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Individual differences in video game experience: Cognitive control, affective processing, and visuospatial processing

Kira Bailey
Iowa State University

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Individual differences in video game experience: Cognitive control, affective processing, and visuospatial processing

by

Kira Marie Bailey

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Robert West, Major Professor
Alison Morris
Craig Anderson

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Abstract

Independent groups of researchers have investigated video game effects on cognitive control (Mathews et al., 2005), affective processing (Kirsh & Mounts, 2007), and visuospatial processing (Green & Bavelier, 2003). However, no published research has studied all three domains in the same sample of gamers and non-gamers. In the current study nonviolent and violent gamers, and non-gamers performed two tasks tapping each of these three domains; the Stroop and N-back tasks for cognitive control, the picture rating and emotion search tasks for affective processing, and the enumeration and the visual short-term memory tasks for visuospatial processing. Consistent with past research (Bailey, West, & Anderson, 2009), there was a negative relationship between video game experience and proactive cognitive control that was more pronounced in the violent gamers than nonviolent gamers. There was a fundamental shift in the processing of violent and positive affective information in the violent gamers relative to the non-gamers and nonviolent gamers. The violent gamers appeared to have a greater span of apprehension and visual short-term memory capacity relative to non-gamers and nonviolent gamers, which is also consistent with past research. The findings of the current study emphasize the need to investigate the effects of different video game genres as they may not influence cognitive control, affective processing, and visuospatial processing in the same way.

Chapter 1. Introduction

Video games represent a popular source of entertainment for children and adults. A 2007 survey by NPD Group, Inc. estimated that 12 to 17 year olds play an average of 10 hours a week, and in one sample of undergraduate males from our laboratory, 25% reported playing four or more hours of video games per day (Bailey, West, & Anderson, 2009). The rapid growth of technology in the gaming industry over the last several years has brought a plethora of new games and consoles to the market and record sales illustrate the ever-growing demand for these products in the United States (Entertainment Software Association, 2008). The popularity of video games brings to light the need for research into the possible effects of playing video games.

Much of the research on video games has focused on the effects of violence in the games. A significant body of literature indicates that playing violent video games can increase aggression in both children and adults (Anderson et al., 2004; Anderson, Gentile, & Buckley, 2007; Bartholow & Anderson, 2002; Anderson & Dill, 2000). Increases in aggression following video game play have been documented in the laboratory (Barlett, Harris, & Bruey, 2007; Giumetti & Markey, 2007; Bartholow, Sestir, & Davis, 2005; Bushman & Anderson, 2002; Anderson & Morrow, 1995) and violent video game experience has also been linked to more aggressive behavior outside of the laboratory (Gentile, Lynch, Linder, & Walsh, 2004).

Video games may also have negative effects on emotional processing and executive function, although less research has been conducted in these areas. A small number of studies have demonstrated that violent video games may negatively influence the processing of emotional stimuli (Kirsh & Mounts, 2007; Kirsh, Olczak, & Mounts, 2005). Two studies have shown that video game exposure can lead to increased interference on the Stroop task and the under recruitment of the brain networks thought to underlie cognitive control. Kronenberger et al. (2005) found a negative correlation between violent media exposure, including playing video games, and performance on the color-word Stroop task for both adolescents with behavior disorders and controls. Matthews et al. (2005) found that similar to adolescents diagnosed with disruptive behavior disorder, individuals with higher media violence exposure showed less activation in the anterior cingulate cortex and inferior frontal gyrus. This lack of activation may indicate a failure to recruit cognitive control networks during performance of the Stroop task.

In contrast to the studies showing a negative effect of video game play on aggression, emotion processing, and executive function, other studies have demonstrated that action video games have a positive effect on visuospatial skills. Studies have shown that video game players outperform non-players on measures of visuospatial attention and spatial acuity, and that non-players show similar enhancements after as little as 10 hours of training on video games (Clark, Lanphear, & Riddick, 1987; Dorval & Pepin, 1986; Dye, Green, & Bavelier, 2009; Green & Bavelier, 2003; Green & Bavelier, 2007; Lintern & Kennedy, 1984).

The positive and negative effects attributed to video games are not necessarily mutually exclusive. The action video games associated with improved visuospatial skills often contain violent content, and are similar to the games linked to disruptions in emotion processing and cognitive control. No study to date has examined all of these areas in the same sample of video game players. Therefore, the current investigation was designed to examine visuospatial skills, affective processing, and cognitive control in high video game players and non-gamers at the behavioral and neural levels.

In the following sections of this proposal, the literature regarding video game effects on visuospatial attention and affective processing are reviewed. Cognitive control has not been as extensively studied with video game players, so a theory of conflict processing and cognitive control that may be relevant to individual differences in video game players and non-players will be introduced and described within the context of the Stroop task. Then I describe components of the event-related brain potentials (ERPs) associated with cognitive control, visual working memory, and affective processing. Finally, I will describe the design of the current study.

Video Games and Visuospatial Attention

Research conducted over the last few decades indicates that exposure to video games has beneficial effects in the areas of visuospatial attention and motor skills. Positive correlations have been found between video game play and hand-eye coordination (Griffith, Voloschin, Gibb, & Bailey, 1983), efficiency of visual search (Castel, Pratt, & Drummond, 2005), and tracking in a flight simulator (Lintern & Kennedy, 1984). Additionally, research has demonstrated that performance on many of these tasks can be improved by training on video games (Dorval & Pepin, 1986; Green & Bavelier, 2003; Green & Bavelier, 2007; Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994). One implication of these studies is that video games may be used to improve the visuospatial and motor abilities of groups whose performance on visual and spatial tasks is below average, such as the very young, the elderly, and the disabled (Whitcomb, 1990). Moreover, video games may have the potential to improve visuospatial abilities in groups that could benefit from superior abilities, for instance military personnel (Green & Bavelier, 2006c; Lintern & Kennedy, 1984). In the following pages I review the critical findings of individual difference and training studies and describe one theory of how training on video games may improve visuospatial abilities.

Individual Differences in Video Game Experience

A few studies have revealed differences in the motor abilities of video game players (gamers) and non-video game players (non-gamers). Griffith et al. (1983) investigated eye-hand motor coordination in gamers and non-gamers using a rotary tracking system. Using a stylus, participants tracked a moving light over a glass plate. Participants were tested on three different shapes (i.e. circle, square, and triangle) at several different speeds. The gamers performed significantly better on this task than the non-gamers. Video game experience has also been linked to information processing speed. For instance, kindergarten children who reported higher interest in and experience with video games displayed faster reaction times than their peers who reported less interest in and experience with video games when comparing successively presented pictures of frogs that could differ on color or shape (Yuji, 1996). In contrast, there were no differences in accuracy between the groups indicating that the video game effect did not represent a speed-accuracy trade-off.

More research has been devoted to the differences between gamers and non-gamers' visuospatial skills. To test divided visual attention, Greenfield et al. (1994) asked subjects to indicate the location of a flashing asterisk by pressing a left or right key. Probabilities were manipulated so that in one condition the asterisk appeared at one location 80% of the time and in the other condition the asterisk appeared at each location 45% of the time. In both conditions there was a 10% chance the asterisk would appear at both locations. An attentional benefit for the high probability (80%) location measured as a faster reaction time was found for both gamers and non-gamers. An attentional cost (representing slower reaction time) to the low probability location was found for the non-gamers but not for gamers. This finding indicates that gamers may be able to shift or disengage attention more quickly than non-gamers. While gamers out-perform non-gamers on many tasks, not all video games have been associated with general improvements in visuospatial performance. For example, Sims and Mayer (2002) demonstrated that expert *Tetris* players were faster than controls at mentally rotating Tetris-like shapes, but were not any better at other tests of mental rotation.

Green and Bavelier (2003) found that gamers outperformed non-gamers on multiple measures of visuospatial attention. A modified flanker task was used to test for a general increase in attentional capacity in gamers. Six rings were displayed on the computer screen, and participants were instructed to indicate whether a diamond or a square appeared in any of the rings, while ignoring a distractor shape presented outside of the rings. The difficulty of the target task was manipulated by varying the number of rings containing shapes. The compatibility effect was indexed by subtracting the reaction time for compatible trials (where target and distractor are the same shape) from incompatible trials. A large effect indicates more attentional resources are left-over to process the distractor (Lavie & Cox, 1997). As the target task became more difficult, the compatibility effect decreased for non-gamers, indicating they had limited attentional resources left to process the distractor. For gamers, the size of the effect remained fairly constant as task difficulty increased, leading to the interpretation that gamers had more attentional capacity than non-gamers.

The gamers’ performance on an enumeration task further supported a general increase in attentional capacity. In this task, participants indicated the number of items that appeared in a briefly flashed display. When participants are allowed to freely view the display, reaction time is the measure of interest and the data are usually characterized by two processes, subitizing and counting (Trick & Pylyshyn, 1993). For small displays (one to three items) reaction times are fast and accuracy is high (subitizing). As more items are added to the displays, participants begin to count the items, resulting in an increase in reaction times and a decrease in accuracy (Trick & Pylyshyn, 1994). When participants are shown displays briefly, accuracy becomes the measure of interest and the span of apprehension is the number of items quickly and accurately reported. Green and Bavelier (2003) examined accuracy on the enumeration task and found that gamers had a larger span of apprehension than non-gamers. Gamers could accurately apprehend an average of 4.9 compared to 3.3 items. Conversely, Green & Bavelier (2006b) argued that gamers' improved performance on the enumeration task was due to better counting and not an increase in subitizing range. The accuracy breakpoint on the enumeration task was approximately two items larger for gamers than non-gamers, although reaction times for the gamers increased beyond about three items. The authors suggest that the divergence between accuracy and reaction time indicates that gamers' performance on enumeration is due to more accurate counting rather than an increase in their subitizing range.

Video game experience has also been found to increase the spatial and temporal distribution of attentional resources (Green & Bavelier, 2003). In the useful field of view task, participants indicate which one of eight spokes a target appeared on while remaining fixated on the center of the screen. The target appears at multiple eccentricities and gamers were more accurate at all eccentricities, demonstrating improved distribution of attention over the visual field. Similarly, Castel et al. (2005) demonstrated that gamers were faster to detect targets in a visual search task, regardless of task difficulty. Here participants searched for the letter “b” or “d” among one letter distractors in the easy search and multiple letter distractors in the difficult search. The gamers displayed over all faster reaction times, and a significant set size by group interaction suggested the gamers searched more efficiently than non-gamers.

In order to measure the temporal distribution of visual attention in gamers and non-gamers, Green and Bavelier (2003) used the attentional blink task. Participants had to identify one target and detect a second target. The attentional blink, the difficulty to detect a second target 200-500 ms after the first target appears, was larger for non-gamers, as indicated by less accurate detection of the second target. Taken together, these findings show that the gamers’ enhancements in visuospatial attention extend to a number of tasks in the spatial and temporal domains.

One study has demonstrated the influence of individual differences in video game experience on an inhibition of return task (Castel et al., 2005). This task consisted of a cue (a bold outline around one of two boxes to the left or right of a fixation cross) displayed briefly followed by a target equally likely to appear inside either box. Participants were told the cue had no relevance to target location and were instructed to press the space bar as quickly as possible when the target appeared. At the 200 ms stimulus onset asynchrony (SOA), gamers and non-gamers had faster reaction times for targets at cued locations demonstrating facilitation. This finding varies from Greenfield et al. (1994) where non-gamers also demonstrated a facilitation effect for cued objects. At longer SOAs, both groups had slower reaction times for targets at cued locations, displaying inhibition of return to the originally cued location. For targets at cued and uncued locations, gamers had significantly faster reaction times. The results show that while there were no group differences in inhibition of return, the gamers are faster than non-gamers to detect visual targets.

In summary, individual difference studies have revealed a relationship between playing video games and better performance on motor and visuospatial skills. This research has shown that gamers are more efficient at visual search tasks (Castel et al., 2005), have faster reaction times (Greenfield et al., 1994), and greater visual capacity (Green & Bavelier, 2003). One drawback to individual difference studies is that they do not allow for the conclusion of a causal relationship. The findings could be due to a self-selection bias or to other unknown variables. The training studies described in the following section serve to establish a causal link between video game play and improvements in visuospatial attention.

The Effects of Video Game Training

The research discussed above is suggestive of a link between video game experience and enhanced visuospatial processing and motor skills. Further support for this comes from training studies. Typically, training studies involve exposing non-gamers to action video games for at least 10 hours of play and then measuring changes in visuospatial cognition. A group of non-gamers trained on the action video game, *Medal of Honor*, and another group of non-gamers trained on the puzzle game, *Tetris* were pre- and post-tested on the visual enumeration, useful field of view, and attentional blink tasks (Green & Bavelier, 2003). Training lasted 10 days and consisted of playing the assigned game for one hour per day. The non-gamers trained on the action video game significantly improved their performance on all three tasks, while training on *Tetris* did not result in improvements. Green and Bavelier (2006b) followed up their individual difference study by training non-gamers in the same manner described above. They also found improvements in accuracy on the enumeration task following *Medal of Honor*, but not *Tetris* training. Sims & Mayer (2002) also trained non-gamers on *Tetris* and found that their ability to mentally rotate *Tetris* – like objects improved after training, but no improvements in their ability to mentally rotate other objects were found.

Research has revealed the usefulness of specific video games as training and performance test measures for some skilled professions, such as pilots and surgeons. Two studies using the Atari video game *Air Combat Maneuvering* demonstrated the game's usefulness as part of a test battery for military personnel (Jones, Kennedy, & Bittner, 1981) and as a covariate in research with carrier-landing trainees (Lintern & Kennedy, 1984). Gopher, Weil, and Bareket (1994) compared the flight performance of Israeli Air Force cadets who had been trained on the computer game *Space Fortress II* and a control group of their peers. Game trained cadets performed better in almost all aspects of flight performance, and the video game was adopted as a part of the regular training program. Similarly, it has been demonstrated that surgeons with the highest game scores following training on three different video games, *Super Monkey Ball 2, Star Wars Racer Revenge,* and *Silent Scope*, made fewer errors on a training program for laparoscopic surgery than surgeons with lower video game scores and surgeons with no training (Rosser et al., 2007).

Video game training has also been shown to reduce gender differences on some visuospatial measures. Playing an action video game, Marble Madness, was found to improve fifth graders performance on three computerized tests of dynamic spatial skills (Subrahmanyam & Greenfield, 1994). Pre-test measures revealed a significant gender difference on spatial skills as well as hours spent playing video games. Boys had lower error rates on the tests and reported more time spent on video games. Following training a total of

2 hours and 15 minutes playing Marble Madness, boys and girls' performance on the tests improved compared to a control group that played a word game for the same amount of time. There was no significant gender difference after training. The authors found that participants who began with lower spatial skills showed greater improvements. Another study found that pre-test gender differences on the useful field of view and mental rotation tasks were greatly reduced by 10 hours of training on the action video game, *Medal of Honor: Pacific Assault*, as females showed greater improvements following training than did males (Feng, Spence, & Pratt, 2007). The experimental group as a whole showed significant improvements on both tests compared to the control group that played a puzzle game called *Ballance*.

Why Training Works

While experience with and training on some video games appears to result in specific improvements to visuospatial and motor skill (Sims & Mayer, 2002), other research has revealed that training on action video games can lead to widespread improvement in visuospatial capacity and the temporal and spatial distribution of visuospatial attention (Green & Bavelier, 2003). To successfully play an action video game it is necessary for the player be able to monitor events across the entire screen, process all the information quickly as these games are usually fast-paced, and simultaneously process a large number of events, such as several enemies attacking from different locations. A simple visual puzzle game, like *Tetris*, does not place these demands on players. The unique set of characteristics found in action video games may be responsible for the variety of improvements found in visuospatial and motor abilities and are in fact why some researchers choose to use these games for training (Green & Bavelier, 2006b).

Several avenues have been suggested for how these games may work to improve visuospatial abilities, for instance improved management of multiple tasks, an increase in information processing speed, or changes in attentional bottlenecks (Griffith et al., 1983; Green & Bavelier, 2003). Green and Bavelier (2006a) suggested that action video games may improve players' visuospatial skills by increasing attentional resources and encouraging more efficient selection processes. Two hypotheses result from this suggestion; gamers should be able to process more visual information than non-gamers and gamers should be better at filtering out irrelevant information. Both of these hypotheses have been supported in the literature (Green & Bavelier, 2003, 2006a, 2006b, 2007). Other cognitive skills are required to successfully play many action video games, but it seems increased attentional resources and efficient selection account for much of the visuospatial skill improvement seen in gamers and non-gamers trained on action video games.

The studies discussed here provide support for the view that video games can be used as training tools for visuospatial attention and motor abilities among many different populations. Potential negative effects of action video games on cognitive control and emotional processing, however, should be considered when selecting action video games for training purposes.

Video Games and Affect

Potential negative effects of the violent content in many popular video games have been under investigation for nearly as long as these games have existed. A number of studies have focused on the relationship between violent video games and aggressive behavior, thoughts, and feelings in children, adolescents, and young adults (Anderson, 2004). Findings from a small sample of these studies will be discussed below to demonstrate the generalizability of the effects. Less research has investigated the effects of violent video games on emotional processing. There are studies that suggest that violent video game content may influence processing of negative and positive affective information (Kirsh, Mounts, & Olczak, 2006). The current investigation is concerned with research on the affective processing of gamers and non-gamers and so the small number of relevant studies will also be discussed.

Video Games and Aggression

Individual difference studies have demonstrated that exposure to violent video games is associated with higher levels of aggression. For instance, a survey of 8th and 9th graders found that adolescents who reported playing video games with violent content had a higher frequency of arguments with teachers and physical fights with other students than their peers who reported playing fewer violent games (Gentile, Lynch, Linder, & Walsh, 2004). Among undergraduates, violent video game exposure is positively correlated with aggressive behavior as measured by a self-report Delinquency Scale (Anderson & Dill, 2000). Another study found that fourth and fifth graders with high exposure to violent video games were less empathetic than their cohorts, suggesting that violent video game experience may also influence pro-social behavior (Funk, Baldacci, Pasold, & Baumgardner, 2004).

To establish a causal role of video games on increased aggressive behavior, cognition, and affect, experimental studies have been conducted. The general paradigm for investigating video game effects is to have participants play a violent or nonviolent video game for some amount of time and then assess their aggression. The competitive reaction time task is a frequently used measure of aggressive behavior (Anderson & Dill, 2000). In this task participants are instructed to press a button faster than an opponent to avoid receiving a punishment in the form of a noise blast, the duration and intensity of which is set by the opponent. The participants are further instructed on how to set the duration and intensity of the noise blast to punish the opponent. Higher intensities and longer durations indicate higher levels of aggression. In actuality the opponent does not exist. The task is arranged so that participants lose approximately half of the trials, and the duration and intensity of the punishing noise blasts are set randomly by a computer. Word completion tasks are often used to assess aggressive cognition (Carnagey & Anderson, 2005). In these tasks participants are given word fragments such as “K I _ _”, some of which could have aggressive (KILL) and nonaggressive (KISS) completions, and asked to complete as many as possible within a set amount of time. A portion of the fragments can be completed with aggressive words, and a higher ratio of aggressive words to total words reveals activation of knowledge structures related to aggression. Finally, aggressive affect is usually measured with scales or questionnaires on state and trait hostility (Anderson, 2004).

Research has revealed that violent video games can increase aggressive behavior. Anderson and Dill (2000) found that playing a violent video game led to more aggressive behavior in the form of longer noise blasts against an opponent in the competitive reaction time task compared to playing a nonviolent video game. Similarly, Bartholow and Anderson (2002) found that participants set longer and more intense noise levels to punish opponents after playing a violent video game than after playing a nonviolent video game. More aversive noise was delivered by participants who were rewarded for using violence in a video game than by participants who were punished for using violence (Carnagey & Anderson, 2005). In the latter study, undergraduates played a version of a racing game in which killing pedestrians and opponents was punished, rewarded, or not possible (a nonviolent version;

Carnagey & Anderson). Participants who played the version that rewarded killing displayed more aggressive behavior on the reaction time task than participants who played the punished and nonviolent versions.

Additionally, research has demonstrated an increase in aggressive thoughts following exposure to video game violence. Carnagey and Anderson (2005) measured aggressive thoughts after participants were rewarded or punished for using violence in a video game with a word completion task. The participants who were rewarded for violence in the game completed more words aggressively compared to participants punished for violence. Story stem completion, another method of assessing aggressive thoughts, has yielded similar results. Research has revealed that violent video games lead people to expect more aggressive behavior from others (Bushman & Anderson, 2002). In this study participants played a violent or nonviolent video game and then read three story stems that ended with the question “What happens next?”. Participants who played a violent game gave the stories more aggressive endings than the participants who played a nonviolent game, attributing more aggressive behavior, thoughts, and feelings to the main character. These studies reveal that violent video games lead people to think in more aggressive terms than nonviolent video games.

Violent video games negatively impact emotions as well, resulting in players feeling more aggressive and hostile after playing. Whether the aggressive emotions are directed towards another person, a situation, the world, or even their own self-concept, the violence in video games can create and heighten aggressive affect. Arriaga, Esteves, Carneiro, and Monteiro (2006) measured state hostility as an indicator of aggressive affect and found that participants reported higher levels of hostility after playing violent video games. Another study demonstrated that hostility and aggressive feelings were increased more if a story line was present in the video game (Schneider, Lang, Shin, & Bradley, 2004). Several meta-analyses of the research on video games and aggression have supported the link between violent content and increases in aggression (Anderson & Bushman, 2001; Anderson et al., 2004).

Violent Media and Emotion Processing

The research described in previous paragraphs is only a small subset of the literature linking violent video games to increased aggression. Far less is known about video game effects on emotional processing. A few individual difference studies have revealed that violent content in video games may influence the processing of affective facial expressions. Kirsh et al. (2006) demonstrated a bias for processing angry faces in participants who consume violent media, including television, movies, and video games. In this study participants were shown a face on a computer screen that morphed from a neutral expression to a happy or angry one and indicated which emotion was forming by pressing one of two keys. Not only were participants high in violent media consumption faster to identify a neutral face morphing to angry, they were also slower to identify a neutral face morphing to happy. In contrast, participants with low media violence exposure showed the opposite pattern. This finding is surprising given the happy-face advantage found in most studies on affective face processing (Leppanen, Tenhunen, & Heitanen, 2003; Billings, Harrison, & Alden, 1993), but fits with the literature on video games and aggression, suggesting that exposure to violent media may result in a bias for processing negative social information. Kirsh and Mounts (2007) replicated the reduction in the happy face advantage in violent video game players specifically.

One study has established a causal link between video game play and a bias for processing negative information. Kirsh, Olczak, and Mounts (2005) demonstrated an attentional bias towards negatively valenced words following violent video game exposure. The emotional Stroop task used in the study contained 20 negatively valenced and 20 neutral words presented in 20 different colors. A word appeared at the center of the screen surrounded by a circular palette of the 20 colors. Participants were instructed to identify the color the word was presented in by selecting that color in the palette. The Stroop interference effect was calculated as the average reaction time for correctly identified negative words minus average reaction time for correctly identified neutral words. Participants who played a violent video game (Mean_{Int} = 25 ms) showed a larger interference effect than those who played a nonviolent game (Mean_{Int} = -20 ms).

One published study has used ERPs to examine individual differences in brain activity between high and low video game players (Bartholow et al., 2006). The authors investigated the relationship between the P300 component, elicited by low frequency negative and violent images, and violent video game exposure. The P300 component is related to the orienting of attention and is produced by infrequent stimuli in the context of a frequent stimulus (Courchesne, 1978; Ito, Larsen, Smith, & Cacioppo, 1998; Johnson & Donchin, 1980), and processing emotionally relevant stimuli (Keil et al., 2002). Bartholow et al. used five negative violent pictures (e.g. man holding a knife to a woman’s throat), five negative nonviolent pictures (e.g. decaying dog corpse), and 25 neutral pictures (e.g. man riding a bicycle) from the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005). Male undergraduates classified as violent and nonviolent gamers viewed infrequently presented negative violent and negative nonviolent images among neutral images. The negative violent and nonviolent images were expected to elicit a P300. A reduction in the amplitude of this component could indicate desensitization (e.g. reduced attentional orienting) to the emotional content of the pictures. Violent gamers showed a reduced P300 to negative violent images compared to nonviolent gamers, but there was no effect of game experience on the P300 elicited by negative nonviolent images. The authors concluded that the violent gamers were desensitized to images of violence due to their high exposure to violent content in video games. In summary, video game experience has been associated with increased aggression (Anderson, 2004), desensitization to violence (Bartholow et al.), and differential processing of positive and negative emotional stimuli (Kirsh et al., 2006).

Cognitive Control

Conflict Monitoring and the Stroop Task

A defining feature of cognitive control is the ability to adapt behavior to task demands, specifically focusing on task-relevant information, ignoring task-irrelevant information, and inhibiting habitual or dominant responses that interfere with task-compatible behaviors (Braver, Reynolds, & Donaldson, 2003). Research has revealed that conflict processing plays an important role in determining the need for cognitive control during a task (Botvinick, Cohen, & Carter, 2004). When the conflict between two responses in a task is high, cognitive control acts to bias responding in favor of the task requirements (DePisapia & Braver, 2006). The neural correlates of conflict processing have been investigated in imaging and ERP studies with a variety of tasks (Casey et al., 2000; Botvinick, Braver, Barch, Carter, & Cohen, 2001; Braver, Barch, Gray, Molfese, & Snyder, 2001; West, 2003). The Dual Mechanisms Theory of Cognitive Control has proposed a link between conflict processing and the recruitment of cognitive control networks (Braver, Gray, & Burgess, 2007). The current study investigated the deployment of cognitive control in the Stroop task and the working memory N-back task. Therefore, in the following sections I describe current theories of cognitive control and conflict monitoring, and then discuss the ERP correlates of these processes identified in the Stroop and N-back tasks.

Cognitive control is required to successfully complete many tasks, especially difficult tasks that are unfamiliar. A critical question in the literature on cognitive control has been how control processes are recruited. Botvinick and colleagues have proposed that conflict monitoring is one way the need for cognitive control may be assessed (Botvinick et al., 2004; Botvinick, Nystrom, Fissel, Carter, & Cohen, 1999). The conflict-monitoring hypothesis contends that a system exists to detect conflict as it occurs in information processing. The detection of conflict during a task triggers adjustments in cognitive control, which should maximize performance on subsequent trials in the task (Botvinick et al., 2001). Cognitive control can be recruited, tightened, or relaxed based in the degree of conflict that exists within or between trials.

The Stroop task (Stroop, 1935) has been used extensively to study conflict monitoring and cognitive control (Botvinick et al., 2004; Kerns et al., 2004; West & Travers, 2008). In the color-word task, participants name the color in which a word is presented. There are three types of trials, congruent trials where the word matches the color that it is presented in (i.e. RED presented in red), incongruent trials where the word is a different color than the color it is presented in (i.e. RED presented in blue), and neutral trials where the stimulus may be a string of X's or a non-color word (i.e. DOG presented in red). The counting version of the Stroop task requires participants to name the number of digits present and also has congruent (i.e. 22), incongruent (i.e. 222), and neutral (i.e. XX) trials. The typical finding in the Stroop task is that people are slower and less accurate to name the color of incongruent color-words than congruent color-words (the Stroop interference effect; MacLeod, 1991; MacLeod & Macdonald, 2000).

The conflict-monitoring hypothesis predicts that conflict on any given trial should lead to adjustments in behavior on subsequent trials due to the engagement of cognitive control (Braver et al., 2007). As mentioned previously, conflict in tasks like the Stroop arises from the need to override a prepotent response on incongruent trials relative to congruent trials. The conflict adaptation effect (CAE) represents the finding that reaction times on incongruent trials are faster and more accurate following other incongruent trials (iI trials) than they are following congruent trials (cI). Likewise, congruent trials are faster following other congruent trials (cC) than they are following incongruent trials (iC; Botvinick et al., 2001). After a congruent trial people relax control, allowing the irrelevant stimulus dimension to have more influence. On cC trials, cognitive control is relaxed allowing the irrelevant stimulus dimension to have more influence which leads to facilitation. Conversely, conflict is high after an incongruent trial so people exert more control and are less influenced by the irrelevant stimulus dimension allowing them to perform faster and more accurately when the next trial is also incongruent. Facilitation is reduced on iC trials because control has been tightened due to the conflict arising from the previous incongruent trial (Carter & van Veen, 2007). When control is relaxed and the next trial is incongruent, the result is a greater chance of error and slower reaction time. The functional neuroanatomy underlying the CAE was examined by Kerns et al. (2004), who demonstrated that there is less ACC activation for iI compared to cI trials in the Stroop task.

Neuroimaging evidence indicates that the anterior cingulate cortex (ACC) is involved in monitoring conflict (Botvinick et al., 1999). A number of studies employing functional magnetic imaging (fMRI) have demonstrated ACC activation when conflict arises in a task, such as when two incompatible responses are simultaneously activated or when an error is committed (Kerns et al., 2004; Yeung, Botvinick, & Cohen, 2004). Botvinick et al. found that ACC activation was greatest on trials with the highest conflict in the flanker task. Another study demonstrated greater ACC activation when there was competition among several viable responses in a verb generation task (Barch, Braver, Sabb, & Noll, 2000). Low-frequency responses activate the ACC in the oddball, go/no-go, and two-alternative forced choice paradigms, supporting the hypothesis that conflict arises when a prepotent response must be overridden (Botvinick et al., 1999; Braver et al., 2001; Casey et al., 1997).

The Dual Mechanisms Theory of Cognitive Control

A recent evolution of the conflict-monitoring hypothesis is the Dual Mechanisms of Cognitive Control Theory. This theory is designed to account for the variability in working memory found within and between individuals (Braver et al., 2007). The theory also elaborates on the relationship between the ACC and brain areas engaged in cognitive control. A central hypothesis of Dual Mechanisms Theory is that cognitive control can be divided into proactive and reactive processes and that each type of control has distinct behavioral and neural indicators. Research suggests that proactive control, the processing of information over time to provide moment-to-moment adjustments (Botvinick et al., 2001), is a result of interactions between the ACC and the anterior prefrontal cortex (DePisapia & Braver, 2006). Reactive control serves to resolve conflict arising from competition between responses

(Braver et al.) and results from interactions between the ACC and the lateral prefrontal cortex (DePisapia & Braver).

Neuroimaging studies reveal separate brain areas associated with proactive and reactive control, as well as demonstrate a link between the ACC and these areas. In an fMRI study on the use of cognitive control in task-switching, Braver et al. (2003) demonstrated a double dissociation between brain regions activated during transient (reactive) and sustained (proactive) control. Participants performed two semantic classification tasks in either single or mixed blocks with instructions at the beginning of each block indicating whether one task or both would be performed in that block. Cognitive control was increased in mixed blocks both in a sustained manner across the block and transiently immediately following a switch from one task to the other. Sustained or proactive cognitive control was associated with anterior prefrontal cortex activation, while transient or retroactive control was associated with ventrolateral and dorsolaterial prefrontal cortex activity. Greater activity in dorsolateral prefrontal cortex was observed in trials requiring greater adjustments in behavior due to conflict in a study that also demonstrated greater ACC activity on high conflict trials (Kerns et al., 2004). This research provides support for the distinction between neural networks engaged during proactive and reactive cognitive control.

The Dual Mechanisms theory expands conflict-monitoring by providing a way to understand individual differences in cognitive control (Braver et al., 2007). For example, research has demonstrated differential use of proactive and reactive cognitive control in individuals with high and low general fluid intelligence. One study demonstrated a positive correlation between general fluid intelligence and activation in the lateral prefrontal cortex, an area associated with proactive cognitive control during the working memory N-back task

(Gray, Chabris, & Braver, 2003). Increased activity in lateral prefrontal cortex has also been shown in individuals with high general intelligence in the Sternberg paradigm (Burgess & Braver, 2004). The theory promises to be useful in making clear predictions about how differences in cognitive control strategy will affect task performance within and between individuals.

Cognitive Control in the Stroop Task: ERPs

Three modulations of the ERPs appear to provide an index of various processes underlying cognitive control in the Stroop task (medial frontal negativity (MFN), frontal slow wave, and conflict sustained potential (SP)). The MFN reflects negativity at medial frontal electrodes occurring between 350 and 450 milliseconds after stimulus onset (Liotti, Woldorff, Perez, & Mayberg, 2000; West & Alain, 2000). The MFN differentiates congruent and incongruent trials in the Stroop task, with greater negativity for incongruent trials (West, 2003). The MFN may arise from the activity of neural generators in the ACC and the anterior frontal cortex (Liotti et al., 2000; West, 2003; West, Bowry, & McConville, 2004).

The conflict SP represents a positivity over the parietal region of the scalp and negativity at lateral frontal regions of the scalp beginning approximately 500 milliseconds after stimulus onset (West, 2003). The conflict SP differentiates congruent and incongruent trials, with incongruent trials having greater amplitude than congruent trials (West, Jakubek, Wymbs, Perry, & Moore, 2005). Anterior frontal negativity for incongruent words coupled with a parietal positivity for incongruent relative to congruent words has been demonstrated in three different versions of the Stroop paradigm, overt verbal, covert verbal, and manual (Liotti et al., 2000), demonstrating that the conflict SP is insensitive to the method of responding.

The frontal slow wave (FSW) was first characterized in a paper by West and Travers (2008). In this study the FSW began around 200 ms following the response and continued after the onset of the next stimulus when there was a 500 ms response-to-stimulus interval. When the response-to-stimulus interval was 2000 ms the frontal slow wave dissipated around 500 ms after the response. Correct incongruent trials were more positive than correct congruent trials from 250 to 500 ms following the response for both response-to-stimulus conditions, and from 1500 to 2000 ms following the response this difference remained significant only in the short response-to-stimulus interval. A spatiotemporal dipole model localized the neural generator of the FSW in the lateral frontal cortex fit the frontal slow wave data, consistent with past research indicating cognitive control arises from interactions between the lateral frontal cortex and the ACC (Botvinick et al., 2001). West and Travers suggested that the frontal slow wave's sensitivity to the response-to-stimulus interval may indicate that updating cognitive control and encoding the stimulus compete for attentional resources that are taxed when the processes are engaged simultaneously. In the long response-to-stimulus interval there was enough time to update cognitive control before the next trial, whereas in the short response-to-stimulus interval there was not and so cognitive control processes are prolonged.

The N-back task has been used to examine the neural correlates of working memory load (West, Bowry, & Krompinger, 2006; West & Bowry, 2005). Typically in this task participants are shown a list of stimuli (e.g., words or letters) one at a time and must indicate whether or not each stimulus matches the one directly before it (1-back condition), the stimulus prior to the one before it (2-back condition), or the stimulus that occurred two stimuli before it (3-back condition). The number of items between the current stimulus and the stimulus used for comparison is a manipulation of working memory load (Braver et al., 1997). Research using ERPs has revealed that the amplitude of the N2, a negativity over parietal-occipital regions of the scalp around 200 ms post-stimulus, is greater for targets than non-targets. The amplitude of the P3, a positivity at parietal electrodes around 400 ms post-stimulus onset, was also greater for targets than non-targets (West & Bowry).

Visual Working Memory

Working memory can be defined as “a temporary store for information needed to accomplish a particular task” (Reed, 2004). Working memory has been subdivided into executive processing, verbal, and visuospatial components (Baddeley, 2001; Baddeley & Hitch, 1974). The current investigation is interested in visual working memory capacity, the number of visual representations that can be maintained and acted upon simultaneously. Variants of the sequential comparison procedure have been used to study the capacity of visual working memory (Vogel & Machizawa, 2004; Luck & Vogel, 1997). In this task, participants briefly view a memory array of anywhere from 1 to 12 colored squares, followed by a retention interval (blank screen), and then a test array that may be the same as the memory array or differ by one square. The participant must indicate whether the memory array is the same or different from the test array. Response accuracy is typically high up to three to four items, and then drops off systematically with the addition of more items, suggesting that the capacity of visual working memory is roughly three to fours items (Awh, Barton, & Vogel, 2007).

Research using ERPs has revealed a neural correlate of visual working memory capacity. In a series of four experiments, Vogel and Machizawa (2004) tested memory capacity with the sequential comparison (or visual short term memory) task (VSTM). The size of the memory and test arrays varied over trials. A central fixation cross divided the screen in half. At the beginning of each trial an arrow over the fixation cross informed the participants which hemifield they were to remember and compare to the test array. The arrow was presented for 200 ms followed by a memory array of four colored squares in each hemifield for 100 ms. A retention interval, a blank screen with the central fixation cross, lasted 900 ms followed by the test array of colored squares presented in each hemifield. The participants indicated by pressing one of two buttons whether or not the test array differed from the memory array.

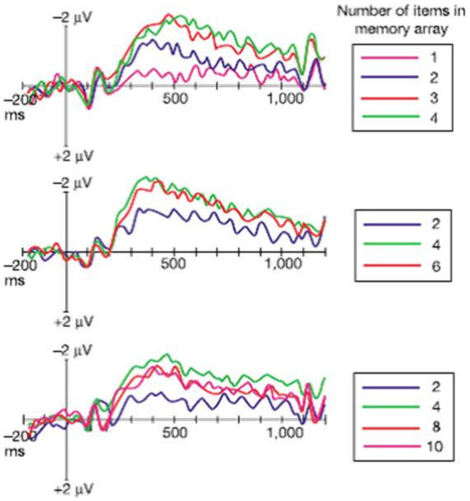

Figure 1. **ERP difference waves showing greater negativity as array size increases up to about four items. No differences in amplitude for array sizes of four to ten items (Vogel & Machizawa, 2004).**

The results of Experiment 1 revealed a large negative-going wave at posterior parietal and lateral occipital electrodes lasting from about 200 ms after onset of the memory array through the retention interval over the hemisphere that was contralateral to visual field where the target display was presented. Experiment 2 revealed that the amplitude of the slow wave increased as the size of the memory array varied from one to two squares and from two to three squares. Experiments 3 and 4 established that varying the size of the array from two to four items resulted in an increase in the amplitude of the slow wave, but no further increase was seen between four to ten items (see Figure 1). In summary, the contralateral slow wave appears to be a neural correlate of visual working memory capacity, increasing in amplitude up to three or four items, but not for arrays larger than the number of items most people can keep in working memory. The current study used this task to investigate differences in visual working memory capacity that may be associated with video game experience. Individual differences in visual working memory capacity for high video game players and non-gamers should be evident in the amplitude of the slow wave.

Affective Picture Processing

ERPs have been used to examine the neural correlates of affective picture processing for over 40 years. Recently Olofsson, Nordin, Sequeira, and Polich (2008) summarized the general findings in an integrative review. They concluded that the emotional valence of pictures influences the amplitude of the ERPs between 100 and 1000 milliseconds following picture onset. ERPs from 100 to 200 milliseconds at occipital electrodes, such as the P1, reflect sensory processing, and differentiate negative from positive pictures (Smith, Cacioppo, Larsen, & Chartrand, 2003). At approximately 300 milliseconds after picture onset, a slow positive going wave emerges at parietal electrodes that lasts until at least 1000 milliseconds after picture onset (Olofsson & Polich 2007; Keil et al, 2002). This effect, hereafter labeled the parietal slow wave (PSW), typically reflects greater positivity for positive and negative pictures compared to neutral pictures. Researchers have interpreted these findings as reflecting automatic processing of emotional content (Hajcak, Dunning, & Foti, 2007) or as an indication of sustained attention to emotionally salient stimuli that are motivationally relevant because of evolutionary significance (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000). One limitation of accounts of the PSW for affective picture processing rests in the absence of a clearly defined task for participants to engage in during these studies.

The vast majority of studies investigating the neural correlates of picture processing use the International Affective Picture System (IAPS; Lang, Bradley, & Cuthbert, 2005). The

IAPS contains normative data on the valence (positive>neutral>negative) and arousal ratings of 956 pictures. Ratings were made by 100 college students using the Self-Assessment Manikin (SAM). SAM is a depiction of a human-like figure whose expression ranges from smiling to frowning for the valence ratings and from wide-eyed to sleepy for the arousal ratings. Participants simply choose which figure best describes how each picture makes them feel on both dimensions. The content of the pictures varies widely and includes images of families, children, animals, flowers, household objects, sports scenes, violence, and erotica. There are pictures of humans, animals, and objects in each valence category, although objects are more typical of neutral pictures. Arousal ratings for positive and negative pictures vary from highly arousing which is typical of scenes depicting erotica and mutilations to the less arousing which is typical of scenes depicting romance and loss, while neutral pictures are low on arousal by definition (Lang et al.). Given its normative nature, the IAPS has been the source of stimuli for a number of the studies investigating the neural correlates of affective picture processing (Olofsson et al, 2008).

Much of the research using the IAPS has demonstrated differences in ERP amplitude between positive and negative images compared to neutral images when people view the pictures. As an example, Cuthbert et al. (2000) selected 18 neutral, 18 negative, and 18 positive pictures from the IAPS. Subjects were instructed to view the pictures for six seconds and then image the picture following offset “for a short period” until a tone was heard to ensure a “stable mental state”. Increased positivity was found at frontal, central, and parietal electrodes along the midline for valenced pictures compared to neutral pictures, with this difference being greater for positive than for negative pictures between 400 to 700 ms after picture onset. After 700 ms, the amplitude of the parietal slow wave was similar for positive and negative pictures and continued to be more positive than for neutral pictures until 1000 ms after picture onset. The authors interpreted these data as reflecting sustained attention to emotionally salient stimuli. In a similar study, Keil et al. (2001) asked subjects to view 60 pictures from the IAPS (20 negative, 20 neutral, and 20 positive) presented either to the left and right hemifields separately or to both simultaneously. The parietal slow wave was greater in amplitude for valenced pictures than for neutral pictures. This effect was again maximal at central electrodes and was unaffected by hemifield of presentation. The authors concluded that this finding supports the hypothesis that attention is allocated to motivationally relevant stimuli, of which emotional pictures are an example. Keil et al. (2002) also used 60 pictures, but did not examine hemifield differences. Subjects viewed each picture for 6 seconds. The results replicated previous findings that the amplitude of the parietal slow wave was greater for emotionally valenced images than for neutral images. These findings were again interpreted as reflecting sustained attention to emotionally salient stimuli of motivational relevance. This is consistent with other evidence that indicates that parietal activity may be generally related to the relevance of a stimulus. Johnson (1986), for example, proposed that directing attention to specific stimuli, thereby establishing “task relevance”, was one of three dimensions influencing the P300.

As a test of the attention hypothesis, Codispoti, Ferrari, and Bradley (2007) investigated the effects of habituation on the neural correlates of picture processing, by presenting the same 15 pictures (5 positive, 5 negative, and 5 neutral) to subjects in three habituation blocks, followed by a new set of 15 pictures in a dishabituation block at two different sessions separated by 10 days. The parietal slow wave was greater in amplitude for positive and negative pictures than for neutral pictures over the central-parietal region of the scalp. Some evidence for habituation was found in comparing the parietal slow wave of habituation block 1 to block 3, with the difference between emotionally valenced pictures and neutral pictures being smaller, but still present. Codispoti and colleagues argued that the slow wave was indicative of an increase in the resources allocated to affective pictures due to their motivational relevance.

Overall, the literature supports the suggestion that there is differential processing of emotional and neutral pictures. A potential limitation of these studies is that they do not require the participants to perform a task during picture processing. Without a task there is no behavioral output, so it is unclear what subjects were doing during picture viewing. Other explanations for these results may exist, for example, differences in arousal between emotional and neutral pictures or the interest level the subjects had in specific pictures (i.e. viewing erotic couples compared to household objects). Controlling attentional allocation is one way to address this limitation. A few methods of controlling the allocation of attention have been considered in the literature, these include adding a second task, manipulating the relevance of the pictures, and varying the way the pictures are processed.

Using the pictures as targets in a visual oddball task, Olofsson and Polich (2007) demonstrated differential processing of emotionally valenced compared to neutral images. The authors chose 72 negative, neutral, and positive pictures to use as targets and the standard was a pattern of red and white triangles. Analysis of reaction times to identify an stimulus as a target or non-target revealed that there were no differences between the three classes of valenced images. They found greater positivity for negative and positive target pictures compared to neutral target pictures at central electrodes from about 500 to 800 ms, similar to studies without a task (Codispoti et al., 2007; Cuthbert et al., 2000).

Pictures have also been used as the novel stimuli in an oddball task. Delplanque, Silvert, Hot, and Sequeira (2005) used a target/standard oddball task with geometric shapes as the targets and standards and 40 pictures from each of the three valence categories as novel stimuli. Participants were instructed to press the spacebar when they detected a geometric shape wider than the standard, and were given no instructions regarding the presence of the novel emotional pictures. The ERPs for targets and all novel picture stimuli, regardless of valence, were approximately equal and all were more positive than the standard at central and parietal electrodes. The authors argued that this suggests that in this paradigm all deviant stimuli attract attention.

Studies that require participants to perform a task have the potential to determine whether processing emotional content occurs automatically or requires attention. Hajcak et al. (2007) investigated the effects of a task on passive picture viewing and found support for the hypothesis that attention is automatically allocated to emotionally relevant stimuli. Participants viewed 120 pictures (40 from each valence category) while performing no task, and then viewed them again while performing easy or difficult mental arithmetic. The parietal slow wave was greater for emotional images relative to neutral images in all three conditions. The authors' concluded that the parietal slow wave was not influenced by concurrent tasks or the difficulty of those tasks.

One explanation for the parietal slow wave elicited by emotional stimuli is the "relevance-for-task-effect" (Carretie, Hinojosa, Albert, & Mercado, 2006). This effect refers to the possibility that when participants are asked to passively view pictures or perform a task that seems unrelated to the pictures they may pay more attention to the stimuli they think are relevant. Therefore, the effects of attention for affective stimuli and attention for task relevant stimuli are confounded. Carretie et al. had subjects respond yes or no regarding whether or not a person appeared in each of 24 pictures (eight from each valence category) in an attempt to control for the “relevance-for-task-effect”. At frontal electrodes from 600 to 1000 ms ERPs for negatively valenced pictures were more positive than neutral pictures which were more positive than positive pictures. At parietal electrodes from about 200 to 600 ms, positive pictures had the greatest amplitude followed by negative then neutral pictures. This is somewhat different from previous results, and the authors concluded that implicit tasks are better suited for investigating how attention is allocated to the emotional content of the pictures.

In summary, the parietal slow wave reflects greater positivity for positive and negative pictures than for neutral pictures in studies both with and without tasks, indicating that the effect is robust against various manipulations. Generally, the findings of studies with a task support the view that affective pictures are either processed automatically or that sustained attention is allocated to emotional stimuli. Most of the tasks in these studies, however, are not related to the content of the pictures, so the studies cannot speak to whether or not attention can be directed to emotional content differentially or if affective pictures are always processed distinctively from neutral pictures.

Preliminary Study

In an effort to expand the findings of Mathews et al. (2005) and Bartholow et al. (2006), an ERP investigation of cognitive control and affective processing was conducted on fifty-one male undergraduates with high and low video game experience (Bailey et al., 2009). Participants were recruited based on their responses to a 12-item questionnaire that assessed the number of hours spent playing video games per day. Twenty-five high and 26 low gamers were tested on the Stroop task and a picture rating task.

Based on Dual Mechanisms theory, distinct behavioral and neural correlates of proactive and reactive control should be evident in performance on the Stroop task (Braver et al., 2007; De Pisapia & Braver, 2006). Variation in the magnitude of the interference effect and the amplitude of the conflict SP may provide indices of reactive control processes, with the magnitude of both effects being greater when reactive processes are in use (West et al., 2005). Variation in the magnitude of the CAE (Botvinick et al., 2001), the MFN, and the FSW (West & Travers, 2008) may provide indices of proactive control. The attenuation of these effects may indicate that proactive control is not being utilized during the task.

The participants in Bailey et al. (2009) performed the color-word Stroop task with short (500 ms) and long (2000 ms) response-to-stimulus intervals. Behaviorally, the interference effect did not differ between groups on response time or accuracy. Response time was slower for incongruent trials, $M = 786$ ms, than for congruent trials, $M = 672$ ms, revealing a significant interference effect, $F(1,49) = 171.19$, $p = .001$, $\eta_p^2 = .78$. The interference effect did not differ between low gamers, $M = 120$ ms, and high gamers, $M = 109$ ms, $F = .400$, $p = .530$, $\eta_p^2 = .01$. Response accuracy was lower for incongruent trials, $M = .95$, than for congruent trials, $M = .97$, revealing a significant interference effect, $F(1,49) = 29.01$, $p = .001$, $\eta_p^2 = .37$. The interference effect also did not differ between high gamers, $M = .01$, and low gamers, $M = .03$, $F(1,49) = 1.20$, $p = .28$, $\eta_p^2 = .02$. These data indicate that reactive control was not influenced by video game experience.

The CAE was compared in high and low gamers. In the short RSI condition the CAE was similar in low gamers, $M = 19$ ms, and high gamers, $M = 21$ ms, $t(49) = -.11$, $p = .91$; in the long RSI condition the CAE was larger in low gamers, $M = 26$ ms, than in high gamers, $M = -14$ ms, $t(49) = 2.10$, $p = .04$. These data suggest that proactive control was negatively affected by video game experience when there were two seconds between trials.

The ERP data converged with the behavioral results. There was an effect of congruency on the amplitude of the conflict SP, $F(1,49) = 46.86$, $p = .001$, $\eta_p^2 = .49$, reflecting greater positivity for incongruent trials, $M = 1.79$ µV, than for congruent trials, $M = .74$ µV. The effect of congruency did not interact with group, $F < 1.0$, $\eta_p^2 = .02$. In contrast, the MFN was present in low gamers, $F(2,50) = 9.87$, $p = .001$, $\eta_p^2 = .28$, and was attenuated in high gamers, $F < 1.00$, $\eta_p^2 = .03$. Video game experience also influenced the FSW. For the low gamers there was no effect of Epoch on the frontal slow wave, $F < 1.00$, $\eta_p^2 = .003$; for the high gamers the frontal slow wave was reliable from 800-1000 ms and was attenuated thereafter, $F(2,48) = 7.20$, $p = .002$, $\eta_p^2 = .23$. Figure 2 displays the grand-averaged waveforms and scalp topography for the MFN, FSW, and conflict SP. These data extend previous research with fMRI (Matthews et al., 2005) that showed that video game experience was related to a disruption of cognitive control by demonstrating that video game experience is associated with disruptions in a specific type of cognitive control.

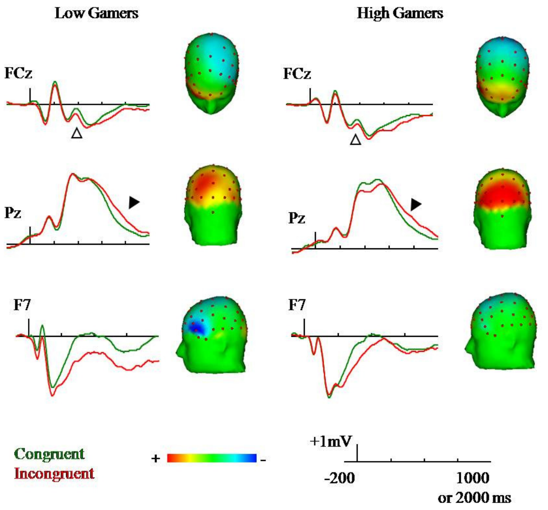

Figure 2. Grand-average ERPs for high and low gamers illustrating the MFN (FCz), conflict SP (Pz), and the FSW (F7).

The second task participants performed in Bailey et al. (2009), investigated individual differences in the processing of positive, negative, and neutral pictures from the IAPS. The task required participants to rate the pleasantness, colorfulness, and threat of 40 positive, 40 neutral, and 40 negative pictures. The negative pictures were further subdivided into 20 nonviolent and 20 violent images. The ratings were performed in three separate blocks. Behaviorally, high gamers ($M = 2.47$) rated violent images as more colorful than low gamers ($M = 2.23$), $F(1, 46) = 4.34$, $p = .043$. There were no other significant differences in the ratings, all F's < 3.197, all p's $> .08$.

Partial Least Squares (PLS) analysis was used to analyze the ERP data (McIntosh & Lobaugh, 2004; Lobaugh, West, & McIntosh, 2001). Figure 3 shows the design scores for LV's that expressed differences between high and low gamers on the color and pleasant rating tasks, which are discussed below.

For the color rating block, the permutation test revealed three significant LVs ($p = .001$, $p = .001$, and $p = .002$); these LVs accounted for 38.67%, 27.14%, and 20.02% of the crossblock covariance, respectively. LV3 was most relevant to the current study. This LV expressed the neural correlates of processing violent pictures for low gamers, representing a contrast between the violent images and the other three types of pictures. In the high gamers this LV expressed the neural correlates of processing violent and positive images, representing a contrast between positive and violent images versus negative and neutral. The electrode saliences reflected a frontal-central positivity between 400 and 800 ms, a frontal negativity on the right between 400 and 600 ms, and an central-parietal negativity between 200 and 400 ms.

In the pleasant rating block, the permutation test revealed that the first two LVs were significant (*p* = .001 and *p* = .001); these LVs accounted for 53.88% and 29.45% of the crossblock covariance, respectively. LV2 was the most relevant in this analysis. For the low gamers the latent variable contrasted neutral and violent pictures from positive picture; for the high gamers, the latent variable contrasted neutral pictures with positive and violent pictures. This latent variable reflected a frontal-central positivity between 400 and 1000 ms and an occipital-parietal negativity between 400 and 700 ms. This suggests that individuals with high exposure to video games may be processing violent and positive images in a similar manner. In contrast to Bartholow et al. (2006), these data indicate violent video game exposure influences processing of positive and negative emotional images as opposed to simply desensitizing players to violent content.

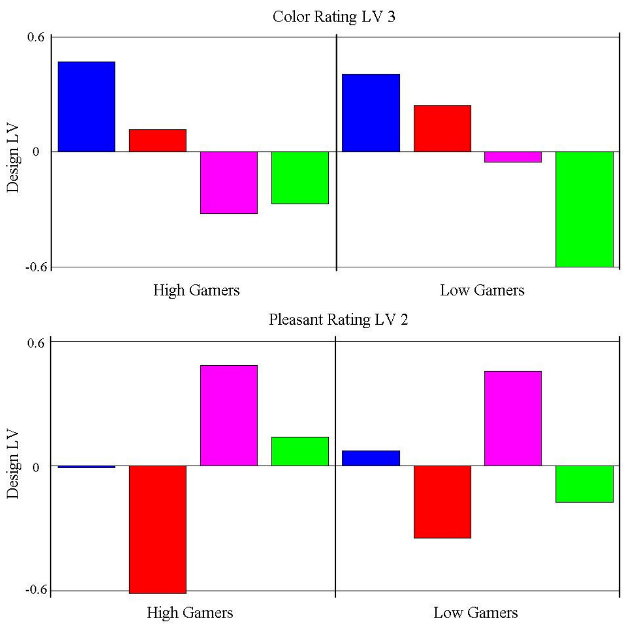

Figure 3. Design scores for LV 3 (color rating) and LV2 (pleasant rating). Blue are negative pictures, red are neutral pictures, pink are positive pictures, and green are violent pictures.

Chapter 2. The Current Study

Independent groups of researchers have investigated video game effects on visuospatial attention (Green & Bavelier, 2003), cognitive control (Mathews et al., 2005), and affective processing (Kirsh & Mounts, 2007); however, no published research has studied all three domains in the same sample of gamers and non-gamers. The current investigation was designed to remedy this limitation by measuring performance on visuospatial attention, cognitive control, and affective processing in two groups of high gamers (violent and nonviolent) and a group of non-gamers. The distinction between high gamers who play mostly violent games and high gamers who generally play nonviolent games is theoretically important in light of research demonstrating that violent video games in particular have detrimental effects on levels of aggression (Anderson, 2004) and emotional processing (Kirsh & Mounts, 2007). The action games that high gamers report playing and that are used in training studies typically contain violent content (Green & Bavelier, 2003, 2006b, 2007). Theoretically and practically it would be important to know if the gains in visuospatial attention are observed in high nonviolent gamers and if cognitive control and affective processing are negatively impacted in both types of high gamers.

In addition to behavioral measures, ERPs associated with each task were examined. This facilitated the replication of past research examining the impact of video game experience on cognitive control (Mathews et al.) and affective processing (Bailey et al., 2008). The use of ERPs also provided information on individual differences in brain functioning of high gamers and non-gamers on new measures of cognitive control and affective processing, as well as the neural correlates of visuospatial attention. Table 1 outlines the tasks used to investigate each domain, the behavioral and ERP dependent variables, and the hypotheses.

Table 1

Domain	Task	Behavioral	ERP	Hypothesis
Cognitive Control	Stroop	Reaction time, Accuracy	MFN, FSW, conflict SP	High game experience will have a negative effect on behavioral and neural indices of proactive control
	N-Back	Reaction time, Accuracy	P3	Working memory will be negatively affected by high video game experience
Affective Processing	Picture Rating	Ratings	Parietal slow wave	Differential processing of positive and negative images based on game experience
	Emotion Search	Reaction time, Accuracy	N1, P3	High gamers will be less sensitive to threatening stimuli due to desensitization
Visuospatial Attention	Enumeration	Reaction time, Accuracy	Occipital/Parietal activity, P3	High gamers will be faster and more accurate than non-gamers
	VSTM	Reaction time, Accuracy	Occipital/Parietal slow wave	High gamers will show increased capacity relative to non-gamers

Cognitive control was assessed with two tasks. Participants performed the Stroop task where they identified the color of congruent and incongruent color-words (e.g. RED in red, or RED in blue). Based on previous research (Bailey et al., 2009), proactive cognitive control was expected to be attenuated in high gamers relative to non-gamers. It was hypothesized that the CAE would be greater in non-gamers than in high gamers (regardless of game genre), that the MFN would be attenuated for high gamers relative to non-gamers, and that the FSW would be attenuated in high gamers compared to non-gamers, reflecting the disruption of proactive cognitive control in the high gamers (Bailey, et al., 2009; Kronenberger et al., 2005). Participants also performed the N-back working memory task with 1-back and 3-back conditions. The N-back task has been used to examine working memory in neuroimaging research (Koch et al., 2007; Gray et al., 2005; Gray, Braver, & Raichle, 2002) and is sensitive to individual differences in general fluid intelligence (Gray et al., 2003) and in measures of Behavioral Activation Sensitivity (BAS; Gray & Burgess, 2004). It was expected that the N2 and P3 components of the ERPs would be modulated by working memory load, revealing greater negativity and positivity respectively for 1-back than 3-back targets (West & Bowry, 2005). If video game experience negatively affects working memory function, the high gamers would be less accurate than non-gamers in the 3-back condition and the influence of working memory load on the N2 and P3 would be more strongly expressed in the non-gamers.

Two tasks were used to examine affective processing: the picture rating task and the emotion search tasks. Only the colorfulness rating condition from the picture rating task described by Bailey et al. (2009) was used. Participants rated the colorfulness of neutral, positive, negative nonviolent, and violent images. Differences in the processing of violent and positive images were expected between the violent gamers and the non-violent and non-gamers. Threat detection is another area of emotion processing that may be impacted by video game experience. In a typical emotion search task, participants are asked to indicate whether all the schematic faces in a display are the same or different and reaction times to report the faces are faster when the discrepant face is angry rather than happy (Fox et al., 2000). Threatening stimuli, including angry faces, are prevalent in action video games with violent content. Experience with these types of games could alter threat processing by either hyper-sensitizing players to this type of social information (Kirsh & Mounts, 2007) or by desensitizing them to the threat (Bartholow, Bushman, & Sestir, 2006). The emotion search task in this study required the participants to indicate whether all the faces in a display were the same or different, in displays that included all neutral faces, one happy face among neutral faces, or one angry face among neutral faces.

Participants performed two tasks that measure visuospatial attention: an enumeration task similar to that used by Green and Bavelier (2003) and the VSTM task (Vogel & Machizawa, 2004). In the enumeration task, participants indicated the number of white squares presented in a briefly flashed array. Based on Green & Bavelier (2006b), both violent and nonviolent high gamers were expected to have a greater span of apprehension (by approximately two items) than non-gamers. In the VSTM, participants viewed an array of colored squares (the memory array) followed by a test array and indicated whether or not the test array was identical to the memory array. If visual working memory capacity is greater for high than non-gamers, then we would expect to see differences in the amplitude of slow wave activity over the occipital and parietal regions of the scalp for 3-item and 5-item arrays for both types of high gamers and no differences in the amplitude of this negativity between 3 and 5 item arrays for non-gamers.

Method

Participants

A total of 50 male undergraduates were recruited to participate in this study through the mass testing pool maintained by the Department of Psychology. Data from one non-gamer and one nonviolent gamer were excluded due to excess movement during recording, leaving 16 participants in each group. Recruitment was based on individuals' responses on a media usage questionnaire (see Appendix). Mean hours spent playing video games per week were 2.9 (SD = 7.9) for non-gamers, 34.8 (SD = 18.6) for violent gamers, and 25.4 (SD = 13.9) for nonviolent gamers. Violent gamers reported more experience with the games listed in items 9 through 13 of the media usage questionnaire and the nonviolent gamers reported more experience with the games listed in items 15 through 19. The mean age was 20.5 years for the non-gamers, 19.3 years for the violent gamers, and 20.7 years for the nonviolent gamers. There were 13 right-handed non-gamers, 13 right-handed violent gamers, and 10 right-handed nonviolent gamers based on the Edinburgh Brief Handedness Inventory (see Appendix A).

Materials and Design

Stroop Task. Stimuli in the Stroop task were congruent (e.g. RED in red) and incongruent (e.g. RED in blue) Stroop color-words. The Stroop task included a keymapping, practice, and test phase. In the key-mapping phase the stimuli were strings of four X's (e.g., XXXX) presented in red, blue, green, or yellow. All stimuli were presented on a black background in uppercase bold Arial 14 point font, vertically and horizontally centered in the display. During key mapping, participants learned the color-to-key mappings used in the practice and test phases. The colors red, blue, green, and yellow were mapped to the keys 'v', 'b', 'n', and 'm', respectively. This phase had 40 trials, ten for each color, presented randomly. The practice phase consisted of one block with 12 congruent and 12 incongruent trials, presented randomly with a 500 ms response to stimulus interval (RSI). Participants were instructed to always report the color of the color-word. The test phase consisted of two blocks of 96 trials, presented randomly with a 2000 ms RSI. Half of the trials in each block were congruent, and the remaining trials were incongruent.

N-Back Task. The working memory n-back task stimuli were black letters (A-Z) presented in Arial 14 point font on a white background (see Figure 6). Participants performed two practice blocks of 20 trials each for the 1-back and 3-back conditions. In the 1-back condition, participants indicated whether each letter matched the previous letter. In the 3-back condition, they indicated whether each letter was the same or different from the letter presented two letters before the previous letter (i.e. was 3-back in the list). Participants pressed the ‘n’ key to indicate the letter was the same and pressed the ‘m’ key to indicate it was different. There were two experimental blocks consisting of 30 targets and 40 non-targets for a total of 70 trials in each block. Each trial consisted of a fixation cross for 250 ms followed by the stimulus until a response was made after which the fixation cross appeared again for 250 ms to start the next trial.

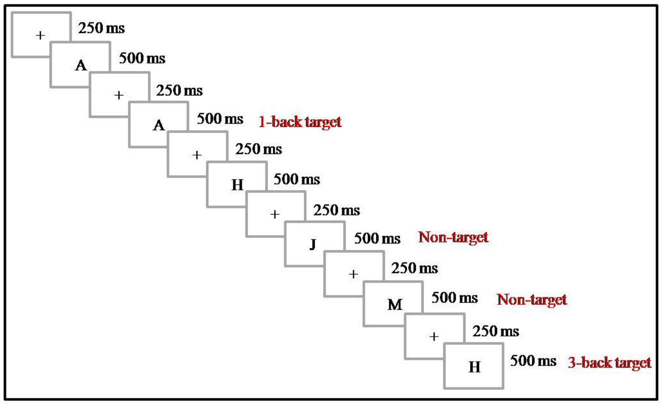

Figure 6. N-back procedure with 1-back and 3-back targets.

Picture Rating Task. The stimuli in the picture rating task were items from the International Affective Picture System (Lang et al., 2005). Valence ratings from the normative data were used to divide the picture set into negative, neutral, and positive affect. The set was further divided so that negative and positive pictures would have similar arousal ratings. A total of 120 pictures were selected, including 40 neutral (IAPS numbers: 2102, 2104, 2191, 2215, 2221, 2235, 2305, 2383, 2393, 2396, 2397, 2410, 2440, 2480, 2485, 2487, 2499, 2513, 2514, 2516, 2518, 2579, 2580, 2593, 2595, 2597, 2620, 2635, 2745.1, 2830, 2840, 2850, 2870, 4605, 7493, 7496, 7506, 8010, 8311, 8465), 40 positive (IAPS numbers: 2058, 2071, 2160, 2209, 2216, 2345, 2346, 4599, 4626, 4640, 4641, 5460, 5470, 5621, 5623, 5629, 5833, 7325, 7502, 8030, 8034, 8080, 8090, 8180, 8185, 8186, 8190, 8200, 8210, 8300, 8350, 8370, 8380, 8400, 8420, 8470, 8490, 8496, 8499, 8540), and 40 negative that were subdivided into 20 violent (IAPS numbers: 2683, 3500, 3530, 6212, 6250, 6312, 6313, 6315, 6350, 6360, 6530, 6540, 6550, 6560, 6571, 6821, 9423, 9424, 9427, 9428) and 20 nonviolent (IAPS numbers: 2710, 2730, 2751, 3005.1, 3168, 3170, 3230, 3261, 3266, 6834, 8485, 9050, 9410, 9421, 9635.1, 9800, 9810, 9903, 9910, 9925; see Figure 4). All images contained people. Violent images were defined as those that included at least two people where one person either held a weapon or was attacking the other person (e.g. a man choking a woman). Pictures were 512 by 384 pixels and presented on a white background. All stimuli were presented using E-Prime 1.2 Software (Psychology Software Tools, Pittsburgh, PA). Pictures were displayed on the screen until the participant responded followed by a blank screen for 500 ms. Participants rated the pictures on how colorful they were using the keys ‘v’, ‘b’, ‘n’, and ‘m’, with ‘v’ being least and ‘m’ being most colorful. After instructions, subjects were shown three practice pictures, one picture from each valence category that was not included in the 120 pictures, to practice rating. The pictures were presented in a different random order for every subject.

Figure 4. Sample pictures from each category in the Picture Rating Task.

Emotion Search Task. The stimuli for the emotion search task were similar to that used by Mather and Knight (2006). Stimulus displays consisted of nine schematic faces arranged in a three by three matrix (see Figure 5). Each display was 200 by 267 pixels. There was one same face display composed of all neutral faces and two target face displays, one happy face among 8 neutral faces and one angry face among 8 neutral faces. The happy and angry faces appeared in each of the nine positions 5 times, for a total of 45 happy target and 45 angry target trials. Another 90 trials were same face displays of all neutral faces. Participants were instructed to press the ‘n’ key if all faces were the same and press the ‘m’ key if one of the faces was different. Participants completed 9 practice trials, three of each type of display, followed by two experimental blocks of 90 trials each. Each trial began with a fixation cross for 500 ms and then the face matrix until the participant responded. The matrix was then replaced by the fixation cross for 500 ms before the next stimulus appeared.

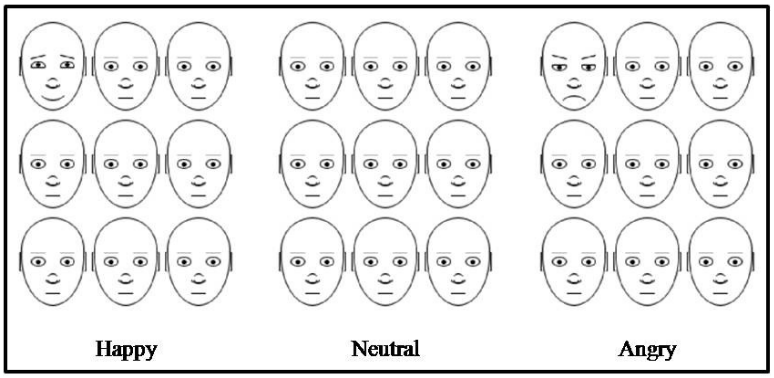

Figure 5. The three displays used in the Emotion Search Task.

Enumeration Task. In the enumeration task, the stimuli were white squares presented on a black background (see Figure 7). Participants were asked to report the number of squares in the display

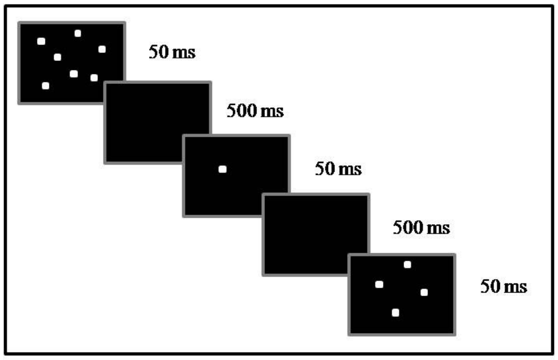

Figure 7. Enumeration task.

and this was entered by the experimenter. The displays were presented for 50 ms followed by a blank screen until a response was made. The number of squares in the display was randomly selected between 1 and 9 items. A display for each number of stimuli appeared 10 times each for a total of 90 trials.

Visual Short Term Memory Task. Stimuli in the VSTM were similar to those used by Vogel and Machizawa (2004). Colored squares appeared in a memory array and the color of each square was selected randomly from a set of seven colors and no color appeared more than twice in any display. Participants indicated if the test array was identical or different than the memory array by pressing the ‘n’ or ‘m’ key, respectively. Displays of one, three, or five colored squares were randomly presented for 100 ms, then a fixation cross alone was presented for 900 ms. The test array was presented until the response followed by a fixation cross for 500 ms (see Figure 8). The task consisted of 300 trials, half of which had identical memory and test displays and half of which had test displays that differed from the memory display by one colored square.

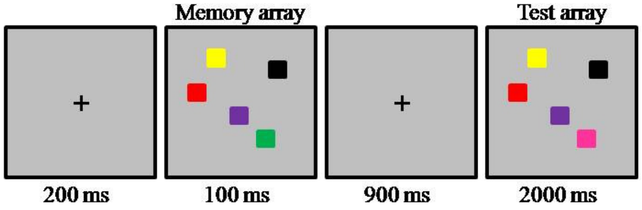

Figure 8. Example of a trial on the VSTM where the correct answer would be “different”.

Procedure

The cap application procedure was briefly explained to participants when they enter the lab. Participants then gave informed consent and completed the Edinburgh Handedness Inventory, the BIS/BAS scale (see Appendix A), and the Beck Depression Inventory. After cap application subjects were moved to the testing room and asked to sit comfortably in front of the computer monitor. Half the participants performed the tasks in the following order: Stroop, enumeration, emotion search, N-back, VSTM, picture rating. The other half of the participants performed the tasks in the reverse order. Following testing, participants completed the media usage questionnaire and the Buss/Perry Aggression Questionnaire (see Appendix A). Participants were asked to limit eye and head movements during recording.

Electrophysiological Recording and Analysis

The EEG (filter .02 – 150 Hz, gain 1000, 16-bit A/D conversion) was recorded from an array of 68 tin electrodes sewn into an Electro-cap (Electro-Cap International, Eaton, OH) or affixed to the skin with an adhesive patch (C4, Fc4, Fc6, Ft10, F4, F6, F8, F10, LO2, Af4, FcZ, C2, Fz, Fc2, Fp2, F2, C1, IO2, F1,Fc1, FpZ, Fp1, Af3, IO1, LO1, F5, F3, F9, F7, Fc5, Fc3, C3, Ft9, T7, C5, PO4, PO10, P4, P6, P8, CP4, CP6, TP8, M2, C6, T8, Iz, O2, Oz, PO2, POz, P2, Pz, P1, CP2, CPZ, CP1, O1, PO1, PO3, PO9, P3, P5, P7, CP3, CP5, TP7, M1). Vertical and horizontal eye movements were recorded from electrodes placed next to and below the right and left eyes. During recording all electrodes were referenced to electrode Cz, then re-referenced to an average reference for data analysis.

Ocular artifacts associated with blinks and saccades were removed from the data using a covariance-based technique including empirically derived estimates of the EEG associated with artifact and artifact free data (Electromagnetic Source Estimation; Source-Signal Imaging, San Diego). An 8 Hz IIR filter was applied offline to the picture rating, N-back, and the VSTM tasks due to the high levels of alpha activity. The rest of the tasks were filtered offline with a 20 Hz IIR filter. ERP analysis epochs were obtained offline with -200 ms prestimulus activity and 1000 ms poststimulus activity for the picture rating, emotion search, N-back, enumeration, and VSTM tasks. For the Stroop task -200 ms prestimulus activity and 1500 ms poststimulus activity was obtained. Table 2 lists the epoch, stimuli, ERP of interest, and the prediction for each of the six tasks.

Table 2

Task	Epoch	Stimuli	ERP	Prediction
Stroop	-200 to 1500 ms	Congruent/Incongruent color-words	MFN, FSW, conflict SP	Attenuation of MFN and FSW (1000 ms post-stimulus) for high gamers; no effect on conflict SP
N-back	-200 to 1000 ms	Letters (A-Z)	P3	Negative influence of video game experience
Picture Rating	-200 to 1000 ms	IAPS images	Parietal slow wave	Violent and positive images will be processed similarly in high gamers relative to non-gamers
Emotion Search	-200 to 1000 ms	Schematic faces	P3	Threatening stimuli elicit less activity for high gamers than non-gamers
Enumeration	-200 to 1000 ms	White squares	Occipital/Parietal activity, P3	Video game experience enhances processing in this task
VSTM	-200 to 1000 ms	Colored squares	Occipital/Parietal activity	Video game experience will be associated with increased visual working memory capacity

Chapter 3. Results

The results reported here are organized in the three domains of interest; cognitive control, affective processing, and visuospatial attention, respectively. For each task, analysis of reaction time and accuracy, mean amplitude of specific ERP components, and temporal-spatial analysis of the ERP data using PLS when novel results emerge relative to the analyses of mean amplitude are described. The means and standard error for the full factorial design of the analysis for each task are included in Appendix B.

Cognitive Control

Stroop Task

Behavioral Data. The mean response time and accuracy for the congruent and incongruent trials are displayed in Figure 9. Response time for incongruent trials was slower than the response time for congruent trials, and response accuracy was lower for incongruent trials than for congruent trials. The level of interference appeared similar in the three groups. The Stroop interference effect was examined in a 3 (group: violent, nonviolent, and non-gamers) x 2 (congruency: congruent or incongruent) ANOVA for response time and accuracy (Table B1).

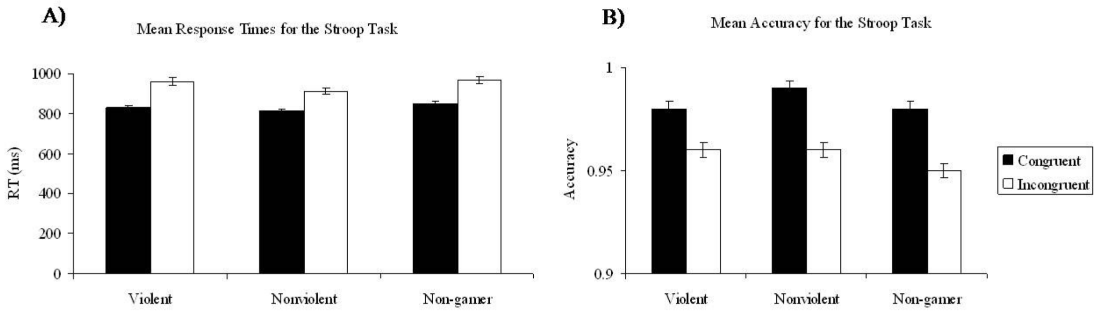

***Figure 9*. Mean reaction time (A) and accuracy (B) for congruent and incongruent trials by group.**

For the analysis of response time, the main effect of congruency was significant, $F(1,45) = 69$, $p = .001$, $\eta_p^2 = .61$, with the reaction time for incongruent trials, $M = 947$ ms, $SE = 48$, being slower than the reaction time for congruent trials, $M = 830$ ms, $SE = 46$. This indicates that the Stroop interference effect was present. The main effect of group and the group x congruency interaction were not significant, F's < 1.0, $\eta_p^2 < .02$. For the analysis of response accuracy, the main effect of congruency was significant, $F(1,45) = 31.78$, $p = .001$, $\eta_p^2 = .41$, with lower accuracy for incongruent trials, $M = .96$, $SE = .010$, than for congruent trials, $M = .98$, $SE = .006$, revealing a significant interference effect. The main effect of group and the group x congruency interaction were not significant, F's < 1.0, $\eta_p^2 = .01$. These data indicate that reactive control was insensitive to gamer status.

The conflict adaptation effect (CAE), the finding that reaction times on incongruent trials are faster and more accurate following other incongruent trials (iI trials) than they are following congruent trials (cI), was examined to determine the influence of gamer status on proactive control. The non-gamers appeared to demonstrate an incongruent benefit (iI-cI). The violent and nonviolent gamers did not appear to show this benefit (Figure 10). To test whether there was an incongruent benefit, a 3 (group) x 2 (match: incongruent-incongruent, congruent-incongruent) ANOVA was conducted (Table B2). The main effects of match and group were not

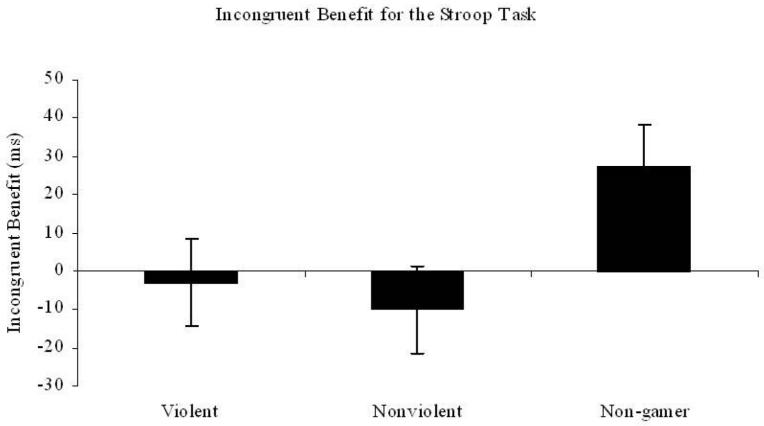

Figure 10. **Incongruent benefit for violent, nonviolent, and non-gamers in the Stroop task.**

significant, F's < 1.0, $\eta_p^2 < .01$. Further analyses revealed that the incongruent benefit was not significant for any group, all t's < 1.14, all p's > .27, although the means were in a direction consistent with the presence of a CAE for the non-gamers and not the gamers.

<u>ERP Data.</u> The amplitude of the conflict SP was greatest over the parietal and occipital regions of the scalp between 600-800 ms after stimulus onset. The conflict SP (Figure 11, POz) appeared to be larger in the violent gamers compared to the non-gamers and nonviolent gamers. The MFN (Figure 11, Fc1, C1) extended from the frontal region to the central-parietal region of the scalp. Between 350-400 ms after stimulus onset, the amplitude of the MFN was similar for gamers and non-gamers. Between 425-475 ms after stimulus onset the amplitude of the MFN appeared to be attenuated for the violent and nonviolent gamers. The FSW (Figure 11, F7) was maximal in amplitude at the left frontal electrodes between 600-800 ms after stimulus onset. The FSW appeared to be present in non-gamers and nonviolent gamers, but not in the violent gamers.

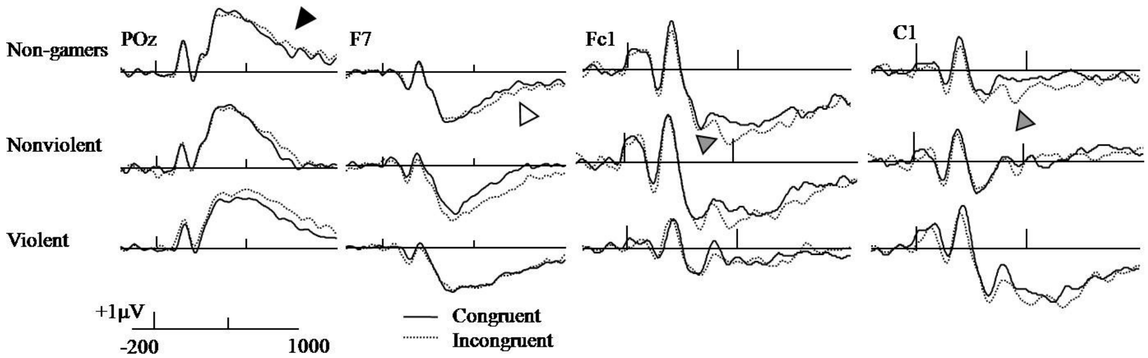

Figure 11. Grand-averaged waveforms for the conflict SP (black arrow), the FSW (white arrow), and the MFN (gray arrow). The tall bars represent stimulus onset, the short bars represent 500 ms increments, and positive is plotted up.

The relationship between video game experience and the conflict SP was examined in a 3 (group) x 2 (region: parietal-occipital and occipital) x 2 (congruency) x 3 (electrode: Left (PO3, O1), Midline (POz, Oz), Right (PO4, O2)) ANOVA (Table B3). The main effect of congruency was significant, $F(1,45) = 18.01$, $p = .001$, $\eta_p^2 = .29$, with greater amplitude for incongruent trials, *M* = 2.72 µV, *SE* = .29, than congruent trials, *M* = 1.79 µV, *SE* = .29. The group x congruency x electrode interaction was also significant, $F(4,90) = 2.93$, $p = .025$, $\eta_p^2 = .12$ (Figure 12). Post hoc analyses (Table 3) revealed that over the left hemisphere, the effect of congruency was significant for violent gamers and non-gamers, but not for the nonviolent gamers. Over the right hemisphere, the effect of congruency was significant for the violent gamers and the nonviolent gamers, but not for the non-gamers. At the midline, the effect of congruency was significant for the violent gamers, marginally significant for the nonviolent gamers, and not significant for the non-gamers. The conflict SP was consistently present for violent gamers, and present on the left for non-gamers and the right for nonviolent gamers, suggesting all groups utilized reactive control. However, the conflict SP was more robust for the violent gamers than the nonviolent gamers and the non-gamers.

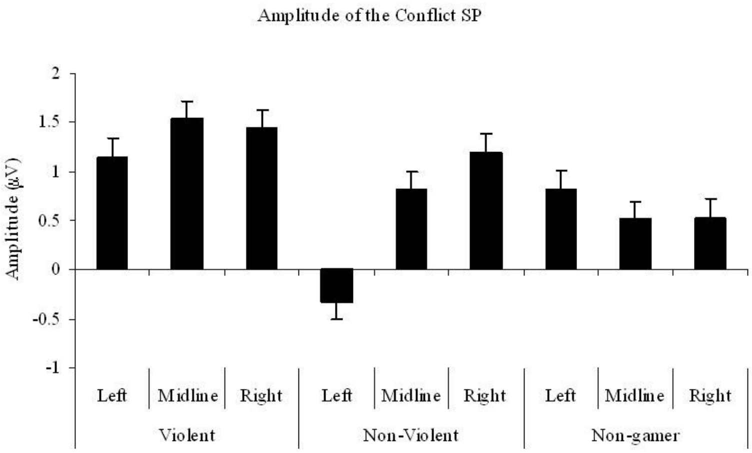

Figure 12. **Mean amplitude incongruent-congruent trials for the conflict SP in the Stroop task.**

Group	Left	Midline	Right
Non-gamers	5.78*	2.54	1.75
Violent	5.18*	8.94*	10.59*
Nonviolent	1.17	4.31	19.97*

Table 3. F-ratios for the group x congruence x electrode interaction in the analysis of the conflict SP. Asterisk indicates the effect is significant.

The relationship between video game experience and the MFN was examined in a 3 (group) x 2 (epoch: 350-400 ms, 425-475 ms) x 2 (region: frontal-central, central) x 2 (congruency) ANOVA (Table B4). Electrodes FC1 and C1 were included in the analysis.

The main effect of congruency was significant, $F(1,45) = 8.72$, $p = .005$, $\eta_p^2 = .16$, with amplitude for the incongruent trials, $M = -.390$ µV, $SE = .31$, being more negative than amplitude for the congruent trials, $M = -.009$ µV, $SE = .28$,. The group x congruency x epoch interaction was significant, $F(2,45) = 8.26$, $p = .001$, $\eta_p^2 = .27$ (Figure 13). Post hoc analyses revealed that the effect of congruency was significant in the 350-400 ms epoch, $F(1,45) = 21.51$, $p = .001$, and the group x congruency interaction was not significant, $F(2,45) = 1.95$, $p = .154$. These findings indicate that the MFN was similar in the three groups in this epoch. For the 425-475 ms epoch, the main effect of congruency was significant, $F(1,45) = 30.71$, $p = .001$, and the group x congruency interaction was significant, $F(2,45) = 11.22$, $p = .001$. To characterize this interaction, separate analyses were performed for the groups. For the violent gamers, the effect of congruency was not significant, $F < 1.0$, $\eta_p^2 = .003$. For the nonviolent gamers the effect of congruency was also not significant, $F < 1.0$, $\eta_p^2 = .12$. For the non-gamers the effect of congruency was significant, $F(1,15) = 13.11$, $p = .003$, $\eta_p^2 = .47$. These results indicate that from 425 to 475 ms after stimulus onset, the MFN was attenuated in the both groups of gamers relative to non-gamers. These findings are consistent with Bailey et al. (2009).

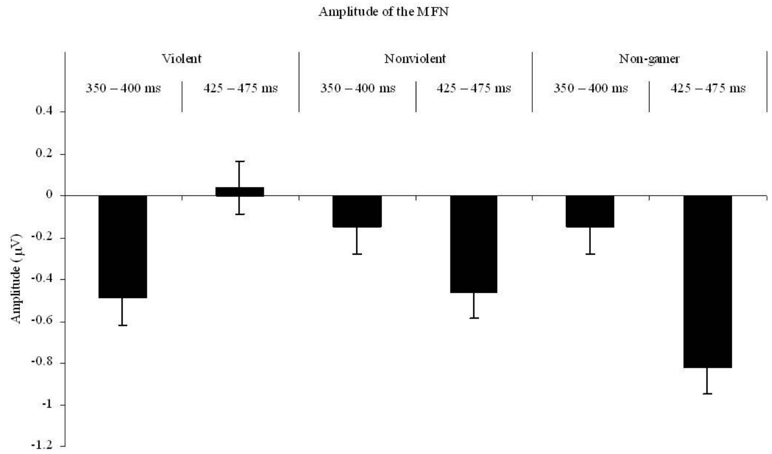

Figure 13. **Mean amplitude of the incongruent-congruent trials for the MFN in the Stroop task.**

The relationship between video game experience and the frontal slow wave was examined in a 3 (group) x 2 (congruency) x 5 (electrode: FT9, F9, F7, F5, FC5) ANOVA

(Table B5). The main effect of congruency was significant, $F(1,45) = 14.23$, $p = .001$, $\eta_p^2 = .24$, with the incongruent trials, $M = -2.40$ μV, $SE = .26$, being more negative than the congruent trials, $M = -1.69$ μV, $SE = .25$. There was also a significant main effect of group, $F(1,45) = 4.67$, $p = .014$, $\eta_p^2 = .17$, with the amplitude decreasing from violent gamers, $M = -3.05$ μV, $SE = .41$, to non-gamers, $M = -1.77$, μV, $SE = .41$, to nonviolent gamers, $M = -1.33$ μV, $SE = .41$ (Figure 14). A separate analysis of each group revealed that for the violent gamers, the effect of congruency was not significant, $F(1,15) = 2.03$, $p = .175$, $\eta_p^2 = .12$. For the nonviolent gamers, the effect of congruency was significant, $F(1,15) = 8.96$, $p = .010$, $\eta_p^2 = .37$. For the non-gamers the effect of congruency was marginally significant, $F(1,15) = 4.29$, $p = .056$, $\eta_p^2 = .22$. These results suggest that the frontal slow wave was present for nonviolent and non-gamers but attenuated or absent for the violent gamers. Game experience influences the MFN regardless of game genre, but the FSW was only attenuated in violent gamers. This finding may reflect a differential effect of video game experience on the ACC and the PFC. The results seem to suggest that to some extent game experience in general is detrimental to recruiting certain neural generators associated with proactive control, but that experience with violent video games (first-person shooters) may be especially disruptive.

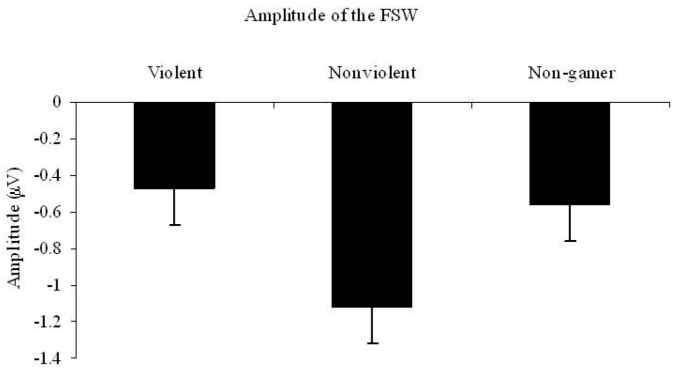

***Figure 14*. Mean amplitude of the incongruent-congruent trials for the FSW in the Stroop task.**

<u>PLS Analysis.</u> The PLS analysis included 0-1500 ms of post-stimulus data for the Stroop task. The permutation test revealed two latent variables (LVs) of interest ($p = .005$, p

= .075) that accounted for 52.67% and 32.00% of the crossblock covariance, respectively (Figure 15). LV1 appeared to express the neural correlates of reactive control, representing a contrast between congruent and incongruent trials that was stronger for the violent gamers than the nonviolent gamers or non-gamers. The electrode saliences for LV1 reflected a parietal negativity between 0 to 800 ms and a frontal-central positivity between 400 to 1000 ms. The first LV appeared to capture the conflict SP and the MFN. LV2 appeared to express the neural correlates of proactive control, representing a contrast between congruent and incongruent trials that was stronger for nonviolent gamers than non-gamers and reversed in the violent gamers. The electrode saliencies for LV2 reflected a frontal negativity over the left hemisphere between 400 to 1500 ms. LV2 appeared to capture the FSW.

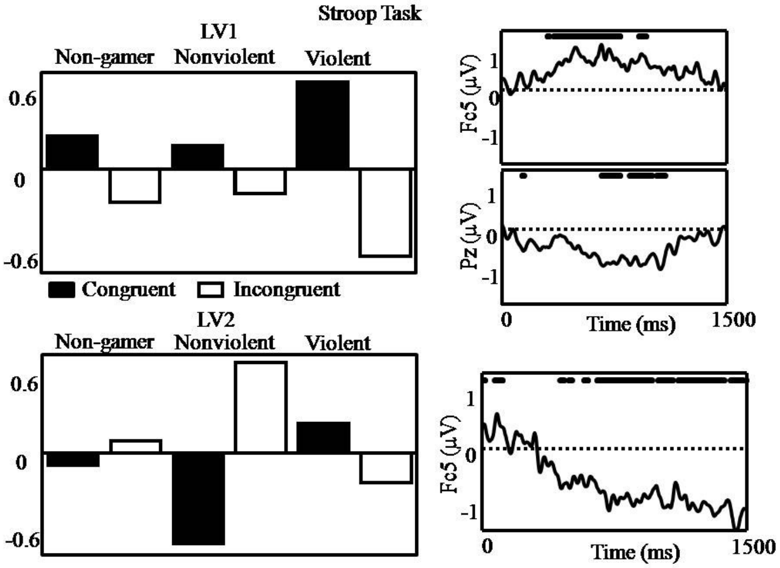

Figure 15. Design scores and electrode saliences for LV's 1 and 2 in the Stroop task.

N-back Task

Behavioral Data. For the N-back task, participants were generally slower and less accurate in the 3-back condition than the 1-back condition. Participants were slower, but more accurate to respond to non-targets than to targets. The effect of working memory load appeared to be similar in the three groups. Response time and accuracy were analyzed in a set of 3 (group) x 2 (stimulus: target or non-target) x 2 (load: 1 or 3) ANOVAs (Table B6).

For the analysis of reaction time, the main effect of stimulus was significant, $F(1,45) = 57.82$, $p = .001$, $\eta_p^2 = .56$, with response time being slower for non-targets, $M = 1155$ ms, $SE = 93$, than for targets, $M = 946$ ms, $SE = 72$. The main effect of load was also significant, $F(1,45) = 147.89$, $p = .001$, $\eta_p^2 = .77$, with response time being slower for the 3-back condition, $M = 1436$ ms, $SE = 125$, than the 1-back condition, $M = 665$ ms, $SE = 40$. These data indicate a significant effect of N-back load on response time. The main effect of group and interactions with group were not significant, all F's < 1.0, $\eta_p^2 = .01$.

For response accuracy, the main effect of stimulus was significant, $F(1,45) = 31.42$, $p = .001$, $\eta_p^2 = .41$, with the accuracy for targets, $M = .83$, $SE = .024$, being lower than for non-targets, $M = .90$, $SE = .017$. The main effect of load was also significant, $F(1,45) = 198.11$, $p = .001$, $\eta_p^2 = .82$, with lower accuracy in the 3-back condition, $M = .77$, $SE = .032$, than the 1-back condition, $M = .96$, $SE = .008$, revealing a significant effect of N-back load on accuracy. The target x load interaction was significant, $F(1,45) = 20.55$, $p = .001$, $\eta_p^2 = .31$. The effect of target appeared larger in the 3-back condition, $M_{diff} = -.12$, $F(1,45) = 27.37$, $p = .001$, $\eta_p^2 = .38$, than in the 1-back condition, $M_{diff} = -.01$, $F(1,45) = 4.24$, $p = .045$, $\eta_p^2 = .09$. The main effect of group and the interactions with group were not significant, all F's < 1.69, $\eta_p^2 = .07$. These data indicate that performance on the N-back task may be insensitive to gamer status.

ERP Data. A slow wave differentiating the 1-back from the 3-back condition was observed over the parietal and frontal regions of the scalp prior to stimulus onset (Figure 16). The slow wave activity appeared to be attenuated in the violent gamers. After stimulus onset, the P3 differed for the three groups (Figure 17). A frontal negativity was also observed beginning around 400 ms after stimulus onset that appeared to differ for the three groups (Figure 17).

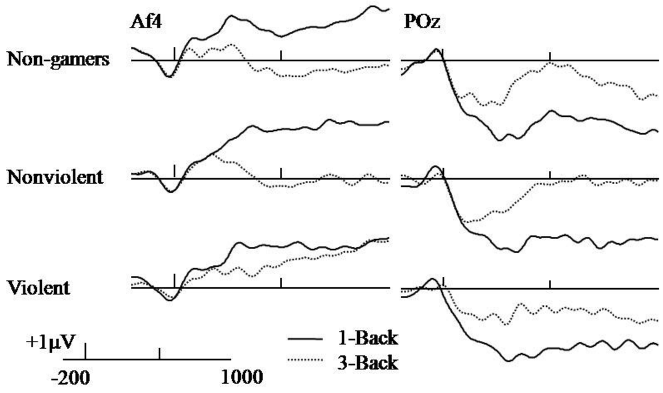

Figure 16. Grand-averaged waveforms for 1 and 3-back targets demonstrating the frontal (Af4) and parietal (POz) slow waves. The tall bars represent 1000 ms before stimulus onset, the short bars represent 500 ms increments, and positive is plotted up.

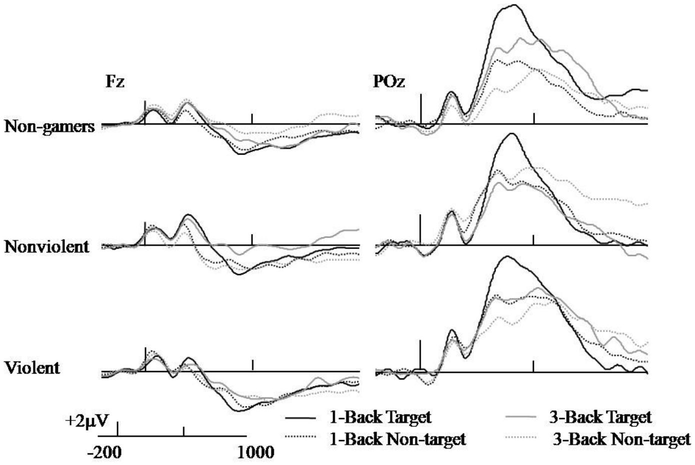

Figure 17. Grand-averaged waveforms for 1 and 3-back conditions demonstrating the frontal negativity (Fz) and the P3 (POz). The tall bars represent stimulus onset, the short bars represent 500 ms increments, and positive is plotted up.

For the analysis of the pre-stimulus data, only the data related to targets were analyzed because the responses to non-targets are ambiguous. The relationship between video game experience and the pre-stimulus slow wave was examined in a set of 3 (group) x 2 (load: 1-back, 3-back) x 3 (electrode) ANOVAs (Tables B7 and B8). The analysis of the parietal region included electrodes PO3, POz, and PO4, and the analysis of the frontal region included electrodes Af3 and Af4.

For the parietal region, the main effect of load was significant, $F(1,45) = 47.65$, $p = .001$, $\eta_p^2 = .51$, with the amplitude of the slow wave being more negative in the 1-back condition, $M = -3.57$ µV, $SE = .59$, than in the 3-back condition, $M = -1.02$ µV, $SE = .48$. These data indicate a significant effect of load on working memory. The group x load interaction was marginally significant, $F(2,45) = 2.90$, $p = .065$, $\eta_p^2 = .11$ (Figure 18a). Post hoc analyses of the groups revealed that the effect of load was significant for the violent gamers, $F(1,15) = 4.72$, $p = .046$, $\eta_p^2 = .24$, the non-gamers, $F(1,15) = 13.29$, $p = .002$, $\eta_p^2 = .47$, and the nonviolent gamers, $F(1,15) = 54.08$, $p = .001$, $\eta_p^2 = .78$, with the effect size increasing across the three groups. These data indicate that the effect of load may be greater for nonviolent gamers and non-gamers than for violent gamers.

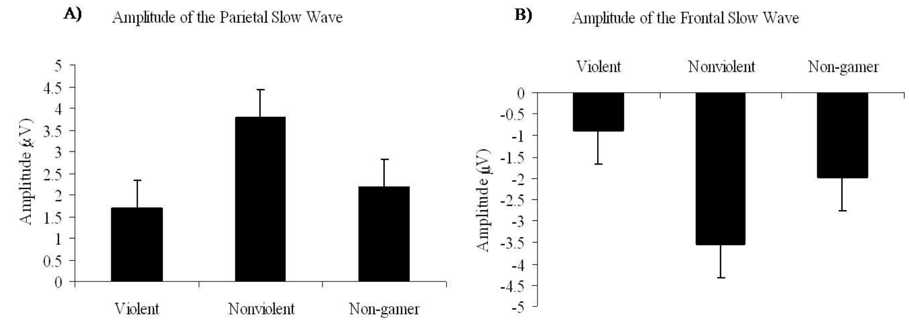

***Figure 18*. Mean amplitude of the parietal (A) and frontal (B) slow waves for 3-back-1-back targets100 to 300 ms prior to stimulus onset in the N-back task.**

For the frontal region, the main effect of load was significant, $F(1,45) = 28.18$, $p = .001$, $\eta_p^2 = .39$, with the frontal slow wave being more positive for the 1-back condition, $M = 2.46$ µV, $SE = .59$, than the 3-back condition, $M = .32$ µV, $SE = .62$. The group x load interaction was significant, $F(2,45) = 3.71$, $p = .032$, $\eta_p^2 = .14$ (Figure 18b). Post-hoc analyses of the groups revealed that for the violent gamers, the effect of load was not significant, $F(1,15) = 1.59$, $\eta_p^2 = .10$. The effect of load was significant for the nonviolent gamers, $F(1,15) = 19.07$, $p = .001$, $\eta_p^2 = .56$, and for the non-gamers, $F(1,15) = 12.67$, $p = .003$, $\eta_p^2 = .46$. These data indicate that the effect of working memory load on the frontal slow wave was present for the nonviolent gamers and non-gamers, but not for the violent gamers.

For the stimulus-locked data, the amplitude of the P3 was maximal over the parietal and occipital regions of the scalp between 300 to 500 ms after stimulus onset. The amplitude of the P3 was greater for 1-back targets than 3-back targets in all three groups. The influence of gamer status on the P3 was examined in a 3 (group) x 2 (load) x 2 (stimulus: target, non-target) x 2 (region: parietal-occipital, occipital) x 3 (electrode: left (PO3, O1), midline (POz, Oz), right (PO4, O2) ANOVA (Table B9). The main effect of load was significant, $F(1,45)$, $= 9.56$, $p = .003$, $\eta_p^2 = .18$, with the amplitude of the P3 being greater for the 1-back condition, $M = 4.27$ µV, $SE = .37$, than the 3-back condition, $M = 3.33$ µV, $SE = .41$. The main effect of stimulus was also significant, $F(1,45)$, $= 16.45$, $p = .001$, $\eta_p^2 = .27$, with the amplitude of the P3 being greater for targets, $M = 4.26$ µV, $SE = .40$, than non-targets, $M = 3.33$ µV, $SE = .38$. The load x stimulus interaction was significant, $F(1,45) = 4.15$, $p = .048$, $\eta_p^2 = .08$ (Figure 19a). Further analyses revealed that for the 1-back condition the effect of

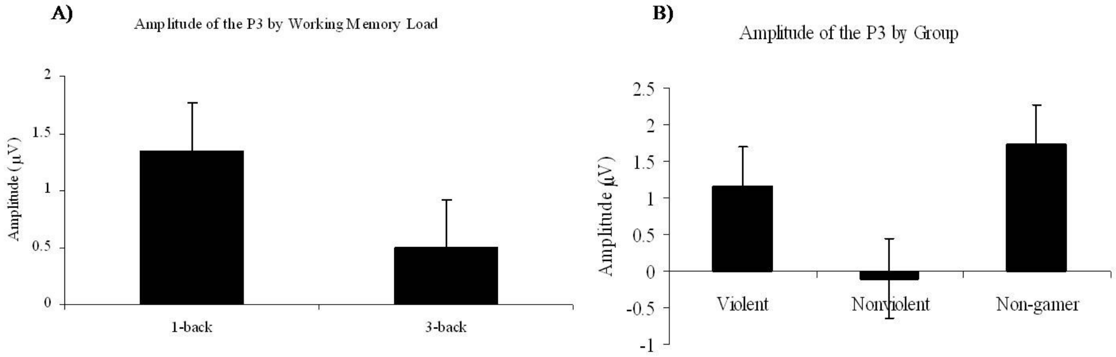

Figure 19. **Mean amplitude of the P3 for targets-non-targets by working memory load (A) and by group (B).**

target was significant, $F(1,45) = 23.82$, $p = .001$, $\eta_p^2 = .35$. For the 3-back condition, the effect of target was not significant, $F(1,45) = 2.23$, $\eta_p^2 = .05$. The group x stimulus interaction was significant, $F(2,45) = 5.50$, $p = .007$, $\eta_p^2 = .20$ (Figure 19b). Separate analyses of the groups revealed that the effect of target was significant for the violent gamers, $F(1,15) = 14.21$, $p = .002$, $\eta_p^2 = .49$ and the non-gamers, $F(1,15) = 21.62$, $p = .001$, $\eta_p^2 = .59$. The effect of target was not significant for the nonviolent gamers, $F < 1.0$, $\eta_p^2 = .002$. These data indicate that there was no influence of target on the P3 for the nonviolent gamers, whereas for the violent gamers and the non-gamers, targets elicited a larger P3.

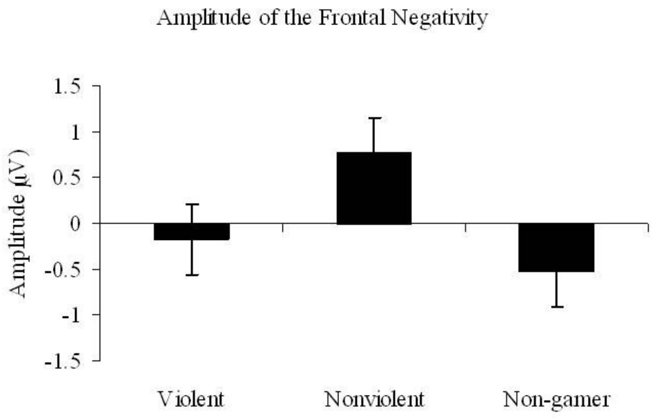

***Figure 20*. Mean amplitude of the frontal negativity for targets-non-targets by group.**

A frontal negativity was also observed between 400 to 600 ms after stimulus onset for nonviolent gamers and non-gamers, that appeared to be attenuated in the violent gamers. The influence of gamer status on the frontal negativity was examined in a 3 (group) x 2 (load) x 2 (stimulus) x 3 (electrode: F1, Fz, F2) ANOVA (Table B10). The main effect of load was significant, $F(1,45)$, = 14.15, $p = .001$, $\eta_p^2 = .24$, with the amplitude being more negative for the 1-back condition, $M = -2.35$ μV, $SE = .30$, than the 3-back condition, $M = -1.41$ μV, $SE = .33$. The group x stimulus interaction was significant, $F(2,45) = 3.41$, $p = .042$, $\eta_p^2 = .13$ (Figure 20). Separate analyses of the groups revealed no effect of target for the violent gamers, $F(1,15) = .24$, $p = .633$, η_p^2

= .02. The effect of target was marginally significant for the nonviolent gamers, $F(1,15) = 3.56$, $p = .079$, $\eta_p^2 = .19$. The effect of target was not significant for the non-gamers, $F(1,15) = 2.75$, $p = .118$, $\eta_p^2 = .16$. The effect sizes increased from the violent gamers to the non-gamers to the nonviolent gamers. For the nonviolent gamers, the frontal slow wave was greater for non-targets. To summarize the stimulus-locked data, the P3 demonstrated sensitivity to targets for the violent gamers and non-gamers, whereas the fontal negativity was sensitive to targets in the nonviolent gamers. These data may reveal different patterns of neural recruitment for the processing of targets in nonviolent gamers than in non-gamers or violent gamers.

Affective Processing

Picture Rating Task

Behavioral Data. In the picture rating task, response time was slower for negative and violent pictures compared to the neutral and positive pictures. Positive pictures were generally rated as more colorful than other picture types. Gamer status did not seem to influence response time or the ratings. Response time and mean ratings of colorfulness were analyzed in a set of 3 (group) x 4 (picture) ANOVAs (Table B11).

For the analysis of response time, there was a main effect of picture, $F(3,135) =$

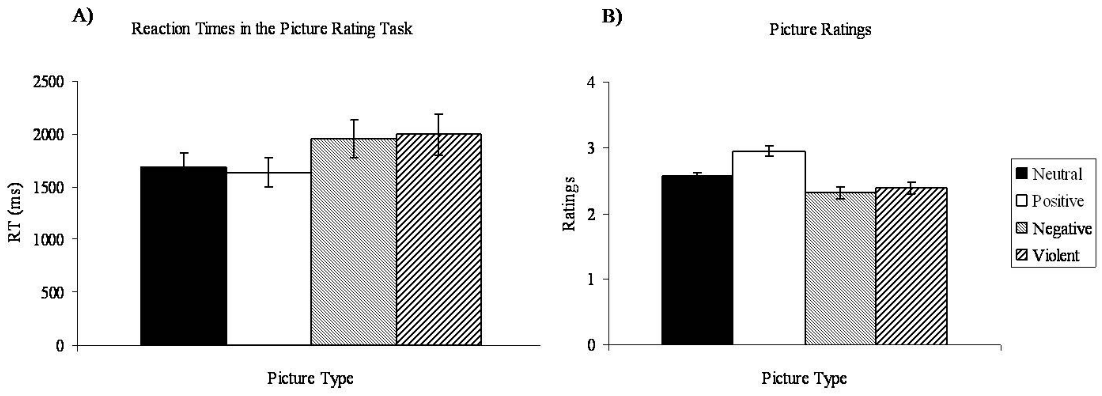

Figure 21. Mean reaction times (A) and ratings (B) in the picture rating task.

26.37, $p = .001$, $\eta_p^2 = .37$ (Figure 21A). Follow-up analyses revealed that response time for neutral and positive pictures was not significantly different, $F(1,45) = 2.34$, $p = .133$, $\eta_p^2 = .05$, that response time for the neutral pictures and the negative pictures was significantly different, $F(1,45) = 30.74$, $p = .001$, $\eta_p^2 = .41$, and that response time for the negative and violent pictures was not significantly different, $F < 1.0$, $\eta_p^2 = .01$. The main effect of group and the group x picture interaction were not significant, F's < 1.4, η_p^2's $< .02$. These results indicate that participants rated the colorfulness of the neutral and positive pictures faster than they rated the negative and violent pictures, and this was not influenced by gamer status.

For the analysis of the ratings, the main effect of picture was significant, $F(3,135) = 69.96$, $p = .001$, $\eta_p^2 = .62$ (Figure 21b). Follow-up analyses revealed that the positive pictures were rated significantly more colorful than the neutral pictures, $F(1,45) = 113.8$, $p = .001$, $\eta_p^2 = .72$. The neutral pictures were rated significantly more colorful than the negative pictures, $F(1,45) = 33.49$, $p = .001$, $\eta_p^2 = .43$. The mean ratings of the negative and violent pictures were not significantly different, $F(1,45) = 3.48$, $p = .069$, $\eta_p^2 = .07$. The main effect of group and the group x picture interaction were not significant, all F's < 1.4, $\eta_p^2 < .05$. These data indicate that participants rated positive pictures as more colorful than other picture types, and this was not influenced by gamer status.

ERP Data. As in the preliminary study and the past research on the neural correlates of affective picture processing (cf. Oloffson et al. 2008), the amplitude of the parietal slow wave was examined. The amplitude of the parietal slow wave was greater for violent and negative pictures than neutral and positive pictures between 400 to 600 ms after stimulus onset. The amplitude appeared similar for the three groups (Figure 22). A frontal slow wave was also observed during the same epoch and appeared similar for the three groups. The amplitude of the frontal slow wave also appeared to be greater for violent and negative pictures (Figure 22). The influence of video game experience on the parietal slow wave (PSW) was examined in a 3 (group) x 4 (picture: negative, neutral, positive, violent) x 3 (electrode: PO3, POz, PO4) ANOVA (Table B12). The main effect of picture was significant, $F(3,135) = 4.82$, $p = .003$, $\eta_p^2 = .10$ (Figure 23A). Further analyses revealed that

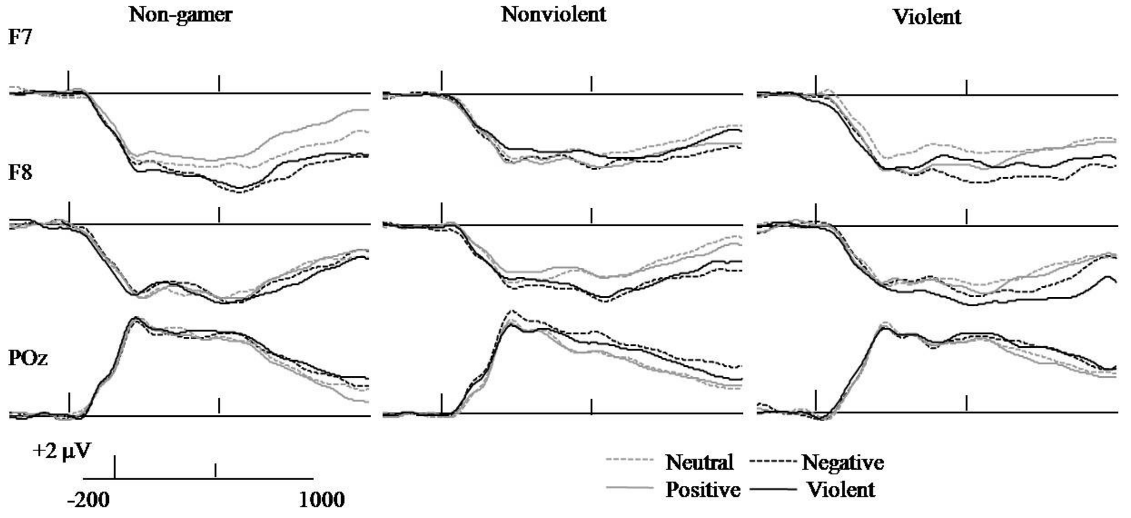

Figure 22. Grand-averaged waveforms demonstrating the frontal (F7 and F8) and parietal (POz) slow wave in the picture rating task. The tall bars represent stimulus onset, the short bars represent 500 ms increments, and positive is plotted up.

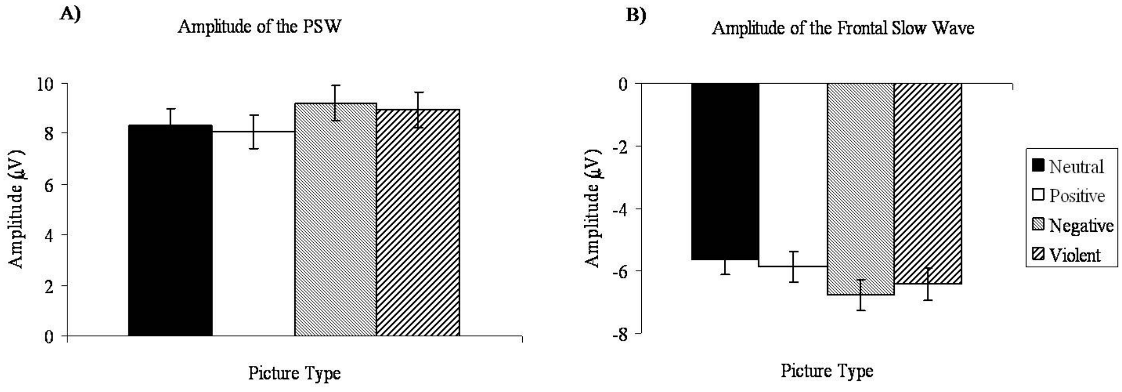

Figure 23. Mean amplitude of the PSW (A) and frontal slow wave (B) in the picture rating task.

Picture Type	Negative	Violent	Positive
Neutral	5.87*	3.31	1.42
Negative		.53	9.90*
Violent			7.53*

Table 4. F-ratios for the parietal slow wave in the picture rating task. Asterisk indicates the effect is significant.

the amplitude of the PSW was similar for neutral and positive pictures, as well as for violent and neutral pictures (Table 4). The amplitude of the PSW was greater for violent pictures than for positive pictures. The amplitude of the PSW was greater for negative pictures than for positive and neutral images, but the amplitude was similar for negative and violent images. There was no effect of group or a group x picture interaction, F's < 1.19, $\eta_p^2 < .05$. These results indicate the presence of a negativity bias in the PSW and the effect was not influenced by gamer status.

The frontal slow wave was examined in a 3 (group) x 4 (picture) x 4 (electrode: F7, F5, F6, F8) ANOVA (Table B13). The main effect of picture was significant, $F(3,135) = 6.04$, $p = .001$, $\eta_p^2 = .12$ (Figure 23B). Further analysis revealed that the amplitude of the frontal slow wave was similar for neutral and positive pictures. The amplitude of the frontal slow wave was more negative for violent than positive pictures. The amplitude of the frontal slow wave was similar for violent and negative pictures (Table 5). These data indicate a negativity bias was present over the frontal region. There was no effect of group or a group x picture interaction, F's < 1.0, $\eta_p^2 < .03$. These data indicate the negativity bias was not influenced by gamer status.

Picture Type	Negative	Violent	Positive
Neutral	12.08*	10.97*	1.26
Negative		.92	6.80*
Violent			4.63*

Table 5. F-ratios for the frontal slow wave in the picture rating task. Asterisk indicates the effect is significant.

<u>PLS Analysis.</u> The PLS analysis included 0-1000 ms of post-stimulus data. The permutation test revealed two significant LVs (*p* = .001, .002) that accounted for 45.23% and 20.94% of the crossblock covariance, respectively (Figure 24). LV1 expressed the neural correlates of the negativity bias, representing a contrast of the negative and violent pictures with the neutral and positive pictures. The electrode saliences for LV1 reflected positivity over the central-parietal region between 600 and 1000 ms and a negativity over the left frontal region between 800 and 1000 ms. LV2 expressed the neural correlates of processing affective pictures for all three groups, representing a contrast between neutral pictures and the positive, negative, and violent pictures. For the nonviolent and violent gamers, the contrast appeared stronger for positive pictures than the negative and violent pictures, which might indicate a positivity bias. The electrode saliences reflected negativity over the central-parietal region between 400 to 800 ms and positivity over the occipital region between 400 to

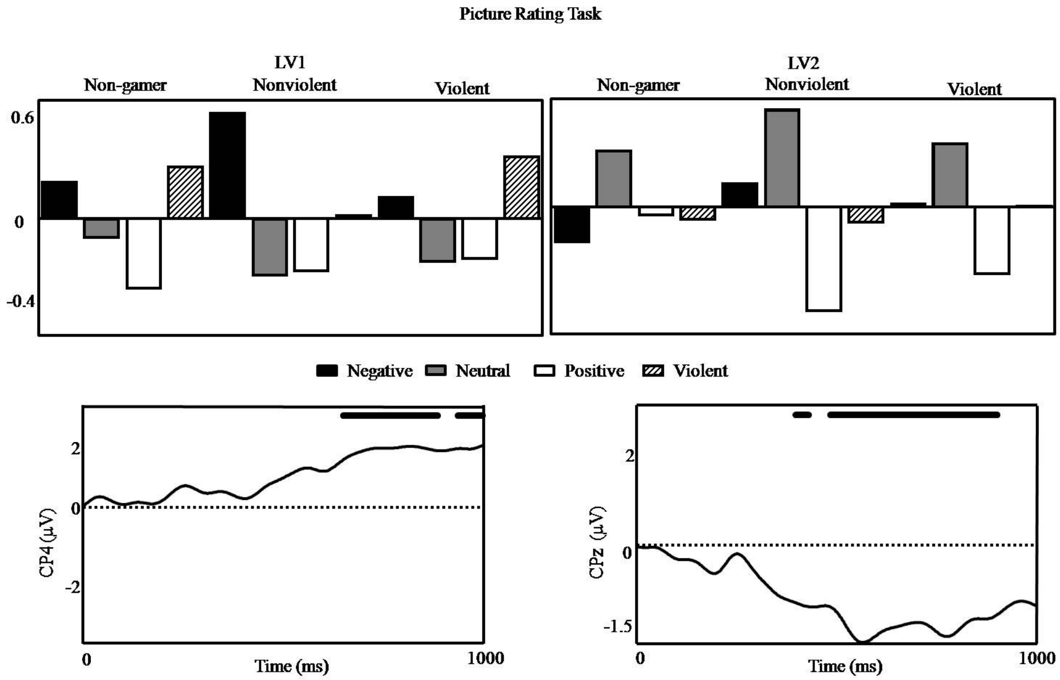

Figure 24. Design scores and electrode saliences for LV's 1 and 2 in the analysis of all three groups in the picture rating task.

1000 ms. The PLS analysis was not consistent with the findings of Bailey et al. (2009), but does support an effect of video game experience on affective picture processing.

To compare the results of the current study to those of the preliminary study using the picture rating task, a second analysis was performed that included the non-gamers and violent gamers (Figure 25). The permutation test revealed two LV's of interest (p = .001, .092) that accounted for 48.61% and 17.35% of the crossblock covariance, respectively. LV1 expressed the neural correlates of the negativity bias for both groups, representing a contrast between the negative and violent pictures with the neutral and positive pictures. The electrode saliences for LV1 reflected positivity over the central-parietal region between 600 and 1000 ms and negativity over the left frontal region between 400 and 1000 ms. LV2 expressed the neural correlates of processing positive pictures for non-gamers, representing a contrast between positive pictures and other picture types, and expressed the neural correlates of

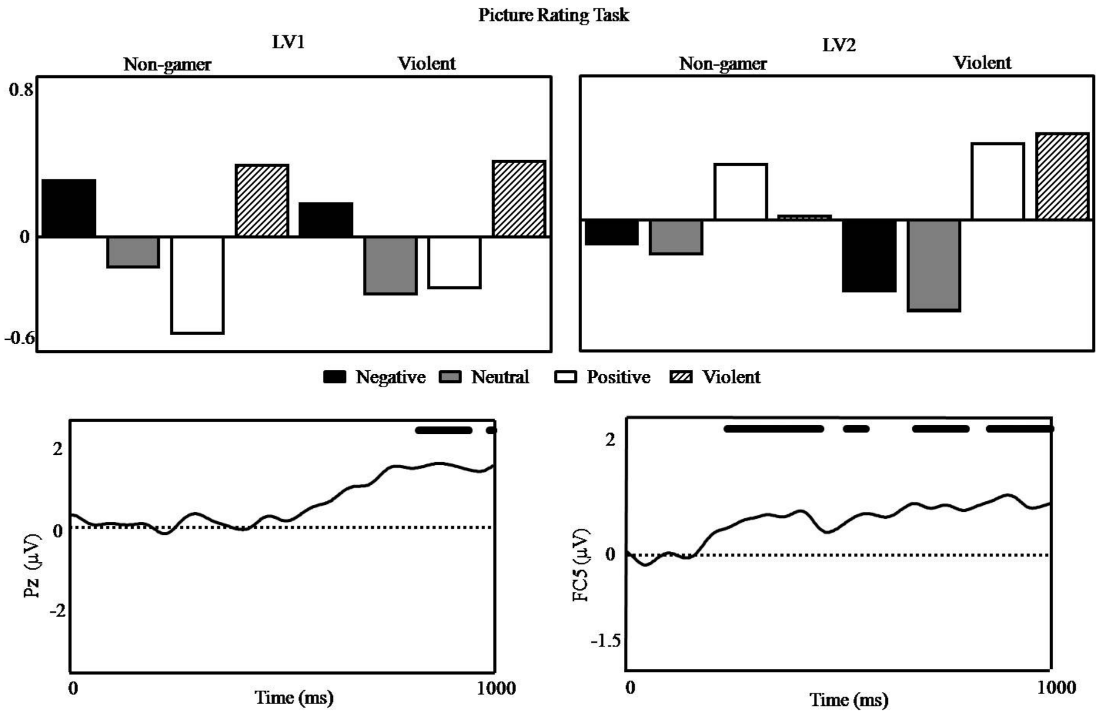

Figure 25. Design scores and electrode saliences for LV's 1 and 2 in the analysis of non-gamers and violent gamers in the picture rating task.

processing positive and violent pictures for violent gamers, representing a contrast between positive and violent pictures versus neutral and negative pictures. The electrode saliences reflected a left frontal-central positivity from 600 to 1000 ms. Although this LV was not significant in the current sample, the latent variable was similar to what was shown in the preliminary study.

Emotion Search Task

Behavioral Data. In the emotion search task, participants tended to be slower to respond when no emotional face was present in the display. Participants appeared to be more accurate for the neutral and angry face conditions, than the happy face condition, and this seemed to differ by group. Response time and accuracy were analyzed in a set of 3 (group) x 3 (face) ANOVAs (Table B14).

For the analysis of response time, the main effect of face was significant, $F(2,90) = 64.99$, $p = .001$, $\eta_p^2 = .59$. Follow-up analyses revealed that response time for angry and happy faces was significantly different, $F(1,45) = 12.67$, $p = .001$, $\eta_p^2 = .22$, with response time being faster for angry faces, $M = 867$ ms, $SE = 49$, than for happy faces, $M = 932$ ms, $SE = 61$. Response time for happy and neutral faces was significantly different, $F(1,45) = 72.31$, $p = .001$, $\eta_p^2 = .62$, being faster for happy faces than for neutral faces, $M = 1152$ ms, $SE = 87$. The main effect of group and the group x face interaction were not significant, all F's< 1.0, $\eta_p^2 = .04$. These results demonstrate the presence of a negativity bias that was not influenced by gamer status.

For the analysis of accuracy, the main effect of face was significant, $F(2,90) = 10.90$, $p = .001$, $\eta_p^2 = .20$. Follow-up analyses revealed that accuracy for neutral and angry faces was not significantly different, $F < 1.0$, $\eta_p^2 = .01$, with accuracy being similar for the neutral faces, $M = .95$, $SE = .015$, and angry faces, $M = .94$, $SE = .018$. Accuracy for happy and angry faces was significantly different, $F(1,45) = 24.97$, $p = .001$, $\eta_p^2 = .36$, with accuracy being higher for angry faces than happy faces, $M = .89$, $SE = .022$,. The group x face interaction was significant, $F(4,90) = 2.73$, $p = .034$, $\eta_p^2 = .11$. For the violent gamers, the effect of face was marginally significant, $F(2,30) = 3.07$, $p = .061$, $\eta_p^2 = .17$. The effect of face was significant for the nonviolent gamers, $F(2,30) = 4.23$, $p = .024$, $\eta_p^2 = .22$, and for the non-gamers, $F(2,30) = 7.54$, $p = .002$, $\eta_p^2 = .33$. These data indicate that the presence of a happy or angry face did not influence accuracy in the violent gamers. The effect of face was significant for the nonviolent gamers and the non-gamers, which is consistent with habituation or desensitization in the violent gamers.

ERP Data. The P3 was greater in amplitude for angry and happy face conditions than for the neutral face condition (Figure 26). The amplitude of the P3 appeared to be greater for the non-gamers and the non-violent gamers than the violent gamers. The amplitude of the P3 was maximal at parietal electrodes from 400 to 500 ms after stimulus onset. The relationship between video game experience and the P3 was examined in a 3 (group) x 3 (face: angry, happy neutral) x 3 (electrode: P3, Pz, P4) ANOVA (Table B15). The main effect of face was significant, $F(2,90) = 13.88$, $p =$

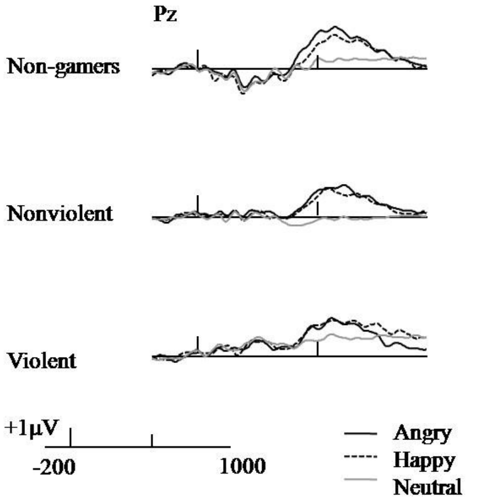

Figure 26. Grand-averaged waveforms for displays with happy, angry, and neutral faces demonstrating the P3. The tall bars represent stimulus onset, the short bars represent 500 ms increments, and positive is plotted up.

.001, η_p^2 = .24. The amplitude of the P3 was similar for angry faces, *M* = 1.87 μV, *SE* = .36, and happy faces, *M* = 1.70 μV, *SE* = .34, *F* < 1.0, η_p^2 = .01. The amplitude of the P3 was greater for happy than neutral faces, *M* = .71 μV, *SE* = .24, *F*(1,45) = 19.93, *p* = .001, η_p^2 = .31. The main effect of group and the group x face interaction were not significant, *F*'s < 1.0, η_p^2's < .03. However, the amplitude of the P3 appeared to differ by group, so further analyses were performed (Figure 27). For the violent gamers, the main effect of face was significant, *F*(2,30) = 4.78, *p* = .016, η_p^2 = .24. For the nonviolent gamers, the main effect of face was also significant, *F*(2,30) = 9.64, *p* = .001, η_p^2 = .39. For the non-gamers, the main effect of face was not significant, *F*(2,30) = 2.85, *p* = .074, η_p^2 = .16. These data may indicate that the difference in amplitude of the P3 for happy and angry faces compared to neutral faces is larger for both groups of gamers relative to non-gamers.

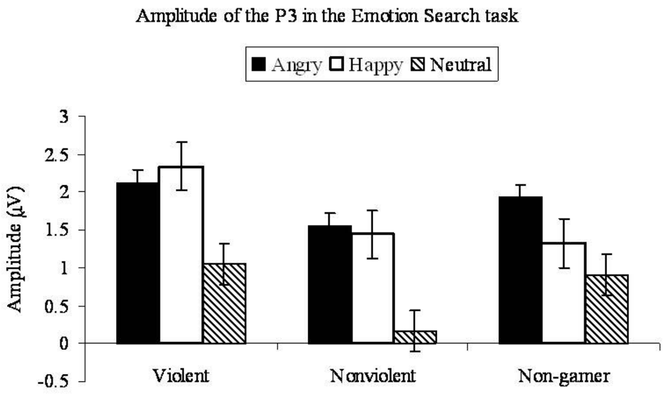

Figure 27. **Mean amplitude of the P3 for the emotion search task.**

<u>PLS Analysis.</u> The PLS analysis included 0-300 ms of post-stimulus data. The permutation test revealed one significant LV (*p* = .035) that accounted for 35.48% of the crossblock covariance (Figure 28). This LV reflected a group x face interaction. For the non-gamers and nonviolent gamers, the LV expressed the neural correlates of processing an angry face, representing a contrast between angry faces versus neutral and happy faces. In contrast, for the violent gamers this LV expressed the neural correlates of processing a happy face,

representing a contrast between happy faces and the other two. The electrode saliences reflected a left frontal negativity between 50 to 150 ms and between 200 to 300 ms. These data may indicate that for violent gamers there is a reorganization of how affective facial information is processed.

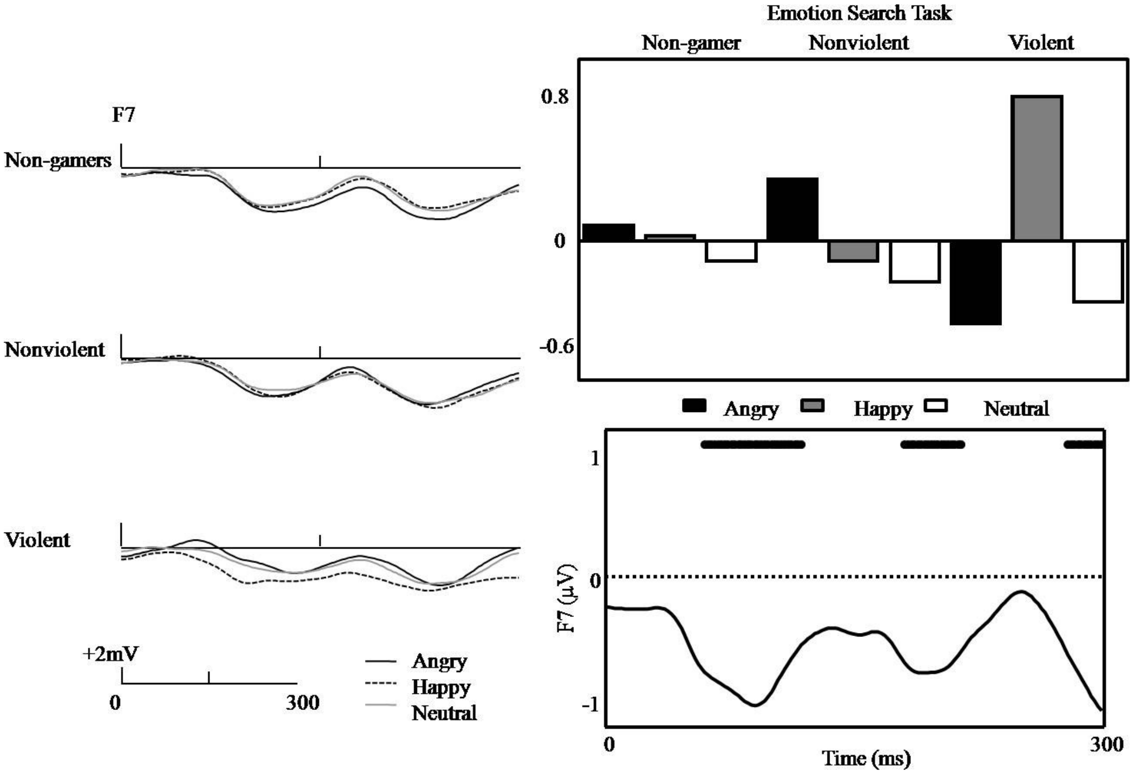

Figure 28. Waveforms for happy, angry, and neutral faces and design scores and electrode saliences for LV 1 in the emotion search task. The tall bars represent stimulus onset, the short bars represent 150 ms increments, and positive is plotted up.

Visuospatial Processing

Enumeration Task

Behavioral Data. Response time was relatively constant up to displays of 5-squares and then increased progressively with display size. Accuracy appeared to differ by group for medium to high display sizes, but response time did not appear to differ by group. The relationship between video game experience and the span of apprehension was examined in a set of 3 (group) x 9 (display size) ANOVAs for accuracy and response time (Figure 29). Median rather than mean response time was analyzed because the number of trials for each display size was relatively small (i.e. at most 10).

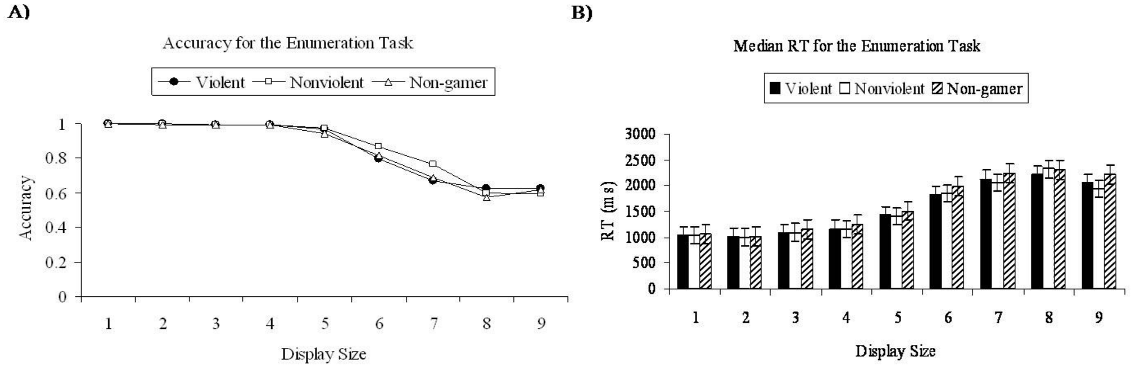

***Figure 29*. Median reaction times (A) and mean accuracy (B) for the enumeration task by group.**

Accuracy was nearly perfect in this task for display sizes of up to 5 squares. For the analysis of accuracy, the main effect of display size was significant, *F*(8,352) = 92.89, *p* = .001, η_p^2 = .68. Accuracy was similar for displays sizes of 1 to 4-squares, *F*(3,135) = 1.38, *p* = .25, η_p^2 = .03. Accuracy decreased from display sizes of 4 to 9-squares, *F*(5,220) = 66.91, *p* = .001, η_p^2 = .60. The main effect of group and the group x size interaction were not significant, *F* < .8, η_p^2 < .03. These data indicate that accuracy decreased as set size increased, but there was no effect of gamer status on the span of apprehension. These results are surprising given the findings of Green and Bavelier (2003, 2007).

For response time, the main effect of display size was significant, *F*(8,352) = 136.24, *p* = .001, η_p^2 = .76. Response time increased from 1 to 4-square displays, *F*(3,135) = 39.01, *p* = .001, η_p^2 = .46, and increased more from 4 to 9-square displays, *F*(5,220) = 85.69, *p* = .001, η_p^2 = .66.The effect of group and the group x size interaction were not significant, *F*'s <

1.0, η_p^{2}'s < .02. These results suggest that gamer status did not influence the span of apprehension.

ERP Data. To test the influence of gamer status on the neural correlates of visuospatial processing, the effect of display size on the amplitude of the P3 was examined. The amplitude of the P3 was greater for small display sizes than for medium or large display sizes. Some group differences in the amplitude of the P3 were apparent. The amplitude of the P3 was maximal at central and parietal regions of the scalp between 400 to 500 ms after the stimulus onset (Figure 30). The relationship between video game experience and the P3 was examined in a 3 (group) x 3 (display size: displays of 1-3, 4-6, 7-9 squares) x 2 (region: central-parietal, parietal) x 3 (electrode: Cp1, Cpz, Cp2; P1, Pz, P2) ANOVA (Table B16). The main effect of display size was significant, $F(2,90) = 13.70$, $p = .001$, $\eta_p^2 = .23$. The amplitude of the P3 was greater for small display sizes, $M = 4.53$ µV, $SE = .40$, than for medium display sizes, $M = 3.04$ µV, $SE = .37$, $F(1,45) = 21.21$, $p = .001$, $\eta_p^2 = .32$, and the amplitude of the P3 was similar for medium and large displays, $M = 2.83$ µV, $SE = .41$, F

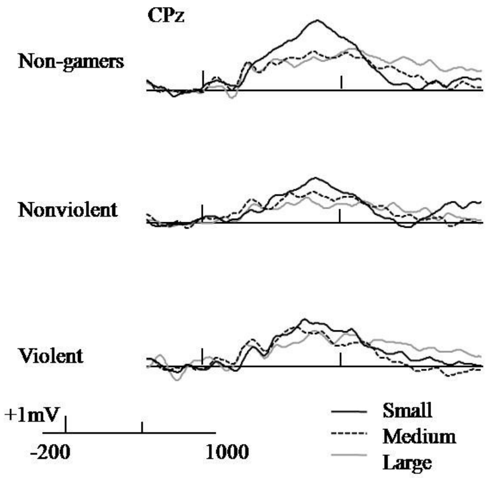

Figure 30. Grand-averaged waveforms for small, medium and large displays demonstrating the P3 in the enumeration task. The tall bars represent stimulus onset, the short bars represent 500 ms increments, and positive is plotted up.

< 1.0, $\eta_p^2 = .01$. The main effect of group and the group x size interaction were not significant, F's < 1.0, $\eta_p^2 < .03$. However, the P3 appeared to differ across the groups, so separate analyses were performed for each group (Figure 31). For the violent gamers, the effect of display size on the amplitude of the P3 was not significant, $F = 1.69$, $\eta_p^2 = .10$. The effect of display size was significant for the nonviolent gamers, $F(2,30) = 4.47$, $p = .020$, $\eta_p^2 = .23$. For the non-gamers, the effect of display size was also significant, $F(2,30) = 12.83$, $p = .001$, $\eta_p^2 = .46$. These data suggest that for violent gamers, display size did not influence the amplitude of the P3 whereas for the nonviolent gamers and the non-gamers the amplitude of the P3 was greater for the small displays, possibly indicating an effect of difficulty for those two groups and an increase in visuospatial capacity for the violent gamers.

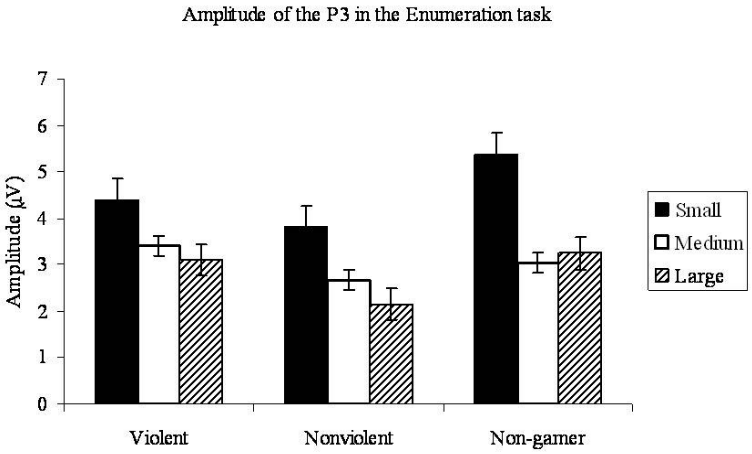

***Figure 31*. Mean amplitude of the P3 for small, medium, and large displays in the enumeration task.**

<u>PLS Analysis.</u> The PLS analysis included 0-1000 ms of post-stimulus data. The permutation test revealed two significant LVs ($p = .000$, .015) that accounted for 55.86% and 17.12% of the crossblock covariance, respectively (Figure 32). LV1 appeared to express the neural correlates of subitizing, representing a contrast between the small displays compared to the medium and large displays. Subitizing typically has a range of 3 or 4 items (Trick & Pylyshyn, 1993). In this analysis, the small displays were one to three items, the medium

displays were four to six items, and the large displays were seven to nine items. The contrast for LV1 shows small and large displays differing greatly from one another and the medium displays falling in between. This is what would be expected of an LV that reflected the process of subitizing. The electrode saliences for LV1 reflected a frontal-central negativity between 300 to 500 ms and a parietal-occipital positivity between 800 to 1000 ms. The design scores for LV1 were smaller in the violent gamers than the other two groups which may indicate that the parallel extraction of visual information in the display was more efficient for the violent gamers.

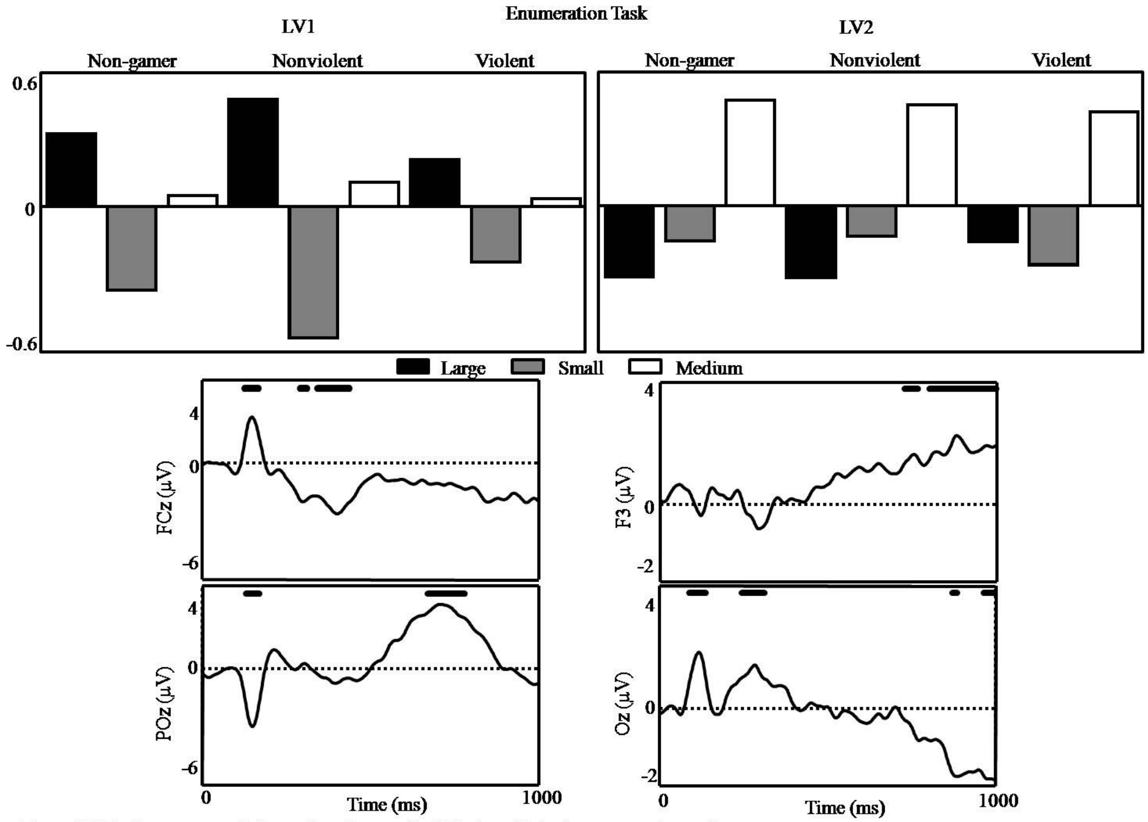

Figure 32. Design scores and electrode saliences for LV's 1 and 2 in the enumeration task.

LV2 appeared to express the neural correlates of counting, representing a contrast between the small and large displays compared to the medium displays. Counting is typically most effective for medium display sizes, in this case of 4 to 6 squares (Trick & Pylyshyn, 1994). Small display sizes fall within subitizing and large display sizes contain too many items to be accurately counted. The contrast in LV2 is what would be expected of a process indicative of counting. The pattern of design scores was similar across the three groups. The electrode saliences for LV2 reflected an occipital positivity between 0 to 400 ms and a frontal positivity over the left hemisphere between 800 to 1000 ms. The results of the PLS analysis indicate that the groups may not differ in their use of counting for medium size displays. These data are not consistent with Green and Bavelier (2007), who suggested that the gamers' improved performance on the enumeration task is due to more efficient counting, not more effective subitizing.

VSTM Task

Behavioral Data. In the VSTM task, response time increased as display size increased, and accuracy decreased as display size increased. Response time and accuracy were examined in a set of 3 (group) x 3 (display size) x 2 (response: same or change) x 2 (display side: left or right) ANOVAs (Table B17).

For the analysis of response time, the main effect of display size was significant, $F(2,90) = 88.85$, $p = .001$, $\eta_p^2 = .66$. Follow-up analyses revealed that the response time for 1-square displays was significantly faster than for 3-square displays, $F(1,45) = 76.96$, $p = .001$, $\eta_p^2 = .63$, and the response time for 3-square displays was significantly faster than for

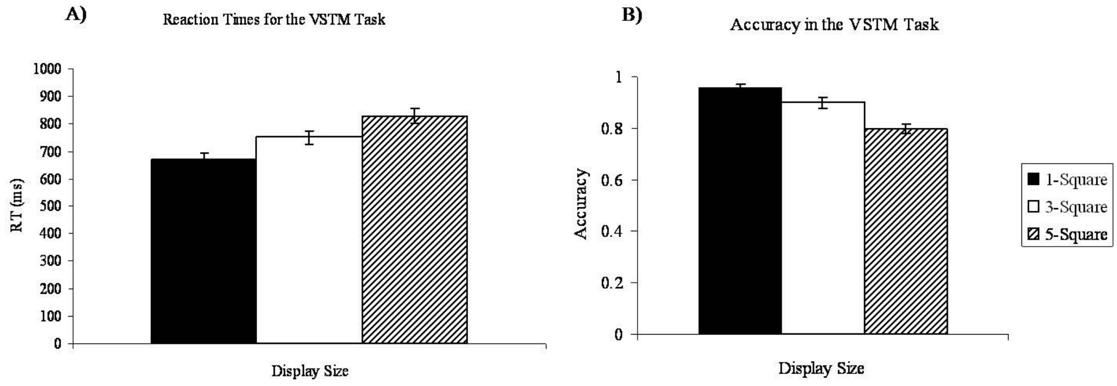

Figure 33. Mean reaction time (A) and accuracy (B) for 1, 3, and 5-square displays in the VSTM task.

5-square displays, $F(1,45) = 53.93$, $p = .001$, $\eta_p^2 = .55$ (Figure 33A). The main effect of response was also significant, $F(1,45) = 11.07$, $p = .002$, $\eta_p^2 = .19$, with decreased response time when the memory and test displays were the same, $M = 727$ ms, $SE = 47$, compared to when the displays were different, $M = 775$ ms, $SE = 39$.

The display size x response x display side x group interaction was significant, $F(4,90) = 2.50$, $p = .048$, $\eta_p^2 = .10$. Post-hoc analyses revealed that for change trials, the size x display side x group interaction was not significant, $F(4,90) = 1.45$, $\eta_p^2 = .06$, but for same trials the interaction was marginally significant, $F(4,90) = 2.43$, $p = .053$, $\eta_p^2 = .10$. Further analysis of the same trials revealed that the display side x group interaction was not significant for 1 and 3-square displays, F's < 1.17, $\eta_p^2 < .05$, but was significant for the 5-square displays, $F(2,45) = 3.24$, $p = .048$, $\eta_p^2 = .13$. Separate analyses of the groups revealed that for 5-square displays, display side was not significant for the nonviolent gamers or the non-gamers, F's < 1.0, $\eta_p^2 < .02$, and was significant for the violent gamers, $F(1,15) = 8.63$, $p = .010$, $\eta_p^2 = .37$ (Figure 34).

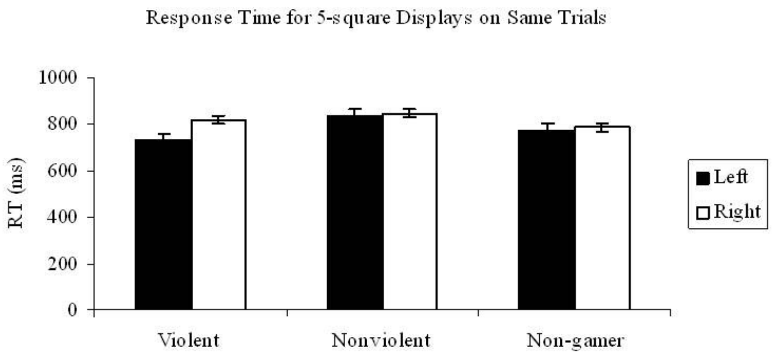

Figure 34. **Mean reaction time for 5-square displays on same trials by group in the VSTM task.**

For the analysis of accuracy, the main effect of display size was significant, $F(2,90) = 145.52$, $p = .001$, $\eta_p^2 = .76$ (Figure 33B). Accuracy was higher for 1-square than 3-square displays, $F(1,45) = 91.43$, $p = .001$, $\eta_p^2 = .67$, and was higher for 3-square than 5-square displays, $F(1,45) = 111.5$, $p = .001$, $\eta_p^2 = .71$.

The main effect of response was significant, $F(1,45) = 39.58$, $p = .001$, $\eta_p^2 = .47$, with higher accuracy for the same trials, $M = .93$, $SE = .01$, than the change trials, $M = .83$, $SE = .03$. The display size x response interaction was also significant, $F(2,90) = 59.19$, $p = .001$, $\eta_p^2 = .57$. Further analysis revealed that the effect of response was not significant for the 1-square displays, $F < 1.0$, $\eta_p^2 = .01$, but was significant for 3-square displays, $F(1,45) = 15.61$, $p = .001$, $\eta_p^2 = .26$, and 5-square displays, $F(1,45) = 64.69$, $p = .001$, $\eta_p^2 = .59$. This indicates that accuracy decreased significantly on different trials for 3 and 5-square displays. There was no effect of group, $F < 1.0$, $\eta_p^2 = .02$. Thus, gamer status did not appear to influence accuracy on the VSTM task.

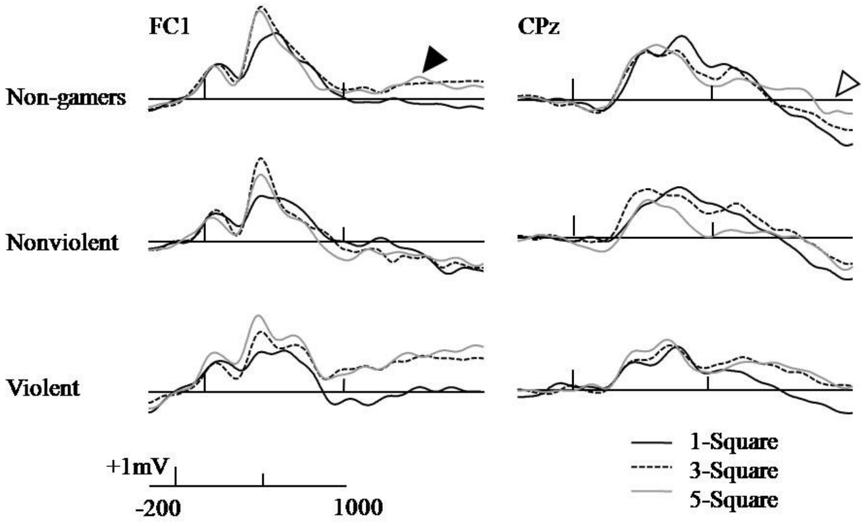

Figure 35. Grand-averaged waveforms for one, three, and five square displays in the VSTM task demonstrating the frontal slow wave (FC1; black arrow) and the parietal effect (CPz; white arrow). The tall bars represent onset of the memory array, the short bars represent 500 ms increments, and positive is plotted up.

<u>ERP Data.</u> For this task, the ERP data for change trials were analyzed. At the frontal-central region between 500-700 ms after onset of the memory array, a slow wave was present that differentiated display sizes of one square from display sizes of three and five squares for the violent gamers. This effect appeared to be smaller in the non-gamers and absent in the nonviolent gamers (Figure 35). The effect was examined in a 3 (group) x 3 (display size: 1, 3, 5) ANOVA (Table B18) that included electrode FC1. The main effect of display size was not significant,

$F(2, 90) = 2.24$, $p = .11$, $\eta_p^2 = .05$. The group x display size interaction was significant, $F(4,90) = 3.17$, $p = .017$, $\eta_p^2 = .124$. Separate analyses of the groups revealed a significant effect of display size for the violent gamers, $F(2,30) = 4.39$, $p = .021$, $\eta_p^2 = .23$. The effect of display size was not significant for the nonviolent gamers, $F < 1.0$, $\eta_p^2 = .06$, or the non-gamers, $F(2,30) = 1.26$, $\eta_p^2 = .08$.

Over the central-parietal region between 700-900 ms after onset of the memory array, the ERPs for displays of 3 and 5 squares were greater in amplitude than for displays of 1 square for the violent gamers and this effect was not present in the nonviolent gamers and non-gamers (Figure 35). This effect was examined in a 3 (group) x 3 (display size) ANOVA (Table B19) that included electrode CPz. The main effect of display size was significant, $F(2,90) = 6.32$, $p = .003$, $\eta_p^2 = .12$. The amplitude of the ERPs for 1-square displays, $M = -.52$ µV, $SE = .54$, was less than for 3-square displays, $M = .17$ µV, $SE = .85$, $F(1,45) = 6.38$, $p = .02$, $\eta_p^2 = .12$. The amplitude of the ERPs for display sizes of 3 and 5 squares, $M = .41$, $SE = .65$, were similar, $F < 1.0$, $\eta_p^2 = .02$. The main effect of group and the group x size interaction were not significant, F's < 1.0, η_p^2's< .03. However, further analyses of the groups revealed that the effect of display size was marginally significant for the violent gamers, $F(2,30) = 2.99$, $p = .066$, $\eta_p^2 = .17$. For the nonviolent gamers and the non-gamers, display size was not significant, F's < 2.5, $\eta_p^2 < .14$. These data indicate the violent high gamers may have a greater visual memory capacity.

Chapter 4. Discussion

The purpose of the current study was to investigate the influence of video game experience on cognitive control, affective processing, and visuospatial processing. The current study offers two primary contributions to the literature. First, previous studies have examined these domains separately (cf. Bartholow et al., 2006; Green & Bavelier, 2007; Matthews et al., 2005), but the current study is the first to consider cognitive control, affective processing, and visuospatial processing in the same gamers. It is theoretically and practically important to know if the benefits and costs associated with the video game experience seen across these domains exists in the same gamers. Second, the current study is one of the first to divide gamers according to game genre. The sample of violent gamers in the current study reported playing primarily first-person shooter video games. This group is similar to the action gamers investigated in studies of visuospatial processing (Green & Bavelier, 2003). The sample of nonviolent gamers reported playing primarily music video games, such as Rock Band and Guitar Hero. This group of gamers has not been studied in previous work. The importance of gaining a clearer understanding of the effects of video games becomes apparent when one considers that some researchers have recommended using video games as training tools (Feng et al., 2007; Green & Bavelier, 2006; Gopher et al., 1994; Jones et al., 1981). The current body of research has not sufficiently answered the question of how video games lead to improvements in some domains and declines in others. The answer to this question will be important to know for selecting or creating video games for training purposes.

To briefly summarize the results of this study, the type of video games one plays are associated with differential effects on cognitive control, affective processing, and visuospatial processing. The violent gamers in this study demonstrated some benefits to visuospatial processing, but at a cost to affective processing and the use of proactive cognitive control. Nonviolent gamers may have better use of proactive cognitive control, but do not seem to have enhanced visuospatial skills. In the following pages, the findings for each task are discussed in turn, followed by a discussion of the implications and future directions for the specific domain. Finally the limitations of the current study and conclusions are considered.

Cognitive Control

Stroop Task

The Stroop task was used to examine the relationship between video game experience and two types of cognitive control. It was hypothesized that video game experience would have a negative influence on proactive, but not reactive cognitive control. The Stroop interference effect and the conflict SP were indicators of reactive control (Loitti et al., 2000; West et al., 2005). Participants were slower and less accurate on incongruent than congruent trials, demonstrating a significant interference effect. This effect was not influenced by group membership. The conflict SP was present in all three groups, but was more consistently observed in the violent gamers than the other two groups. This may indicate that violent video games encourage and enhance the use of reactive control. The results for reactive control extend the findings of Bailey et al. (2009), demonstrating that gamers and non-gamers utilize reactive control in the Stroop task, but that violent gamers may employ reactive control more efficiently than the non-gamers and the nonviolent gamers. The findings of the current study and Bailey et al. may seem inconsistent with those of Kronenberger et al. (2005) who found that video game experience was associated with poor performance on the Stroop color-word card task. This discrepancy may be explained by the use of the clinical version of the Stroop task by Kronenberger et al. in which all of the stimuli are incongruent for the color-word card. This version would place high demands on the use of proactive control (Carter & van Veen, 2007). Therefore, the interference effect in the card version of the task may be primarily determined by variation in proactive control rather than reactive control.

The CAE, MFN, and FSW were considered as indicators of proactive control in the Stroop task (Botvinick et al., 2001; West, 2003; West & Travers, 2008). The analysis of the CAE did not reveal any significant differences between the groups. However, the pattern of results for the incongruent benefit revealed an attenuation of the CAE in the violent and nonviolent gamers compared to the non-gamers. This is consistent with Bailey et al. (2009). The failure to find significant group differences may have resulted from a lack of statistical power, as the CAE is a relatively small effect (i.e., on the order of 15 to 30 ms) and there is a wide ranged of individual differences for the measure.

The MFN was analyzed at two epochs following past research demonstrating that the MFN is associated with the activity of two or more neural generators (Markela-Lerenc, Ille, Kaiser, Fiedler, Mundt, & Weisbrod, 2004). Between 350-400 ms, the MFN was robust in all three groups; between 425-475 ms there was a significant difference between groups. The MFN was present in the non-gamers, but absent in both types of gamers during the later epoch. This finding is consistent with Bailey et al. (in press) and indicates that proactive control as indexed by the MFN was negatively influenced by video game experience regardless of game genre. The FSW was present in the non-gamers and the nonviolent gamers, but absent in the violent gamers. The FSW was in fact larger for the nonviolent gamers than for the non-gamers. This may indicate that experience with nonviolent games may be associated with greater recruitment of neural generators related to proactive control.

The PLS analysis of the Stroop data revealed two significant LVs representing the neural correlates of reactive and proactive control, respectively. Consistent with the analyses of mean amplitude of the ERPs, the first LV appeared to capture the conflict SP and was stronger for the violent gamers than the non-gamers or nonviolent gamers, indicating greater recruitment of the neural indices of reactive control. The second LV appeared to capture the FSW and was stronger for the nonviolent gamers and non-gamers than in the violent gamers. This is again consistent with previous work indicating that video game experience, particularly experience with first-person shooter video games, has a detrimental effect on proactive control (Bailey et al., 2009; Mathews et al., 2005).

The results for proactive control both converge with and diverge from the findings of Bailey et al. (in press). For the non-gamers, the three indices of proactive control were present. The three indices of proactive control were attenuated in the violent gamers. Conversely, the CAE and MFN were attenuated for the nonviolent gamers, and the FSW was not. This pattern of results is suggestive of a differential effect of game genre on the neural indices of proactive control. More work is needed to gain a clearer understanding of the influence of game genre on proactive and reactive control.

N-Back Task

The N-back task was used to examine the influence of video game experience on working memory. It was hypothesized that video game experience, violent and nonviolent, would disrupt the maintenance of information in working memory. At the behavioral level, participants responded more quickly and accurately in the 1-back condition than the 3-back condition. Participants were less accurate, but faster to respond to targets than non-targets. These data reveal an effect of N-back load on task performance. Gamer status did not influence the behavioral data for the N-back task.

The ERP data revealed group differences before and after stimulus onset. There was a slow wave in the response-to-stimulus interval that distinguished 1-back from 3-back targets over the frontal and parietal regions of the scalp. The slow wave is related to maintenance in working memory (West et al., 2006). Between -300 and 0 ms prior to stimulus onset, the slow wave revealed an effect of working memory load that was more strongly expressed in the non-gamers and the nonviolent gamers, than in the violent gamers. These data are consistent with the findings of the Stroop task, where maintenance of control appears to be attenuated in violent gamers relative to non-gamers, and enhanced in nonviolent gamers, relative to non-gamers.

Following stimulus onset in the N-back task, there were two modulations of the ERPs that differentiated targets from non-targets, the P3 and the frontal negativity (West & Bowry, 2005). The P3 was greater for targets than non-targets for the violent gamers and the non-gamers, but not the nonviolent gamers. A slow negative-going wave was observed over the frontal region that differentiated targets from non-targets. The analysis of the frontal negativity revealed that the effect of target was only present for the nonviolent gamers. This may indicate recruitment of different neural generators for target processing in the nonviolent gamers, reflecting a difference in the use of proactive and reactive strategies to perform the task.

Whereas performance on the N-back task was similar for the three groups, differences in neural activity did emerge. One possible reason for this discrepancy is that target judgments in the N-back task may be performed on the basis of familiarity alone. In the current study, slightly more than one-third of the trials were targets, making this version of the task particularly easy to perform based on familiarity. Future studies could include lures, which should bias participants towards the use of recollection to perform the task (Braver et al., 2007). If violent gamers are using familiarity to perform the task and are unable to actually maintain the items in working memory, then their performance should be worse than the nonviolent gamers and non-gamers.

Integration: Cognitive Control

The findings from this study are consistent with the small amount of research indicating that experience with at least some types of video games may have a negative effect on cognitive control (Bailey et al., 2009; Kronenberger et al., 2005). The current study demonstrates differences in the use of proactive and reactive control related to experience with various video game genres. The current findings lead one to wonder what it is about first-person shooter and music video games that may bias individuals towards the differential use of proactive and reactive control.

The major characteristics of the video games related to changes in cognitive control are fast-paced, violent, and external motivation for the player (Boot et al., 2008; Green & Bavelier, 2007). In these games, the player is not required to endogenously maintain attention; instead the game directs the player’s attention toward relevant stimuli. This is not true of all violent games, or even all action video games. Some games within this genre do have intricate story lines that require the player to stop and make decisions that can have long-term consequences for their character’s success in the game. The games typically used for training visuospatial processing require the player to navigate an environment to kill enemies, reacting to the targets as they appear (Dye et al., 2009; Green & Bavelier, 2003; Li, Polat, Makous, & Bavelier, 2009). The characteristics of these games do not require the engagement of proactive cognitive control over a prolonged period. Therefore, it may not be surprising that violent gamers are less likely to use proactive control; they seldom practice it in their gaming worlds. In contrast, the video games played by the nonviolent gamers, such as Rock Band, Guitar Hero, and the Sims, may be more suited to the use of planning and sustained attention, i.e. proactive cognitive control. For example, Rock Band players are required to plan and execute motor sequences for multiple events over the course of several minutes. Rock Band and other games in this genre may actually encourage the use of proactive cognitive control by encouraging the ability to sustain attention over time. This hypothesis should be investigated in further individual difference studies and directly tested in training studies to verify the causal nature of the effect.

Affective Processing

Picture Rating Task

The effects of video games, particularly those containing violent content, on aggression are well-documented (Anderson, 2004; Anderson et al., 2007; Bartholow et al., 2005). The influence of video games on affective processing has only been examined in a few studies (e.g. Kirsh et al., 2006; Kirsh & Mounts, 2007). The current study used the picture rating task to examine emotion processing independent of the participants' intention. Based on the preliminary study, it was hypothesized that the violent gamers would process violent pictures similarly to positive pictures, and this would not be true for non-gamers. The nonviolent gamers were expected to be more similar to the non-gamers than the violent gamers.

Game experience did not affect the colorfulness ratings of the pictures. Slower response times to rate violent pictures indicated a negativity bias. The parietal and frontal slow waves were also not influenced by gamer status, although there was clearly a negativity bias present over both regions of the scalp. The presence of the negativity bias replicates some past research on affective picture processing (Ito et al., 1998). These findings do not appear to be consistent with Bartholow et al. (2006) where there was a reduction in the amplitude of the P3 for violent images in violent gamers. Differences in the design of the current study and Bartholow et al. may account for the inconsistent findings. Participants in Bartholow et al. viewed the same negative and violent pictures multiple times. This has been shown to result in habituation to the stimuli (Codispoti et al., 2007). Bartholow et al.'s findings may actually indicate that violent gamers habituate to violent images more quickly than non-gamers, which would not be inconsistent with the data of the current study. In fact, this could be viewed as a type of desensitization.

As with the preliminary study, the data were analyzed with PLS, and this did reveal some differences between the groups. With all three groups in the analysis, the first LV reflected the negativity bias, while the second LV represented processing affect in general. These processes appeared similar in the three groups. When the non-gamers and violent gamers were analyzed, the second LV revealed that violent pictures appear to take on a positive valence for the violent gamers, and this was not true for the non-gamers. This replicates the findings of the preliminary study (Bailey et al., 2009).

Emotion Search Task

The emotion search task offers the opportunity to examine the influence of video game experience on the detection of threat. It was hypothesized that nonviolent and non-gamers would perform similarly on this task. Violent gamers were expected to be desensitized to the threatening faces, resulting in worse performance for angry face displays, or to be hypersensitized to find threatening faces, resulting in better performance for angry face displays relative to happy and neutral face displays (Kirsch & Mounts, 2007). In the emotion search task, gamers and non-gamers demonstrated a negativity bias (Fox et al., 2000; Mather & Knight, 2006) that reflected faster responding when an angry face was in the display. The violent and nonviolent gamers were also more accurate when an angry face was in the dispay, but the non-gamers were not. These findings do not appear to be consistent with Kirsh and Mounts who found a happy face advantage in non-gamers that was reduced in the gamers, or with research demonstrating the presence of a happy face advantage (Leppanen et al., 2003). The results of the current study are more consistent with the presence of a negativity bias in all three groups (Cacioppo & Bernston, 1994).

The ERP data revealed that the P3 was larger for happy and angry face displays than neutral face displays in all three groups. This does not indicate desensitization or habituation to threatening faces in the violent gamers (Bartholow et al., 2006). The PLS analysis for the emotion search data was more telling. One of the latent variables revealed a negativity bias for the non-gamers and the nonviolent gamers, differentiating the neural responses to angry faces from happy and neutral faces. In contrast, for the violent gamers this latent variable distinguished happy faces from angry and neutral faces. This effect does not simply indicate desensitization, but a reversal of the sensitivity to emotional faces. These data converge with the picture rating data in Bailey et al. (2009). The absence of a negativity bias in the ERP data for violent gamers on this task may indicate a fundamental change in the processing of emotionally valenced social information.

Integration: Affective Processing

Past research has demonstrated a relationship between video game experience and increased aggression (Anderson, 2004), desensitization (Bartholow et al., 2006), and affective face processing (Kirsh & Mounts, 2007). The current study demonstrated that violent video game experience may alter the processing of positive and violent information, suggesting a broader effect on affective processing than merely desensitization to violence or increased aggression. Experience with violent video game genres appears to be associated with a fundamental shift in the processing of violent or threatening and positive information, wherein violent stimuli come to have a positive valence. Players are rewarded for effectively responding to violent stimuli (e.g. killing an enemy) and through reinforcement learning may come to view violence as positive. Future studies will need to examine whether there is a causal relationship or an interaction between playing video games and this shift through training studies.

Visuospatial Processing

Enumeration Task

For the enumeration task, it was hypothesized that the violent gamers would have a greater span of apprehension than the non-gamers and nonviolent gamers. At the behavioral level, response time increased and accuracy decreased as the display size increased. There were no group differences, suggesting that the violent gamers did not have a greater span of apprehension. These findings are not consistent with past research (e.g. Green & Bavelier, 2003) and one possible explanation for the discrepancy is discussed in the limitation section.

The amplitude of the P3 was sensitive to gamer status in the enumeration task. The P3 was larger for small displays than medium and large displays for the nonviolent gamers and the non-gamers. In contrast, there was no effect of display size on the amplitude of the P3 for the violent gamers. This may indicate that the medium and large displays place greater processing demands on the non-gamers and nonviolent gamers than on the violent gamers. This finding would be consistent with the research of Green and colleagues (2003, 2006, in press).

The results of the PLS analysis were counter to Green and Bavelier's (2006) interpretation of the basis of the difference between gamers and non-gamers on the enumeration task. Based on a series of experiments, Green and Bavelier proposed that the gamers were faster at counting rather than subitizing. The PLS analysis of the data, however, leads to the conclusion that the neural correlates of counting were similar in the three groups while neural activity related to subitizing differs between groups. Initially, Green and Bavelier (2003) interpreted action gamers' performance on the enumeration task to be more efficient subitizing and later found evidence for more effective counting (Green & Bavelier, 2007). Based on the current and existing findings, the source of the improved performance on the enumeration task for violent action gamers may require further investigation.

VSTM Task

For the VSTM task, it was hypothesized that the violent gamers would have greater visual short-term memory capacity. At the behavioral level, the violent gamers were faster to respond to same 5-square displays, but no other group differences in response time or accuracy were found. The ERP data revealed a slow wave over the frontal-cental region of the scalp that differentiated 3 and 5-square displays from 1-square displays for the violent gamers. Display sizes did not differ for the other two groups, indicating that visual short-term memory capacity may be greater for the violent gamers than the nonviolent gamers and the non-gamers (Awh et al., 2007; Vogel & Machizawa, 2004). These results converge with the findings from the enumeration task. A limited number of studies have examined differences in memory in gamers and non-gamers (Boot et al., 2008), so the results of the VSTM task provide novel information about individual differences in gaming experience. The differences between the two groups of gamers also suggests that violent action games in particular may lead to differences in visual short-term memory capacity.

Integration: Visuospatial Processing

The ERP results of the current study indicate that playing violent action video games may be associated with a greater span of apprehension and greater visual short-term memory capacity. Experience with other genres of video games, in this case games like Rock Back and the Sims, does not appear to be associated with the same benefits to visuospatial processing. The relationship between video game experience and performance on the enumeration task has been studied previously (Green & Bavelier, 2003, 2007), but some question remains as to the locus of the gamers' better performance. Some new work may indicate that gamers' make more efficient use of evidence when making perceptual decisions (Green, 2009). The findings of the current study support this idea as the ERP data indicates that the enumeration task is less process demanding for the violent gamers. The latent variable related to subitizing was stronger in the non-gamers and nonviolent gamers suggesting that process required more neural activity.

The current study is one of the first to examine visual memory capacity, so further research using the VSTM task and other visual memory tasks will be necessary to support the effects reported here. The use of these tasks in training studies will also be necessary to assess the causal nature of the relationship between video game experience and visual short-term memory capacity. The findings of the current study may indicate greater capacity for the violent gamers, which converges with past research indicating that experience with violent action video games has a positive impact on visual processing (Dye et al., 2009; Green & Bavelier, 2003).

Limitations

There are three limitations of the current study worth noting. First, the sample size may not have been sufficient to find behavioral differences between the groups. This may be particularly true for effects that are typically small, such as the CAE. Related to the issue of sample size is the influence of splitting the gamers based on game genre. This has the potential to weaken the effects of the study, but is also a strength of the study because it can reveal differences that would not otherwise be found. Other individual difference studies have not typically separated gamers into violent and nonviolent genres, making the findings of the current study unique. The results reported here demonstrate that there are differences in brain activity between nonviolent and violent gamers. By splitting the groups, the current study may have weakened some of the effects found in past research, but also reveals the importance of understanding the effects of different video game genres.

Second, the failure to replicate the work of Green and Bavelier (2003, 2006, 2007) on the enumeration task may have resulted from the difference in display characteristics of LCD and CRT monitors. The refresh characteristics of the LCD monitor used in this study may have made the timing of the task relatively easy compared to using a CRT monitor. This explanation appears to be supported by the high accuracy across display sizes. Display timing is a relatively simple problem for future studies to address.

Finally, the correlational nature of this study is worth noting. It may be that differences described here are a result of variables other than video game experience per se. Training studies are necessary to determine a causal relationship, and future research should focus on this area. Currently, a training study is being conducted using the first-person shooter game Unreal Tournament and Tetris. Participants are pre and post-tested on the 6 tasks used in the current study. Future research should also expand the types of gamers used for training in order to further assess potential differences between different game genres. Visuospatial processing appears to be mainly influenced by first-person shooter games (Dye et al., 2009), while strategy games may improve cognitive control. The differences found in the current study, indicate that nonviolent games like Rock Band may also encourage the use of proactive cognitive control, while the violent first-person shooters negatively influence this form of cognitive control. These subtle, but important, differences in game genres need to be fleshed out in future studies.

Conclusions

The current study investigated the influence of violent and nonviolent video game experience on cognitive control, affective processing, and visuospatial processing. The findings presented here expand our knowledge of the effects of video games by demonstrating that the costs and benefits previously found in different samples of gamers can be observed in a single sample. The addition of exploring a new task in each of the three domains demonstrates that the effects of playing video games are not limited to a narrow set of task demands. Converging with past research, the current investigation reveals that experience with violent action video games was associated with enhanced visuospatial processing (Green & Bavelier, 2003; Li et al., 2009). Violent video game experience was also associated with a negative influence on the use of proactive cognitive control and the processing of affective information (Bailey et al., in press; Mathews et al., 2005). Nonviolent gamers, a previously unexplored group, may actually have better use of proactive control without the costs to affective processing, and without the gains to visuospatial processing. These findings highlight the need to understand the unique influences of different video game genres, especially if these games are to be incorporated into training regimes.

Appendix A. Questionnaires

MEDIA USAGE QUESTIONNAIRE

On a typical school day (Monday through Friday), for how many hours do you play video games during each of the following times? (Fill in “10” to represent zero.)

1. 6 AM - Noon
2. Noon - 6 PM
3. 6 PM - Midnight
4. Midnight - 6 AM

On a typical weekend day (Saturday or Sunday), for how many hours do you play video games during each of the following times? (Fill in “10” to represent zero.)

5. 6 AM - Noon
6. Noon - 6 PM
7. 6 PM - Midnight
8. Midnight - 6 AM

How often have you played the following video games? Count any video game in the series, where applicable. Please give an answer from 1 to 5 for these questions (from “1” indicating you have never played it to “5” indicating you play it very often).

9. Half-Life
10. Grand Theft Auto
11. Halo
12. Resident Evil
13. Unreal Tournament
14. World of Warcraft or any other Massively Multiplayer Online Roleplaying Game, such as Guild Wars
15. Madden NFL
16. Tony Hawk
17. The Sims
18. Rock Band/Guitar Hero
19. Wii Sports
20. What video game do you play most often? ___________________

Edinburgh Brief Handedness Inventory

Have you ever had any tendency to left-handedness? YES NO

Please indicate your preferences in the use of hands in the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand unless absolutely forced to, put ++. If in any case you are really indifferent, put + in both columns.

Some of the activities require both hands. In these cases, the part of the task or object, for which hand-preferences is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank if you have no experience at all with the object or task.

	Right	**Left**
1. Writing	________	________
2. Drawing	________	________
3. Throwing	________	________
4. Scissors	________	________
5. Toothbrush	________	________
6. Knife (without fork)	________	________
7. Spoon	________	________
8. Broom (upper hand)	________	________
9. Striking Match (match)	________	________
10. Opening Box	________	________

Behavior Inhibition System/Behavior Activation System Scale

Each item of this questionnaire is a statement that a person may either agree with or disagree with. For each item, indicate how much you agree or disagree with what the item says. Please respond to all the items; do not leave any blank. Choose only one response to each statement. Please be as accurate and honest as you can be. Respond to each item as if it were the only item. That is, don't worry about being "consistent" in your responses. Choose from the following four response options:

1 = very true for me
2 = somewhat true for me
3 = somewhat false for me
4 = very false for me

______ A person's family is the most important thing in life.
______ Even if something bad is about to happen to me, I rarely experience fear or nervousness.
______ I go out of my way to get things I want.
______ When I'm doing well at something I love to keep at it.
______ I'm always willing to try something new if I think it will be fun.
______ How I dress is important to me.
______ When I get something I want, I feel excited and energized.
______ Criticism or scolding hurts me quite a bit.
______ When I want something I usually go all-out to get it.
______ I will often do things for no other reason than that they might be fun.
______ It's hard for me to find the time to do things such as get a haircut.
______ If I see a chance to get something I want I move on it right away.
______ I feel pretty worried or upset when I think or know somebody is angry at me.
______ When I see an opportunity for something I like I get excited right away.
______ I often act on the spur of the moment.
______ If I think something unpleasant is going to happen I usually get pretty "worked up."
______ I often wonder why people act the way they do.
______ When good things happen to me, it affects me strongly.
______ I feel worried when I think I have done poorly at something important.
______ I crave excitement and new sensations.
______ When I go after something I use a "no holds barred" approach.
______ I have very few fears compared to my friends.
______ It would excite me to win a contest.
______ I worry about making mistakes.

Buss-Perry

Please rate each of the following items in terms of how characteristic they are of you. Use the following scale for answering these items.

1	2	3	4	5	6	7
extremely uncharacteristic of me						extremely characteristic of me

1) Once in a while I can't control the urge to strike another person.
2) Given enough provocation, I may hit another person.
3) If somebody hits me, I hit back.
4) I get into fights a little more than the average person.
5) If I have to resort to violence to protect my rights, I will.
6) There are people who pushed me so far that we came to blows.
7) I can think of no good reason for ever hitting a person.
8) I have threatened people I know.
9) I have become so mad that I have broken things.
10) I tell my friends openly when I disagree with them.
11) I often find myself disagreeing with people.
12) When people annoy me, I may tell them what I think of them.
13) I can't help getting into arguments when people disagree with me.
14) My friends say that I'm somewhat argumentative.
15) I flare up quickly but get over it quickly.
16) When frustrated, I let my irritation show.
17) I sometimes feel like a powder keg ready to explode.
18) I am an even-tempered person.
19) Some of my friends think I'm a hothead.
20) Sometimes I fly off the handle for no good reason.
21) I have trouble controlling my temper.
22) I am sometimes eaten up with jealousy.
23) At times I feel I have gotten a raw deal out of life.
24) Other people always seem to get the breaks.
25) I wonder why sometimes I feel so bitter about things.
26) I know that "friends" talk about me behind my back.
27) I am suspicious of overly friendly strangers.

29) When people are especially nice, I wonder what they want.

Appendix B. Results Tables

Table 1B. Mean response time (ms) and accuracy for the Stroop task.

Response time		Congruent	Incongruent
Non-Gamers			
	M	850	968
	SE	47	49
Violent Gamers			
	M	828	961
	SE	47	49
Nonviolent Gamers			
	M	813	913
	SE	47	49

Response Accuracy		Congruent	Incongruent
Non-Gamers			
	M	.98	.95
	SE	.01	.01
Violent Gamers			
	M	.98	.96
	SE	.01	.01
Nonviolent Gamers			
	M	.99	.96
	SE	.01	.01

Table 2B. Conflict Adaptation Effect for the Stroop task.

Response time (ms)			
		Congruent	Incongruent
Non-Gamers			
Congruent	M	859	1009
	SE	53	56
Incongruent	M	873	982
	SE	51	54
Violent Gamers			
Congruent	M	849	980
	SE	53	56
Incongruent	M	859	983
	SE	51	54
Nonviolent Gamers			
Congruent	M	832	933
	SE	53	56
Incongruent	M	820	943
	SE	51	54

Table 3B. Mean amplitude (µV) of the conflict SP.

		Parietal-Occipital			Occipital		
		Left	Midline	Right	Left	Midline	Right
Non-Gamers							
Congruent	M	2.19	2.32	2.45	1.95	1.73	1.92
	SE	.51	.52	.51	.63	.63	.69
Incongruent	M	2.93	2.77	3.01	2.86	2.31	2.41
	SE	.52	.49	.54	.69	.63	.61
Violent Gamers							
Congruent	M	2.27	3.22	3.15	1.71	1.65	2.19
	SE	.51	.52	.51	.63	.63	.69
Incongruent	M	3.54	4.43	4.39	2.74	3.51	3.83
	SE	.52	.49	.54	.69	.63	.61
Nonviolent Gamers							
Congruent	M	1.57	1.12	1.08	.83	.46	.32
	SE	.51	.52	.51	.63	.63	.69
Incongruent	M	1.99	1.86	2.27	1.29	1.34	1.51
	SE	.52	.49	.54	.69	.63	.61

Table 4B. Mean amplitude (µV) of the MFN.

		350-400 ms		425-475 ms	
		Congruent	Incongruent	Congruent	Incongruent
Non-Gamers					
Frontal-central	M	-1.99	-2.89	-1.82	-2.14
	SE	.66	.76	.57	.64
Central	M	-.34	-1.19	-.26	-.65
	SE	.57	.63	.56	.59
Central-parietal	M	1.95	1.23	2.08	1.59
	SE	.58	.61	.55	.59
Violent Gamers					
Frontal-central	M	-1.88	-2.14	-1.06	-1.80
	SE	.66	.76	.57	.64
Central	M	-.65	-.61	.02	-.55
	SE	.57	.63	.56	.59
Central-parietal	M	1.23	1.57	1.53	1.35
	SE	.58	.61	.55	.59
Nonviolent Gamers					
Frontal-central	M	-1.69	-2.29	-1.57	-1.67
	SE	.66	.76	.57	.64
Central	M	-.09	-.41	-.07	-.07
	SE	.57	.63	.56	.59
Central-parietal	M	2.30	1.83	2.16	1.83
	SE	.58	.61	.55	.59

Table 5B. Mean amplitude (µV) of the FSW.

		FT9	F9	F7	F5	Fc5
Non-Gamers						
Congruent	M	-1.41	-1.62	-1.36	-1.91	-1.15
	SE	.72	.50	.55	.53	.57
Incongruent	M	-2.03	-1.94	-1.93	-2.49	-1.85
	SE	.86	.50	.55	.63	.54
Violent Gamers						
Congruent	M	-3.86	-2.38	-2.81	-2.59	-2.43
	SE	.72	.50	.55	.53	.57
Incongruent	M	-4.38	-3.36	-2.87	-2.70	-3.07
	SE	.86	.50	.55	.63	.54
Nonviolent Gamers						
Congruent	M	-1.58	-.73	-.69	-.70	-.14
	SE	.72	.50	.55	.53	.57
Incongruent	M	-2.70	-1.88	-2.02	-1.41	-1.44
	SE	.86	.50	.55	.63	.54

Table 6B. Mean response time (ms) and accuracy for the N-back task.

Response time		1-back	3-back
Non-Gamers			
Target	M	577	1348
	SE	26	119
Nontarget	M	790	1496
	SE	56	132
Violent Gamers			
Target	M	541	1248
	SE	26	119
Nontarget	M	723	1576
	SE	56	132
Nonviolent Gamers			
Target	M	584	1379
	SE	26	119
Nontarget	M	778	1573
	SE	56	132

Response Accuracy		1-back	3-back
Non-Gamers			
Target	M	.95	.66
	SE	.01	.04
Nontarget	M	.97	.83
	SE	.01	.03
Violent Gamers			
Target	M	.96	.74
	SE	.01	.04
Nontarget	M	.97	.87
	SE	.01	.03
Nonviolent Gamers			
Target	M	.96	.72
	SE	.01	.04
Nontarget	M	.97	.80
	SE	.01	.03

Table 7B. Mean amplitude (μV) of the parietal slow wave in the pre-stimulus data for the N-back task.

		Left	Midline	Right
Non-Gamers				
1-back	M	-3.45	-3.27	-3.42
	SE	.66	.62	.70
3-back	M	-1.39	-1.15	-1.03
	SE	.50	.51	.58
Violent Gamers				
1-back	M	-3.55	-3.56	-3.15
	SE	.66	.62	.70
3-back	M	-1.65	-1.59	-1.94
	SE	.50	.51	.58
Nonviolent Gamers				
1-back	M	-3.75	-3.86	-4.16
	SE	.66	.62	.70
3-back	M	-.30	-.09	-.01
	SE	.50	.51	.58

Table 8B. Mean amplitude (μV) of the frontal slow wave in the pre-stimulus data for the N-back task.

		Left	Right
Non-Gamers			
1-back	M	2.01	2.03
	SE	.64	.63
3-back	M	.60	-.51
	SE	.72	.69
Violent Gamers			
1-back	M	1.96	2.59
	SE	.64	.63
3-back	M	.56	2.23
	SE	.72	.69
Nonviolent Gamers			
1-back	M	2.85	3.30
	SE	.64	.63
3-back	M	-.89	-.06
	SE	.72	.69

Table 9B. Mean amplitude (μV) of the P3 in the stimulus data for the N-back task.

		1-back		3-back	
		Target	Non-target	Target	Non-target
Non-Gamers					
Parietal-occipital					
Left	M	5.75	3.79	4.23	2.78
	SE	.77	.58	.68	.76
Midline	M	6.29	3.49	4.47	2.23
	SE	.70	.58	.62	.68
Right	M	5.16	2.94	4.28	2.86
	SE	.76	.62	.64	.76
Occipital					
Left	M	4.75	3.36	3.90	2.69
	SE	.92	.77	.97	1.24
Midline	M	4.13	2.47	3.41	1.66
	SE	.75	.58	.68	.87
Right	M	3.88	2.18	3.15	2.22
	SE	.79	.64	.74	.80
Violent Gamers					
Parietal-occipital					
Left	M	5.79	4.23	4.31	3.83
	SE	.77	.58	.68	.76
Midline	M	6.06	4.17	4.20	3.09
	SE	.70	.58	.62	.68
Right	M	5.97	4.54	4.55	3.94
	SE	.76	.62	.64	.76
Occipital					
Left	M	5.47	4.25	3.75	2.10
	SE	.92	.77	.97	1.24
Midline	M	4.96	3.96	3.95	2.79
	SE	.75	.58	.68	.87
Right	M	5.31	4.43	4.23	3.76
	SE	.79	.64	.74	.80
Nonviolent Gamers					
Parietal-occipital					
Left	M	4.85	3.60	3.17	3.63
	SE	.77	.58	.68	.76
Midline	M	4.84	3.31	2.94	3.62
	SE	.70	.58	.62	.68
Right	M	5.47	4.12	3.62	4.16
	SE	.76	.62	.64	.76
Occipital					
Left	M	3.40	3.77	2.18	3.93
	SE	.92	.77	.97	1.24

		1-back		3-back	
		Target	Non-target	Target	Non-target
Midline	M	3.34	2.88	2.15	3.03
	SE	.75	.58	.68	.87
Right	M	3.39	2.95	1.97	3.48
	SE	.79	.64	.74	.80

Table 10B. Mean amplitude (μV) of the frontal negativity in the stimulus data for the N-back task.

		1-back		3-back	
		Target	Non-target	Target	Non-target
Non-Gamers					
Left	M	-2.30	-1.67	-1.34	-.98
	SE	.62	.52	.64	.65
Midline	M	-2.52	-2.07	-1.67	-.83
	SE	.63	.58	.62	.75
Right	M	-2.56	-1.86	-1.31	-1.17
	SE	.64	.53	.70	.61
Violent Gamers					
Left	M	-3.16	-2.76	-2.10	-1.86
	SE	.62	.52	.64	.65
Midline	M	-3.16	-2.94	-2.33	-2.33
	SE	.63	.58	.62	.75
Right	M	-2.94	-2.70	-1.58	-1.64
	SE	.64	.53	.70	.61
Nonviolent Gamers					
Left	M	-2.36	-2.20	-.07	-1.64
	SE	.62	.52	.64	.65
Midline	M	-1.87	-1.70	-.25	-1.81
	SE	.63	.58	.62	.75
Right	M	-1.88	-1.68	-.33	-2.20
	SE	.64	.53	.70	.61

Table 11B. Mean response time (ms) and ratings for the Picture Rating task.

Response time		Neutral	Negative	Violent	Positive
Non-Gamers					
	M	1634	1831	1819	1600
	SE	144	179	200	141
Violent Gamers					
	M	1791	2056	2153	1795
	SE	144	179	200	141
Nonviolent Gamers					
	M	1616	1985	2010	1506
	SE	144	179	200	141

Colorfulness Ratings		Neutral	Negative	Violent	Positive
Non-Gamers					
	M	2.53	2.31	2.38	2.99
	SE	.06	.09	.09	.08
Violent Gamers					
	M	2.58	2.38	2.41	2.91
	SE	.06	.09	.09	.08
Nonviolent Gamers					
	M	2.57	2.27	2.37	2.95
	SE	.06	.09	.09	.08

Table 12B. Mean amplitude (µV) of the PSW for the Picture Rating task.

		Neutral	Negative	Violent	Positive
Non-Gamers					
Left	M	9.09	9.55	9.62	9.06
	SE	1.11	1.07	1.26	1.16
Midline	M	6.56	6.76	7.06	6.44
	SE	1.03	1.18	1.24	1.11
Right	M	9.01	9.67	9.87	8.41
	SE	1.41	1.52	1.40	1.33
Violent Gamers					
Left	M	7.87	8.20	8.59	7.91
	SE	1.11	1.07	1.26	1.16
Midline	M	6.64	6.93	7.26	6.72
	SE	1.03	1.18	1.24	1.11
Right	M	9.20	9.66	9.38	8.85
	SE	1.41	1.52	1.40	1.33
Nonviolent Gamers					
Left	M	8.59	10.52	9.13	8.32
	SE	1.11	1.07	1.26	1.16
Midline	M	6.50	8.35	7.60	6.53
	SE	1.03	1.18	1.24	1.11
Right	M	11.51	13.21	11.74	10.34
	SE	1.41	1.52	1.40	1.33

Table 13B. Mean amplitude (μV) of the frontal slow wave for the Picture Rating task.

		Neutral	Negative	Violent	Positive
Non-Gamers					
F7	M	-6.15	-7.68	-7.49	-5.52
	SE	1.20	1.30	1.08	1.25
F5	M	-5.60	-6.61	-6.13	-5.12
	SE	1.05	1.08	1.09	1.11
F6	M	-5.93	-5.75	-5.85	-5.39
	SE	1.13	1.24	1.34	1.20
F8	M	-5.94	-6.05	-6.38	-6.00
	SE	1.05	1.08	1.24	1.05
Violent Gamers					
F7	M	-5.12	-7.94	-6.21	-6.68
	SE	1.20	1.30	1.08	1.25
F5	M	-5.30	-6.88	-5.70	-5.86
	SE	1.05	1.08	1.09	1.11
F6	M	-5.77	-6.15	-7.02	-5.84
	SE	1.13	1.24	1.34	1.20
F8	M	-5.30	-6.22	-7.19	-5.94
	SE	1.05	1.08	1.24	1.05
Nonviolent Gamers					
F7	M	-6.04	-7.18	-6.29	-7.29
	SE	1.20	1.30	1.08	1.25
F5	M	-6.29	-7.24	-5.58	-6.86
	SE	1.05	1.08	1.09	1.11
F6	M	-5.14	-6.43	-6.37	-5.19
	SE	1.13	1.24	1.34	1.20
F8	M	-5.00	-7.21	-6.87	-4.89
	SE	1.05	1.08	1.24	1.05

Table 14B. Mean response time (ms) and accuracy for the Emotion Search task.

Response time		Happy	Angry	Neutral
Non-Gamers				
	M	968	935	1150
	SE	61	49	87
Violent Gamers				
	M	890	808	1130
	SE	61	49	87
Nonviolent Gamers				
	M	941	858	1179
	SE	61	49	87
Response Accuracy		**Happy**	**Angry**	**Neutral**
Non-Gamers				
	M	.87	.92	.97
	SE	.02	.02	.02
Violent Gamers				
	M	.90	.95	.92
	SE	.02	.02	.02
Nonviolent Gamers				
	M	.92	.95	.95
	SE	.02	.02	.02

Table 15B. Mean amplitude (µV) of the P3 in the Emotion Search task.

		Left	Midline	Right
Non-Gamers				
Angry	M	1.80	1.44	2.56
	SE	.59	.70	.72
Happy	M	1.32	.57	2.08
	SE	.55	.66	.69
Neutral	M	1.14	.09	1.47
	SE	.47	.46	.49
Violent Gamers				
Angry	M	1.87	1.71	2.78
	SE	.59	.70	.72
Happy	M	1.96	1.97	3.09
	SE	.55	.66	.69
Neutral	M	1.34	.48	1.32
	SE	.47	.46	.49
Nonviolent Gamers				
Angry	M	1.24	1.00	2.42
	SE	.59	.70	.72
Happy	M	1.50	.71	2.10
	SE	.55	.66	.69
Neutral	M	.47	-.82	.86
	SE	.47	.46	.49

Table 16B. Mean amplitude (µV) of the P3 for the Enumeration task.

			Central-parietal			Parietal		
			Left	Midline	Right	Left	Midline	Right
Non-Gamers								
	Small	M	4.80	5.44	5.18	4.80	6.37	5.63
		SE	.74	.95	.75	.68	.86	.77
	Medium	M	2.54	3.00	2.69	2.93	4.13	3.00
		SE	.64	.89	.69	.60	.78	.70
	Large	M	2.34	2.78	2.90	2.86	4.56	4.00
		SE	.74	.99	.70	.72	.83	.77
Violent Gamers								
	Small	M	3.68	3.30	4.31	4.51	5.46	5.12
		SE	.74	.95	.75	.68	.86	.77
	Medium	M	2.90	2.33	3.25	3.59	4.46	3.93
		SE	.64	.89	.69	.60	.78	.70
	Large	M	2.60	2.41	2.75	3.22	4.38	3.27
		SE	.74	.99	.70	.72	.83	.77
Nonviolent Gamers								
	Small	M	3.58	4.27	3.81	3.40	4.41	3.47
		SE	.74	.95	.75	.68	.86	.77
	Medium	M	2.25	2.86	2.46	2.22	3.56	2.70
		SE	.64	.89	.69	.60	.78	.70
	Large	M	1.51	1.96	1.88	1.77	3.21	2.54
		SE	.74	.99	.70	.72	.83	.77

Table 17B. Mean response time (ms) and accuracy for the VSTM task.

Response time

			1-Square		3-Square		5-Square	
			Left	Right	Left	Right	Left	Right
Non-Gamers								
	Same	M	647	688	703	771	774	787
		SE	45	46	51	52	53	60
	Different	M	737	764	795	786	856	872
		SE	39	46	36	42	42	53
Violent Gamers								
	Same	M	611	653	683	691	734	819
		SE	45	46	51	52	53	60
	Different	M	627	682	700	768	814	833
		SE	39	46	36	42	42	53
Nonviolent Gamers								
	Same	M	653	643	743	817	837	848
		SE	45	46	51	52	53	60
	Different	M	672	705	750	815	834	947
		SE	39	46	36	42	42	53

Response Accuracy

			1-Square		3-Square		5-Square	
			Left	Right	Left	Right	Left	Right
Non-Gamers								
	Same	M	.97	.94	.91	.94	.92	.91
		SE	.01	.02	.01	.01	.02	.02
	Different	M	.97	.94	.84	.86	.66	.65
		SE	.01	.02	.03	.03	.04	.05
Violent Gamers								
	Same	M	.95	.94	.89	.94	.90	.91
		SE	.01	.02	.01	.01	.02	.02
	Different	M	.96	.98	.85	.88	.73	.65
		SE	.01	.02	.03	.03	.04	.05
Nonviolent Gamers								
	Same	M	.96	.96	.93	.94	.92	.91
		SE	.01	.02	.01	.01	.02	.02
	Different	M	.97	.93	.86	.88	.75	.71
		SE	.01	.02	.03	.03	.04	.05

Table 18B. Mean amplitude (μV) of the frontal-central effect in the VSTM task.

		1-Square	3-Square	5-Square
Non-Gamers				
	M	-.08	.42	.36
	SE	.69	.68	.60
Violent Gamers				
	M	-.35	1.25	1.22
	SE	.69	.68	.60
Nonviolent Gamers				
	M	-.04	-.53	-.60
	SE	.69	.68	.60

Table 19B. Mean amplitude (µV) of the central-parietal effect in the VSTM task.

		1-Square	3-Square	5-Square
Non-Gamers				
	M	-.66	-.40	.28
	SE	.54	.68	.65
Violent Gamers				
	M	-.29	.85	1.05
	SE	.54	.68	.65
Nonviolent Gamers				
	M	-.62	.05	-.08
	SE	.54	.68	.65

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