overall design, the results of the training session were analyzed to ensure that participants showed improvement during training and to explore differences in training task improvement between the different training conditions. Training task performance was measured by the required duration of target presentation such that a participant was able to maintain a 60% successful target response rate.

Figure 11 shows the duration of target presentation as a function of training session. As is shown in Figure 11, participants improved across the 10 sessions, $F(9, 8) = 25.93$, $MS_e = .004$, $p < .001$, $\eta^2 = .97$. The shape of the improvement was most accurately fit by a first-order linear function between session and training task performance. The slope of the linear fit was -10 ms/session and the intercept was 810 ms.

Figure 12 shows the duration of target presentation as a function of training session for each of the four training conditions. As is shown in Figure 12, There was an overall advantage across sessions

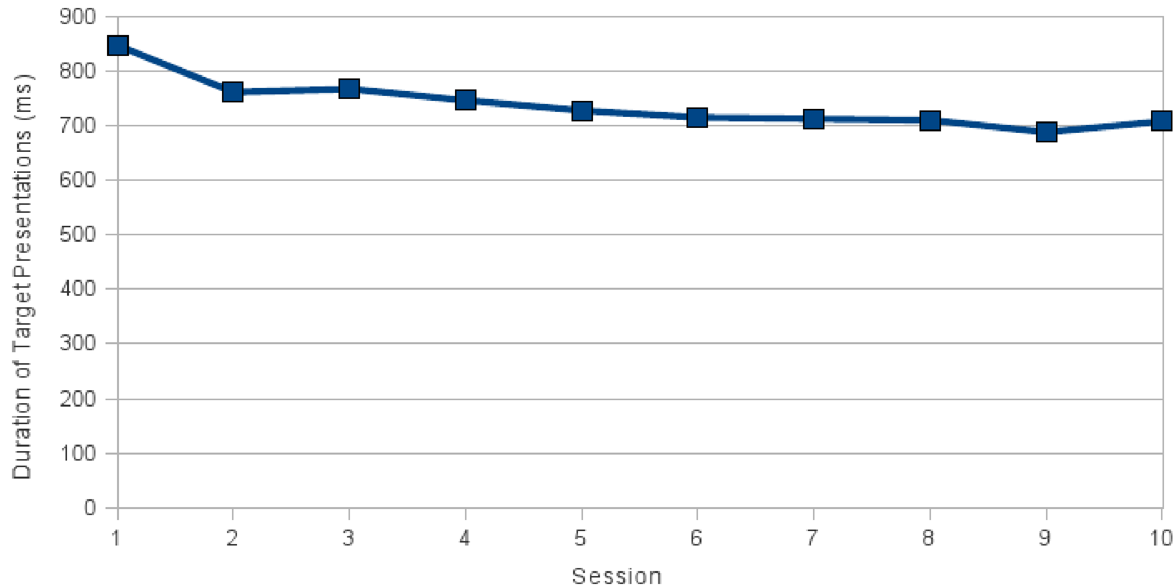

Figure 11. The training function for the simplified action video game over the ten sessions is shown here. A shorter duration means a faster average response time, and the function shows improvement across sessions.

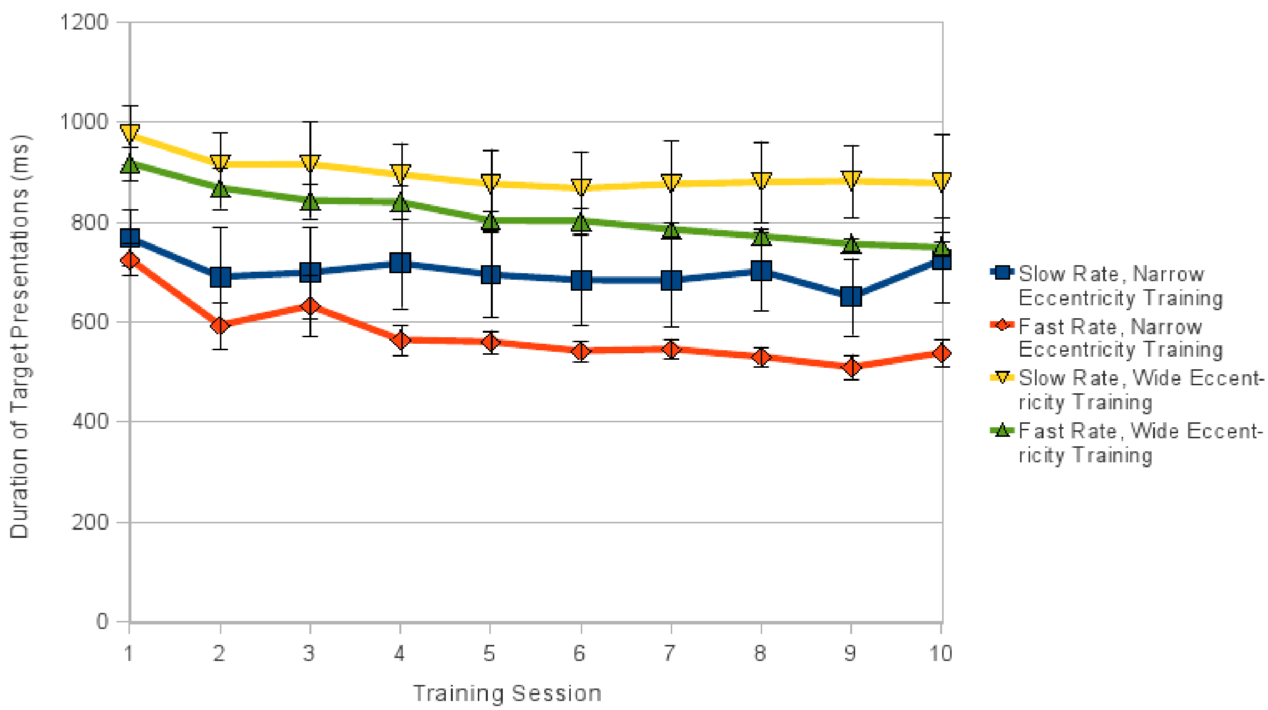

Figure 12. The mean durations of target presentation during training and their standard error is shown for each sesssion for each of the four training conditions.

for the fast-rate conditions (*M* = 681.4 ms, *SD* = 125.85 ms) over the slow-rate conditions (*M* = 795.2 ms, *SD* = 139.96 ms), $F(1, 16) = 13.97$, $MS_e = .84$, $p < .005$, $\eta^2 = .47$. The overall advantage for the fast-rate conditions is interesting because the fast-rate training should be more difficult than the slow-rate training. Also shown in Figure 12, there was an overall advantage across sessions for the narrow-eccentricity (*M* = 640.1 ms, *SD* = 108.6 ms) conditions over the wide-eccentricity conditions (*M* = 841.1 ms, *SD* = 88.81 ms), $F(1,16) = 37.45$, $MS_e = 2.25$, $p < .005$, $\eta^2 = .7$. The advantage shown by those in the narrow-eccentricity conditions is likely due at least in part to the fact that the mouse movements to the wide eccentricities were more difficult to make and took longer to complete.

Figure 13 shows the duration of target presentation as a function of training session for each of the slow-rate and fast-rate training conditions separately. As is shown in Figure 13, those in the fast-

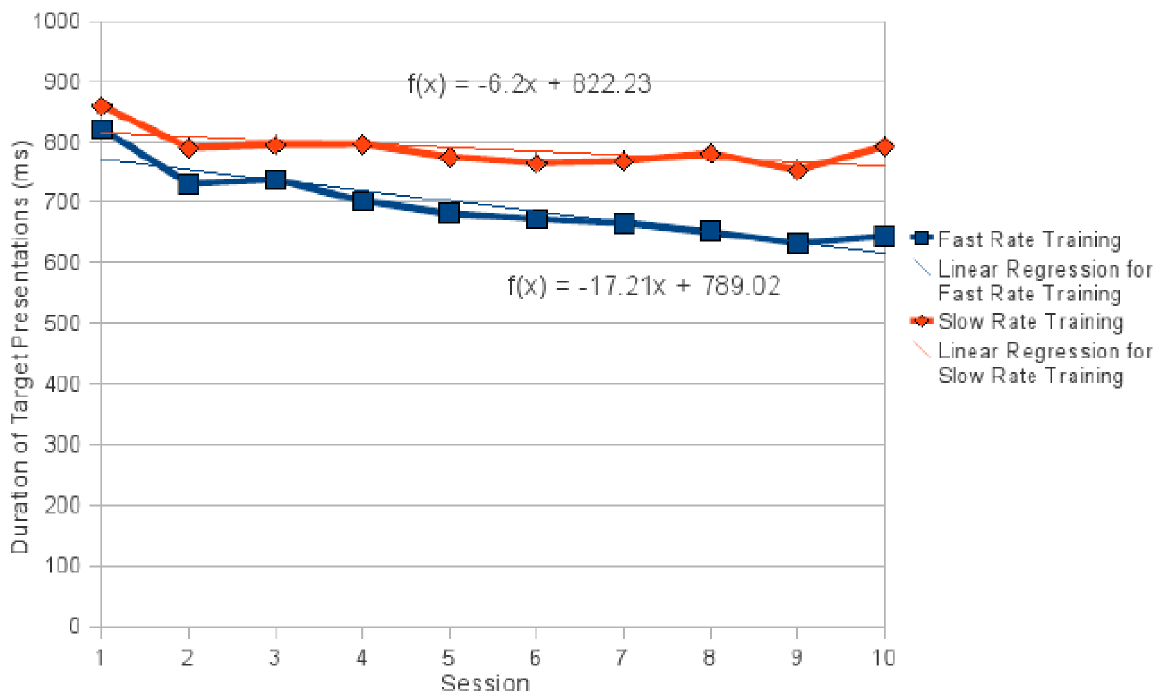

Figure 13. The training functions of those in the fast rate and slow rate training conditions are shown here separately.

rate training conditions showed more improvement over the training sessions than those in the slow-rate conditions, $F(9, 8) = 3.45$, $MS_e = .004$, $p < .05$, $\eta^2 = .8$. The fast-rate training function was best fit by the following linear equation, RT = -17S + 789 (RT = response time in milliseconds; S = session), whereas the linear equation that best described the training function for those in the slow-rate training condition was RT = -6S + 822, indicating that those in the fast-rate condition improved by approximately 10 ms per session more than those in the slow-rate condition. The increase in improvement shown by the fast-rate training conditions confirms that the fast-rate conditions produce more effective training than the slow-rate conditions, at least when measured by aptitude at the training task. The improvement shown by those in the fast-rate training conditions, at least in some part, also explains the overall advantage of the fast-rate training over the slow-rate training. None of the remaining effects and interactions were significant.

Chapter 6: Discussion

In the current study a method was developed to manipulate various aspects of action video game play with the goal of systematically examining the causal relationship between those aspects of practice and the visuo-cognitive changes that occur through this practice. In addition this study allowed an opportunity to examine whether this simplified game can create visual cognitive changes without many of the components of action video games previously studied (Green & Bavelier, 2003).

6.1: Hypothesized and Obtained Results

The hypotheses of this study centred around the idea that training with faster target presentation rates and greater target eccentricity would lead to greater improvement in visual cognitive skills. The results showed that differences in training affected performance on only a few of the visual cognitive tasks explored. See Table 2 for a summary of training results.

For the useful field of view task, those in the fast-rate condition benefited marginally more from training than those in the slow rate condition. This was an unexpected finding as there was no a priori reason to anticipate that training on a faster target rate would improve performance on a useful field of view task. However, it was expected that training with a wide maximum target eccentricity would produce greater improvement on the useful field of view task. But, again in contrast to the prediction, maximum training eccentricity showed no evidence of having an impact on the useful field of view task. The finding that a faster target training rate produced a larger improvement in the useful field of view task has at least three possible explanations. First, target presentation in the useful field of view task is brief (12 ms). In fact, this brief presentation was the reason that some participants needed to be excluded from the study. So although the useful field of view task was designed to measure the spatial spread of attention, this brief presentation of the target stimulus likely requires temporal honing of attention as well. Therefore, it is possible that training with a fast target rate produced a greater ability

	UFOV	AB	Flanker	RT	Visual Search
Test Time	*	*		marginal	*
Training Rate X Test Time	marginal	* at lag 2 and lag 6			
Training Eccentricity X Test Time					

*Table 2. Summary of significant effects for each visual cognitive measure. Significant effects are indicated by *.*

with which participants detected briefly presented stimuli rather than an increase in the actual useful field of view. Second, because those in the fast-rate training condition were presented with more targets, it might be that they simply had more practice with the target detection task regardless of the eccentricity of the targets. Third, it is possible that those in the slow rate conditions did not put as much effort into the training task as those in the fast rate conditions. Although, there was an attempt to equate for effort by equating task difficulty between training conditions, it is still possible that those in the fast training rate condition tried harder on the training task because they found it more engaging. To further theoretical understanding of cognitive training effects, it would be useful to understand the reason that target training rate influenced performance on the useful field of view task. However, for practical applications of this research, it is useful to know that faster target training rates influence useful field of view even if it attributable to an increase in motivation during training. Future research would be wise to utilize post-experiment questionnaires in an effort to determine whether different training conditions produce different degrees of motivation.

As expected, the fast target training rate condition produced greater improvement on the attentional blink task than the slow target training rate condition within the traditional attentional blink window (lag 2). However, unexpectedly, the slow rate training benefited second target detection more if the second target appeared six items after the first. The best explanation for this result is that there might be a trade-off of temporal attention such that if you practice with fast target rates, there is improvement in the processing of multiple targets appearing in quick succession (i.e., lag 2), but that there is a cost for processing targets that occur further apart temporally (i.e., lag 6). The opposite might be true when you practice with slow target rates, in that there is a gain in processing two targets that are slightly further apart temporally, but at a slight cost to their ability to process multiple items presented in quick succession.

Those in the fast-rate training condition showed not only different visual cognitive improvements over those in the slow rate condition on measures pre-training and post-training. They also exhibited different improvement rates than those in the slow-rate condition on the training task itself. Those in the fast-rate condition showed more improvement than those in the slow-rate condition over the ten sessions completing the training task. This was an indication that either those in the fast-rate conditions improved more because of something intrinsic to the task or that the fast rate task caused increased motivation for improvement. In either case, it seems that fast-rate training produces a larger benefit than the slow rate training, toward improving performance on both the training task itself and the useful field of view task. The results of the attentional blink task indicate that there may be trade-offs to these benefits and that there are likely situations and tasks where training with a slower rate of target occurrence is more optimal.

Although some predicted improvement differences between training conditions were found, there were other predicted improvement differences that were not found. Training at wider eccentricities was expected to cause greater improvement on the UFOV task and visual search task. However, for both tasks, there was no evidence that the training effect for wide and narrow training eccentricities differed. One explanation for the lack of difference between these two groups is that participants ignored the instructions and systematically changed their own viewing distances in such a way that the maximum target eccentricity for both the narrow and wide group was roughly equivalent.

This was unlikely, but it was possible, because a surveillance system was not used to monitor participants' behaviour during the training sessions, although an experimenter was always present during the visual search task.

Although the faster training rate produced some differences in training from the slow training rate, there were predicted differences that were not found. It was predicted that the faster rate of target presentation would cause greater improvement in the reaction time task and visual search task but no evidence for either of these effects were found.

Strong visual cognitive improvements on the useful field of view, attentional blink, and visual search tasks were found in all four training conditions. Participants in all conditions improved on the UFOV task from pre-training to post-training which was interesting as previous research has shown that those who played Tetris during a training period of the same duration as the current study showed no improvement on the UFOV task (Green & Bavelier, 2003). A reduction in the attentional blink through training is also unexpected because Green and Bavelier's (2003) found that those who played a non-action video game (Tetris) for the same duration as the current study showed no improvement on the attentional blink task. It seems as though the simplified action video game, even with the narrow eccentricity and slow target rate was able to produce similar results to the action video games previously studied. Although it is not uncommon for people to improve on visual search tasks, it is interesting that not only was there an overall reduction in search times from pre-training to post-training, but there was also a set size interaction with test time indicating that participants improved the efficiency of their search such that the time cost per search item was 13 ms lower post-training. This indicates that training produced not just faster response times once the target had been found, but also increased the participant's visual search efficiency. However, these overall training effects must be interpreted with caution. It is possible that these training improvements were caused simply by the practice that the participants had with the cognitive tasks during pre-training. Two possible control conditions would help with interpretation of the current results: (1) a "no training" condition in which participants completed the pre-training and post-training tests without actually doing the training, and (2) a condition which trains on the Tetris game. Each control option has advantages and disadvantages. The "no training" condition would show the improvement on these tasks caused by repeating them. However, one disadvantage is that there might be motivation differences between the "no training" control condition and the training conditions in which participants complete 10 hours of training between the pre- and post-testing sessions. The Tetris control condition addresses the motivation problem to some degree, but runs the risk that the game itself is influencing post-training testing. Perhaps it is the case for all of the previous research that the gains seen by video game players are really just the benefit of repeating the exact task pre-training and post-training and that those in the Tetris control condition are actually decreasing their visuo-cognitive abilities which might cancel out any pre-training to post-training repetition benefits that might exist. In either case, further research will be needed to fully interpret the meaning of the training improvement on the visual search, UFOV, and attentional blink tasks.

All of the results other than those of the flanker task results were relatively straightforward. The validity of the flanker task as a measure of attentional capacity was questionable because there was less flanker interference in the low load condition than in the high load condition pre-training. Such a result is inconsistent with the load conceptualization of this task--low load conditions should leave spare attentional capacity for flanker processing resulting in flanker interference, whereas high load conditions should exhaust attentional capacity and reduce or eliminate flanker processing and flanker interference. If the load conceptualization cannot be appropriately applied to this flanker task, then this task cannot be used as a measure of attentional capacity. There was also a great deal of variation between participants on this task, with some individuals showing faster reaction times in incongruent conditions than congruent conditions. Again, in contrast to traditional load ideas. There was however one trend in the data that warrants mention. Participants in all conditions showed increased interference post-training in the high load condition. This pattern of results is consistent with load accounts of this flanker task, which suggest that practice reduces attentional needs, increases spare capacity, and therefore increases flanker processing.

6.2: Future Directions

There are many questions still unanswered about the nature of the visual cognitive changes that occur during training. Questions such as: How much practice is required to maintain the changes if any? What is the extent of the training that can occur? Are there any cognitive trade-offs associated with the benefits to the training? Just to name a few. Although many questions remain, the current study's approach of employing a simplified video game in which there is precise control over which components of the video game are trained should be employed in future research studies. Only after the effects of simple training paradigms and their behavioural impact are well-understood, should research move on to examine more complex training tasks. In fact, the complexity of the Space Fortress game may have been the reason why this training game was eventually abandoned as a research tool.

The term “action” in action video games still remains ambiguously defined and therefore the traits or components that comprise an action video games are unclear. To repeat, an action video game is typically defined as any game with at least one and often all of the following traits: rapid responses are required, multiple objects are to be apprehended, multiple objects are to be tracked, and large visual areas must be monitored continuously. This is a loose definition at best. While this definition is useful for classifying most games as either an action video game or a non-action video game, the vagueness of the definition leaves the classification of many games as counter-intuitive. The definition is necessarily broad in order to encompass the large variety of games which seem to cause the cognitive changes that have previously been studied but due to the plethora of games which are currently played it can be hard to discern whether or not the game falls within the category of “action”. For example, if one part of a game requires the participant to track multiple objects that are moving so slowly that they are consistently at ceiling on that aspect of the game, should it still be considered an “action” game? More critically, if two games classified as “action” video games train a different set of skills on a different set of tasks, then the resulting cognitive changes will likely also differ, even though they are both most accurately considered simply “action” games. Rather than a dichotomous categorization of games into two groups, it is more logical to break the games down in terms of the multiple separate tasks they require the player to practice, and categorize the games along a spectrum with regards to those separate task dimensions. Where the game falls on the spectrum in any one task dimension should be measured by a function of both the frequency with which completion of the task is required by the player and by the difficulty of the task the player is required to complete. The more “action” a game is with regards to any task dimension, the more frequently they must carry out that task and/or the more challenging that task must be. Certainly it will not be trivial to create task dimensions that everyone agrees upon or to balance difficulty and repetition in terms of "action" but this is a necessary step if research in this area is to continue to make strides into understanding how practice with these different games is generalizing to other measures. This will be beneficial to researchers in this field as it will allow them to use games which are currently popular for training while being able to more accurately describe the nature of the general tasks the game is practicing.

As the current study was exploratory and examined training of only two components of a video game, it is clear that there are numerous straightforward extensions of this work that are possible. Different rates of target presentation and even wider or narrower eccentricities are the most obvious extensions of the current work, but there are also slight variations which would also be logical next steps. These include, but are not limited to, adding distractors to the training game in order to force participants to discriminate targets from distractors and allocate resources accordingly. This target-distractor component is found in almost all action video games and the cognitive effects of training on a task that requires this type of discrimination would be interesting to explore. Another training dimension that would be interesting to systematically manipulate is that of movement. Again, in most action video games the targets are moving. Therefore, it might be useful to investigate how moving versus non-moving training stimuli impact performance on movement-based tasks such as multiple object tracking tasks. Manipulating the difficulty of target detection by varying the target-background contrast or by disguising high frequency targets in high frequency backgrounds would be an interesting to dimension explore since target-background discrimination is an integral part of most graphically-rich action video games. Such a training manipulation might help in the understanding of how video game training produces benefits to contrast sensitivity and spatial resolution.

Lastly, another simple extension of this paradigm would be to have the rate at which targets appear remain constant but vary the number of targets presented at overlapping intervals such that some participants receive very few or no exemplars of multiple targets and others receive many exemplars of multiple targets. It would be interesting to investigate the effects of perceptual load during training using this simple extension of this paradigm because of the intuitive appeal that practicing with a higher cognitive load could be responsible for increasing attentional capacity. In summary, it is clear that there are many simple training manipulations that should be explored prior to pursuing training research with complex video games.

6.3: Limitations

The major limitation to the current study is that it only included those who had limited experience with video games. This certainly constrains the applicability of this study to the general population. However, it is interesting that approximately 25% of undergraduates who completed the pre-screening questionnaire qualified for recruitment, indicating that those with very limited video game experience are not as small a portion of the university population as might be expected. This is an indication that there is still a sizable portion of the population who might be able to improve their visual cognitive skills through training even in the unlikely event that these results apply exclusively to the inexperienced.

Another limitation of the study was the lack of assessment of motivation. Although the participants were given the same incentive to improve their performance and all conditions were made to be equally difficult by keeping the success rate at 60% across all conditions, no attempt was made to gauge motivational differences between training conditions. Trying to measure an individual's motivation to improve at the training task could be done by having participants report their motivation during each task, during training as well as their motivation on a variety of unrelated tasks to the study in order to gain a baseline for their motivation ratings. By doing this, future researchers will be able to more carefully investigate the interactions of motivation, performance, and training.

Data for these types of studies is difficult to gather. It is difficult to recruit participants, due to the long duration of the study. It is also difficult to compensate participants well enough to have them maintain commitment to the study. Because this type of study requires three uninterrupted weeks of participation, participant recruitment must be stopped three weeks ahead of each break in term as most students leave campus. The small number of participants in the current study means that there were potential issues with lack of power. More participants are currently being run in order to correct this limitation.

A final limitation was lack of sensitivity for the UFOV measure. Unfortunately, four participants needed to be excluded from the study because they were unable to perform above chance on the UFOV task. An adaptive staircase procedure where the target locations are moved wider and narrower according to the participant's response ability would allow for the definition of areas where percentage accuracy of detection was within certain thresholds. This paradigm would likely require more trials but would also likely be more sensitive to training effects.

6.4: Applications

The applications of this research are widespread. There is evidence that the UFOV task is a significant predictor of automobile accident rates among aging populations (Owsley et al., 1998; Clay et al., 2005). If the size of the useful field of view is causally responsible for these accident rates it means that approximately 25% of the population at least may be able to reduce their risk of an accident through some action video game training, particularly games with a high rate of target presentation. Furthermore, athletes, law enforcement officers, and military personnel could all potentially benefit from training on tasks with high rates of target presentation.

6.5: Conclusion

The study of how cognitive processing is influenced by video games is as pertinent as ever in our current society. Video game playing is an integral part of society with approximately 75% of first-year Queen's University psychology students reporting to have had some video-game experience. Therefore, it is important to understand the effects that these video games are having on our cognitive systems so that we can better understand any negative impacts they are having and any benefits they provide. The current study explored two components of most current action video games, the rate of target presentation and the eccentricities with which those targets appear. The results indicate that the rate at which targets are presented during training produces training effects, as measured by the UFOV task and the attentional blink task. In contrast, training with a wide eccentricity produced no additional benefits over training with a narrow eccentricity. With the UFOV task, the increased benefits of the fast rate training condition when compared to slow rate appeared at all eccentricities measured. With the attentional blink task, the benefits of the fast rate condition when compared to the slow rate appeared when the second target appears shortly after the first (lag 2), but those effects were reversed such that those in the slow rate condition show more benefit than those in the fast rate with a longer interval between the two targets (lag 6). This finding is interesting because it highlights that there could be trade-offs with video game training, such that the beneficial aspects might, in some cases, be accompanied with negative effects.

There were also significant training effects, regardless of training condition, in the UFOV, attentional blink and visual search tasks, although additional control conditions will be necessary before strong conclusions can be drawn. However, there is the possibility that training with the simplified action video game even at the slow rate and narrow eccentricity is capable of causing the sort of improvements that have been observed in previous research using complex video games (Green & Bavelier, 2003; Castel, Pratt & Drummond, 2005). This would mean a great reduction in the number of elements of the action video game which are considered necessary to cause these improvements. For example, such a result would indicate that violence is not a necessary component of the video game training task.

Finally, the current study is not promoting excessive playing of video games as a means to improve cognitive processing. The current study simply explored the effect of a small amount of action video game playing at a moderate frequency on specific visuo-cognitive skills with the hope of understanding the changes that occur during this type of training.

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