Psychophysiology, ▮▮▮ (2009), 1–9. Wiley Periodicals, Inc. Printed in the USA.

DOI: 10.1111/j.1469-8986.2009.00925.x

A negative association between video game experience and proactive cognitive control

Print version citation: Bailey, K., West, R., & Anderson, C. A. (2010). A negative association between video game experience and proactive cognitive control. Psychophysiology,47, 34-42.

KIRA BAILEY, ROBERT WEST, AND CRAIG A. ANDERSON
Department of Psychology, Iowa State University, Ames, Iowa, USA

Abstract

Some evidence demonstrates that video game experience has a beneficial effect on visuospatial cognition. In contrast, other evidence indicates that video game experience may be negatively related to cognitive control. In this study we examined the specificity of the influence of video game experience on cognitive control. Participants with high and low video game experience performed the Stroop task while event-related brain potentials were recorded. The behavioral data revealed no difference between high and low gamers for the Stroop interference effect and a reduction in the conflict adaptation effect in high gamers. The amplitude of the medial frontal negativity and a frontal slow wave was attenuated in high gamers, and there was no effect of gaming status on the conflict slow potential. These data lead to the suggestion that video game experience has a negative influence on proactive, but not reactive, cognitive control.

Descriptors: Cognition, Individual differences, EEG/ERP

Video games represent a pervasive leisure activity beginning in middle childhood and continuing through adulthood. Population-based samples indicate that average gaming time ranges from 7 to 13 h per week in children and adolescents (Buchman & Funk, 1996; Gentile & Anderson, 2003), and this may underestimate the prevalence of use in some segments of the population. For instance, in the group of 18–33-year-old men from which the sample for the current study was selected, roughly 25% reported playing video games four or more hours a day. This high level of consumption highlights the importance of gaining a clearer understanding of the potential positive and negative influences of video game experience on cognition (Bioulac, Arfi, & Bouvard, 2008; Green & Bavelier, 2006).

Prior research demonstrates that video game experience has a beneficial effect on visuospatial cognition (Green & Bavelier, 2003, 2006). For instance, studies of individual differences reveal that video game experience may increase the efficiency of laparoscopic procedures in surgical residents (Rosser et al., 2007) and reduce gender differences in visuospatial attention (Feng, Spence, & Pratt, 2007). Additionally, training studies demonstrate that significant improvements in visuospatial cognition are observed with as little as 10 h of video game training (Feng et al., 2007; Green & Bavalier, 2003). These findings have led to the suggestion that video games may provide an effective therapeutic platform in individuals and groups that possess lower levels of visuospatial abilities (Belchior, 2007; Green & Bavalier, 2006).

In contrast to the beneficial effect of video game experience on visuospatial cognition, evidence from a small number of studies demonstrates that video game experience may be negatively related to cognitive control (i.e., the ability to maintain goal-directed information processing in the face of distraction or competing response alternatives). For instance, Swing (2008) reported a positive correlation between video game experience and a composite index of symptoms related to attention deficits and hyperactivity. Importantly, this correlation remained significant after controlling for the total level of exposure to other media including films and television, revealing a unique influence of video game experience on self-reported levels of attentional impairments. Consistent with this finding, two other studies have revealed a negative relationship between video game experience and behavioral and neural indices of cognitive control in the Stroop task. One study used the card version of the Stroop color-word task where individuals identify the color of a series of colored blocks or incongruent color-words (Kronenberger et al., 2005). Kronenberger et al. found a moderate positive correlation between the Stroop interference effect (i.e., the difference in response time between the color-word and color cards) and video game experience. A second study measured neural recruitment using functional magnetic resonance imaging (fMRI) while individuals performed the counting Stroop task (Mathews et al., 2005). In low gamers a typical pattern of neural recruitment was observed, that reflected greater activation of anterior cingulate and lateral frontal cortex for incongruent blocks of trials relative to neutral blocks of trials. In contrast, high gamers failed to activate these structures while performing incongruent trials.

Together, the findings of these three studies indicate that high levels of video game consumption may be associated with a reduction in the efficiency of those processes supporting cognitive control that arise from interactions between anterior cingulate and lateral frontal cortex (Botvinick, Braver, Barch, Carter, & Cohen, 2001). However, given the temporal characteristics of the tasks and recording procedures used in previous research, it is not

---

Address reprint requests to: Kira M. Bailey, Department of Psychology, W112 Lagomarcino Hall, Iowa State University, Ames, IA 50011, USA. E-mail: kmbailey@iastate.edu

known whether video game experience has a general influence on processes supporting cognitive control or whether there are differential effects of video game experience on specific aspects of cognitive control. The current study was designed to address this question within the context of the Dual Mechanisms of Cognitive Control Theory (Braver, Gray, & Burgess, 2007).

The Dual Mechanisms of Cognitive Control Theory holds that individuals can engage in either proactive or reactive modes of cognitive control depending upon environmental demands and individual differences (Braver et al., 2007). Proactive control represents a future-oriented form of regulation that serves to bias the information-processing system before the onset of a critical stimulus. In contrast, reactive control represents a just-in-time form of regulation that is implemented when conflict or ambiguity arises within the information processing system (Braver et al., 2007). Evidence from a number of studies indicates that proactive and reactive control may arise from interactions between anterior cingulate, lateral prefrontal cortex, and anterior prefrontal cortex (DePisapia & Braver, 2006; Paxton, Barch, Racine, & Braver, 2008; Speer, Jacoby, & Braver, 2003). As an example, one recent study used a proportion congruent manipulation with the Stroop task to distinguish the neural correlates of proactive and reactive cognitive control (Braver & Hoyer, 2006). The authors reasoned that reactive control would be utilized when the proportion of congruent trials was high and conflict was experienced on a limited number of incongruent trials, and that proactive control would be utilized when the proportion of incongruent trials was high and conflict was experienced on the majority of trials. Consistent with these predictions, sustained (i.e., across trials) activation was observed in ventrolateral prefrontal cortex in the mostly incongruent condition, and transient (i.e., within trial) activation was observed in the anterior cingulate and dorsolateral prefrontal cortex in the mostly congruent condition. These findings demonstrate that different modes of cognitive control can be observed within a single task in response to variation in task demands (Braver et al., 2007).

Overview of the Present Study

Action video games (i.e., first-person shooter, racing, etc.) require players to quickly and accurately respond to unexpected, rapidly changing stimuli. The structure of these games may, in part, explain the improvements seen in visuospatial attention associated with video game experience (Green & Bavelier, 2006). Action games also reinforce players for quickly modifying their behavior when conflict is experienced (i.e., an enemy is encountered), whereas the ability to maintain attention or cognitive control over the course of the game may not be as valuable for successful game play. This attribute of action video games leads to the suggestion that individual differences in video game experience may be associated with systematic variation in the deployment of proactive and reactive control, wherein high gamers are less likely to employ proactive control and more likely to employ reactive control.

To examine the relationship between video game experience and specific components of cognitive control, complementary behavioral and event-related brain potential (ERP) indices of proactive and reactive processes were measured during performance of the Stroop task in participants with limited or extensive video game experience. The conflict adaptation effect served as a behavioral index of proactive control (Botvinick et al., 2001; Botvinick, Cohen, & Carter, 2004). This effect represents the difference in response time for an incongruent trial when that trial is preceded by a congruent trial or an incongruent trial (i.e., response time for incongruent–incongruent trials is typically faster than response time for congruent–incongruent trials; Botvinick et al., 2001; Gratton, Coles, & Donchin, 1992). Computational and functional neuroimaging evidence demonstrates that the conflict adaptation effect results from the across-trial tuning of top-down control (Botvinick et al., 2001) that arises from interactions between the anterior cingulate and lateral frontal cortices (Kerns et al., 2004).

The Stroop interference effect served as a behavioral index of reactive control. The association of the interference effect with reactive control follows from the idea that response conflict may arise in the Stroop task when levels of task preparation or proactive control are suboptimal before stimulus onset, resulting in slower response time for incongruent trials relative to congruent trials (Braver et al., 2007; West & Alain, 2000; West & Baylis, 1998).

Three modulations of the ERPs were considered as neural indices of proactive and reactive cognitive control. The medial frontal negativity (MFN) and frontal slow wave served as indices of proactive control. The MFN represents a negativity over the frontal-central region of the scalp that may extend to the parietal region of the scalp and is typically maximal in amplitude between 400 and 500 ms after stimulus onset (Liotti, Waldorff, Perez, & Mayberg, 2000; McNeely, West, Christensen, & Alain, 2003; West & Alain, 2000). The MFN is associated with conflict detection in the Stroop task (West, Jakubek, Wymbs, Perry, & Moore, 2005) and may arise from the activity of neural generators in the anterior cingulate cortex (Liotti et al., 2000; West, 2003). The frontal slow wave represents a sustained modulation of the ERPs over the lateral frontal region of the scalp that appears to start around the time of the MFN and may be sustained for several hundred milliseconds after the response (West, 2007). The persistence of the frontal slow wave beyond the response for the current trial leads to the suggestion that this modulation of the ERPs is associated with between-trial adjustments of cognitive control rather than within-trial conflict resolution (West, 2007). Support for this general idea is found in a study examining the ERP correlates of error processing (West & Travers, 2008). In this study, slow wave activity was observed over the frontal region of the scalp following errors that persisted at least until the onset of the next stimulus. Importantly, the amplitude of the frontal slow wave correlated with post-error slowing of response time (West & Travers, 2008), indicating that it was related to behavioral indices of proactive control or conflict adaptation (Botvinick et al., 2001; Kerns et al., 2004).

The conflict slow potential (SP) served as an ERP index of reactive control. The conflict SP reflects greater positivity for incongruent trials than congruent trials over the parietal region of the scalp that is typically observed between 500 and 800 ms after stimulus onset (Liotti et al., 2000; West, 2003; West & Alain, 2000). This modulation of the ERPs may be superimposed on the descending portion of the P3 over the parietal region of the scalp that is typically similar in amplitude for congruent and incongruent trials (Duncan-Johnson & Kopell, 1981). Source modeling indicates that the conflict SP may arise from neural generators in the lateral frontal and posterior cortices (Hanslmayr et al., 2008; West, 2003). The amplitude of the conflict SP is positively correlated with response time and accuracy for incongruent trials, leading to the suggestion that it is associated with processes underlying conflict resolution or response selection (i.e., reactive control) within the current trial (West et al., 2005).

To consider the association between video game experience and proactive and reactive control, individuals high or low in video game experience performed a Stroop task while ERPs were recorded from the scalp. If there is a negative association between video game experience and proactive control, we expected that the conflict adaptation effect, MFN, and frontal slow wave would be attenuated in high gamers relative to low gamers. In contrast, if there is a positive association between video game experience and reactive control, we expected that the Stroop interference effect and the amplitude of the conflict SP might be reduced in high gamers relative to low gamers.

In the Stroop task we varied the response-to-stimulus interval (RSI) between blocks of trials. In the short RSI condition, there were 500 ms between the response for one trial and the onset of the stimulus for the next trial; in the long RSI condition this interval was 2000 ms. This manipulation allowed us to determine whether the influence of video game experience on proactive control resulted from the failure to recruit proactive control or from failure to maintain proactive control during the RSI (West & Schwarb, 2006). If video game experience is negatively associated with the initial recruitment of proactive control, then differences between high and low gamers in the conflict adaptation effect and frontal slow wave should be independent of RSI. In contrast, if video game experience is negatively associated with the ability to maintain proactive control over time, then differences between high and low gamers should be greater in the long RSI condition.

Method

Participants

Fifty-one men from Iowa State University between the ages of 18 and 33 years participated in the study. Participants were recruited based on their responses to a media usage questionnaire completed at least 2 weeks earlier as part of a large department-wide screening session. The sample included 26 low gamers ($M = 1.76$ hours per week, $SD = 4.75$) and 25 high gamers ($M = 43.4$ hours per week, $SD = 16.0$), $t(49) = 12.69$, $p < .001$. The high gamers ($M = 2.44$, $SD = 0.83$) reported more experience with action games than the low gamers ($M = 1.28$, $SD = 0.34$), $t(49) = 6.60$, $p < .001$. The high gamers ($M = 19.83$, $SD = 3.35$) and low gamers ($M = 19.67$, $SD = 1.27$) were similar in years of age and in their distribution of handedness (high gamers, right = 21, ambidextrous = 3, left = 1; low gamers, right = 19, ambidextrous = 5, left = 2; Oldfield, 1971).

Materials and Procedure

Media usage questionnaire. This questionnaire included three higher order questions. Two questions asked the individual to indicate the number of hours spent playing video games on a typical school day (Question 1, Monday through Friday) or weekend (Question 2, Saturday and Sunday) for each of four time periods (6 a.m. to noon, noon to 6 p.m., 6 p.m. to midnight, and midnight to 6 a.m.). The third question asked the participant to indicate how often he played any version of each of four popular action games (i.e., *Counterstrike*, *Grand Theft Auto*, *Resident Evil*, and *Unreal Tournament*) on a 5-point scale (1 = *have never played* to 5 = *play very often*). The questionnaire was completed twice, once as part of a department-level screening exercise that was used for recruitment and once at the end of our laboratory session. The internal reliability was high for the number of hours played (screening coefficient $\alpha = .86$, laboratory session coefficient $\alpha = .83$), and the test–retest reliability of this measure was acceptable ($r = .75$). The internal reliability was acceptable for the level of action game exposure (screening coefficient $\alpha = .70$, laboratory session coefficient $\alpha = .71$), as was the test–retest reliability of this measure ($r = .80$).

Stroop task. The stimuli for the Stroop task were congruent (e.g., RED in red) and incongruent (e.g., RED in blue) color-words (Stroop, 1935) or strings of four Xs that were presented in the colors red, blue, green, or yellow. Stimuli were displayed on a 17-in. LCD monitor on a black background in uppercase bold Arial 14 point font and were vertically and horizontally centered in the display. Stimuli measured 7 mm in height and 17–40 mm in width and subtended 0.40° and 0.97° to 2.29° of visual angle when viewed from 100 cm. During testing, a paper cover was placed over all but the response keys and the space bar. A colored square appeared on the cover above the relevant response key.

The Stroop task included three phases, keymapping, practice, and test. In the key mapping phase, participants practiced the color-to-key associations used in the task (red – V, blue – B, green – N, yellow – M). This phase included 40 trials (10 for each color). The practice phase consisted of 12 congruent and 12 incongruent trials. In the practice phase, participants were instructed to press the key mapped to the color of the stimuli. For the practice phase the RSI was 500 ms. The test phase consisted of four blocks of 96 trials. In each block there were 48 congruent and 48 incongruent stimuli. In two of the blocks the RSI was 500 ms; in the remaining blocks the RSI was 2000 ms. Participants performed the blocks with the same RSI consecutively. RSI was counterbalanced across participants. The task was programmed in EPrime 1.2 (Psychology Software Tools, Pittsburgh, PA).

Electrophysiological Recording and Analysis

The EEG (bandpass 0.02–150 Hz, digitized at 500 Hz, gain 1000, 16 bit A/D conversion) was recorded from an array of 68 tin electrodes based on an extended 10–20 system using an Electrocap (Electro-Cap International, Eaton, OH) that was interfaced to a DBPA-1 amplifier/digitizer (Sensorium Inc., Charlotte, VT). Vertical and horizontal eye movements were recorded from four electrodes placed on the face next to and below the eyes. During recording, all electrodes were referenced to electrode Cz. For analysis, the EEG were re-referenced to an average reference and a 0.1–20 Hz zero-phase-shift bandpass filter was applied. Ocular artifacts associated with blinks were corrected using a covariance-based technique implemented in the EMSE software (Source-Signal Imaging, San Diego, CA). The ERP epoch included -200 to 2000 ms of activity around stimulus onset. ERPs were averaged for trials associated with correct responses where response time was less than 5000 ms.

The amplitude of the MFN was measured as mean voltage between 375 and 425 ms after stimulus onset at electrodes Fz, FCz, CPz, and Pz. The selection of these electrodes was based on the distribution of the MFN reported in prior research (Liotti et al., 2000; McNeely et al., 2003; West & Alain, 2000). The amplitude of the conflict SP was measured as mean voltage between 600 and 800 ms after stimulus onset at electrodes PO3, POz, and PO4. These or similar electrodes have been used in previous studies to measure the conflict SP (Liotti et al., 2000; McNeely et al., 2003; West, 2003; West & Alain, 2000). The frontal slow wave was measured as mean voltage in three epochs (800–1000 ms, 1000–1500 ms, and 1500–2000 ms after stimulus onset) at electrodes F5, F6, F7, and F8 (West, 2007). Mean differences in ERP amplitude were evaluated using analysis of variance (ANOVA) with the Huynh–Feldt (Huynh & Feldt, 1976) corrected degrees of freedom when necessary.

Results

Behavioral Data

Reactive control. To examine the relationship between video game experience and reactive control, we compared the Stroop interference effect in the high and low gamers in a set of 2 (group) × 2 (congruency) × 2 (RSI) ANOVAs for response time and accuracy (Table 1). Response time was slower for incongruent trials, $M = 786$ ms, than for congruent trials, $M = 672$ ms, $F(1,49) = 171.19$, $p = .001$, $\eta_p^2 = .78$, revealing a significant interference effect. Response time was also slower in the long RSI condition, $M = 748$ ms, than in the short RSI condition, $M = 710$ ms, $F(1,49) = 7.59$, $p = .01$, $\eta_p^2 = .13$. The interference effect did not differ between low gamers, $M = 120$ ms, and high gamers, $M = 109$ ms, as the Group × Congruency interaction was not significant, $F < 1.00$, $\eta_p^2 = .01$.

Response accuracy was lower for incongruent trials, $M = .95$, than for congruent trials, $M = .97$, $F(1,49) = 29.01$, $p = .001$, $\eta_p^2 = .37$, revealing a significant interference effect. This interference effect did not differ between high gamers, $M = .01$, and low gamers, $M = .03$, as the Group × Congruency interaction was not significant, $F(1,49) = 1.20$, $p = .28$, $\eta_p^2 = .02$. These data reveal that there was not a significant relationship between video game experience and the Stroop interference effect for either response time or response accuracy and may be taken to indicate that reactive control was relatively insensitive to video game experience.

Proactive control. To examine the relationship between video game experience and proactive control, we compared the conflict adaptation effect (i.e., response time for incongruent–incongruent trials – congruent–incongruent trials that were nonrepetitions[1]) in high and low gamers for the short and long RSI conditions. In the short RSI condition the conflict adaptation effect did not differ between the low gamers, $M = 19$ ms, $SD = 88$ ms, and the high gamers, $M = 21$ ms, $SD = 94$ ms, $t(49) = -0.11$, $p = .91$. In the long RSI condition the conflict adaptation effect was larger in low gamers, $M = 26$ ms, $SD = 63$ ms, than in high gamers, $M = -14$ ms, $SD = 75$ ms, $t(49) = 2.10$, $p = .04$. These data may indicate that both low and high gamers are able to deploy proactive control in response to conflict, but that high gamers were unable to maintain control in the long RSI condition.

Table 1. *Mean Response Time and Response Accuracy for the Stroop Task in Low and High Gamers*

	Congruent	Incongruent
Response time		
Low gamers		
Short RSI		
M	635	757
SD	81	131
Long RSI		
M	677	796
SD	95	151
High gamers		
Short RSI		
M	668	779
SD	106	178
Long RSI		
M	707	814
SD	152	178
Response accuracy		
Low gamers		
Short RSI		
M	.97	.94
SD	.04	.05
Long RSI		
M	.98	.95
SD	.04	.05
High gamers		
Short RSI		
M	.98	.95
SD	.03	.04
Long RSI		
M	.98	.97
SD	.03	.04

ERP Data

The time course and topography of the MFN, frontal slow wave, and conflict SP are portrayed in Figures 1 and 2. The amplitude of the MFN was greatest around 400 ms after stimulus onset and extended from the frontal region to the parietal region of the scalp. Over the frontal and central regions the amplitude of the MFN appears to be attenuated in high gamers relative to low gamers; in contrast, over the central and parietal regions the amplitude of the MFN appeared to be similar in high and low gamers. The frontal slow wave began around 400 ms after stimulus onset and appeared to be more strongly expressed over the left hemisphere. In the low gamers the frontal slow wave persisted until at least 2000 ms after stimulus onset; in the high gamers the frontal slow wave was present between 500 and 1000 ms after stimulus onset and appeared to be attenuated or absent thereafter. The conflict SP was greatest in amplitude over the parietal region of the scalp between 600 and 800 ms after stimulus onset. The amplitude of the conflict SP appeared to be similar in low and high gamers.

Reactive control. The relationship between video game experience and the conflict SP was examined in a 2 (group) × 2 (congruency) × 2 (RSI) × 3 (electrode: PO3, POz, PO4) ANOVA. In this analysis the effect of congruency was significant, $F(1,49) = 46.86$, $p = .001$, $\eta_p^2 = .49$, reflecting greater positivity for incongruent trials, $M = 1.79$ µV, $SD = 1.80$, than for congruent trials, $M = .74$ µV, $SD = 1.51$. The effect of congruency did not interact with group, $F < 1.00$, $\eta_p^2 = .02$. The results of this analysis converge with the results of the behavioral data and reveal that reactive control was insensitive to variation in video game experience.

Proactive control. The association between video game experience and the MFN was examined in a 2 (group) × 2 (congruency) × 2 (RSI) × 4 (electrode: Fz, FCz, CPz, Pz) ANOVA. In this analysis the main effect of congruency was significant, $F(1,49) = 11.44$, $p = .001$, $\eta_p^2 = .19$, reflecting greater negativity for incongruent, $M = .74$ µV, $SD = 1.11$, than for congruent trials, $M = 1.01$ µV, $SD = 1.16$. The Group × Congruency interaction was not significant, $F < 1.00$, $\eta_p^2 < .001$. The Group × Congruency Electrode interaction approached significance, $F(3,147) = 3.39$ $p = .054$, $\eta_p^2 = .065$, $\varepsilon = .483$. To examine the basis of this interaction, separate 2 (congruency) × 4 (electrode) ANOVAs were performed for the high and low gamers. For the low gamers the main effect of congruency was

---

[1] The analysis of the conflict adaptation effect was limited to nonrepetitions to control for the possible influence of repetition priming on the effect.

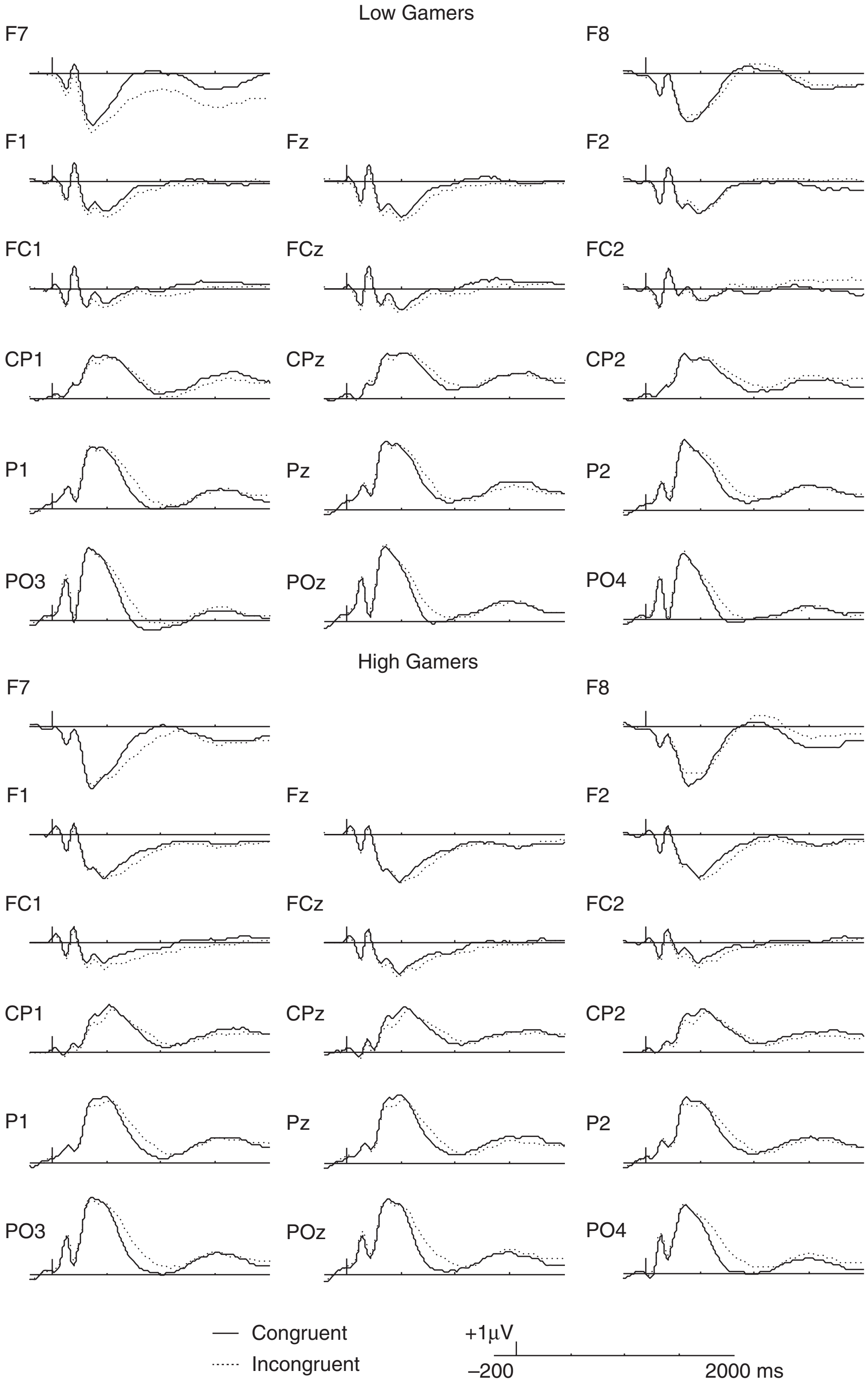

Figure 1. Grand-averaged ERPs for congruent and incongruent stimuli at 17 scalp electrodes demonstrating the time course of the MFN, conflict SP, and frontal slow wave. The tall bars represent stimulus onset, the short bars represent 500-ms increments, and positive is plotted up.

significant, $F(1,25) = 6.93$, $p = .014$, $\eta_p^2 = .22$, and the Congruency × Electrode interaction was not significant, $F < 1.00$, $\eta_p^2 = .02$. These findings indicate that the amplitude of the MFN was similar from the frontal to parietal regions of the scalp for low gamers (Figure 3a). In the high gamers the main effect of congruency was significant, $F(1,24) = 4.93$, $p = .036$, $\eta_p^2 = .17$, and the Congruency × Electrode interaction was significant, $F(3,72) = 5.48$, $p = .016$, $\eta_p^2 = .19$. Post hoc analyses revealed that the effect of congruency was not significant at electrodes Fz, $F < 1.00$, $\eta_p^2 = .03$, and FCz, $F = 1.56$, $\eta_p^2 = .06$, and was significant at electrodes CPz, $F(1,24) = 8.33$, $p = .008$, $\eta_p^2 = .26$, and Pz, $F(1,24) = 8.64$, $p = .007$, $\eta_p^2 = .27$. These findings indicate that the MFN was only reliable over the central-parietal and parietal regions for high gamers. The results of these analyses reveal a negative relationship between video game experience and the amplitude of the MFN that may reflect a reduction in the

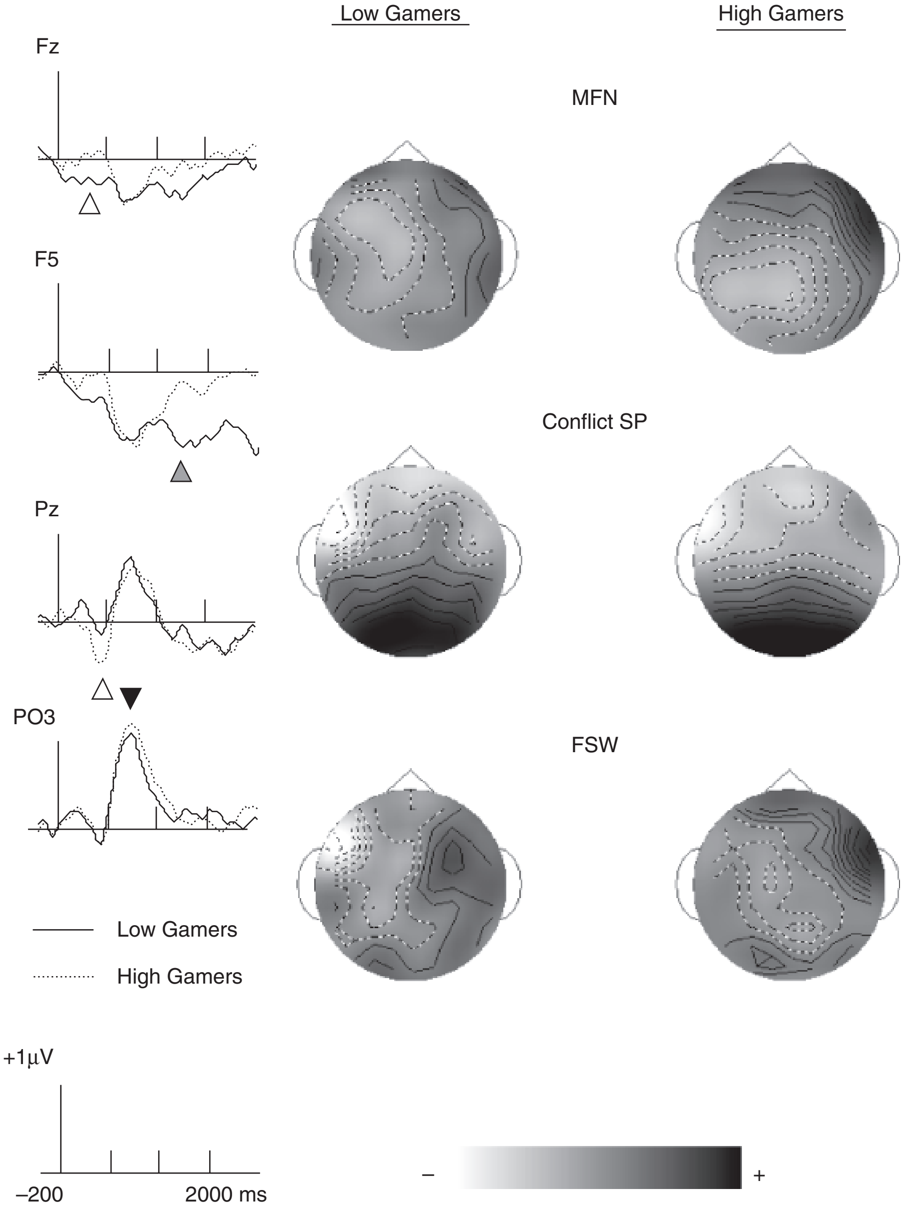

Figure 2. Grand-averaged difference waves (incongruent – congruent) and scalp topography maps demonstrating the time course and topography of the MFN (Fz and Pz, marked by the white arrows), conflict SP (PO3, marked by the black arrow), and frontal slow wave (F5, marked by the gray arrow) in the low and high gamers. The tall bar represents stimulus onset, the short bars represent 500-ms increments, and positive is plotted up.

recruitment of anterior cingulate cortex in the service of proactive cognitive control in high gamers (Mathews et al., 2005).

The association between video game experience and the frontal slow wave was examined in a 2 (group) × 2 (congruency) × 2 (RSI) × 2 (hemisphere) × 2 (electrode: F5–F6, F7–F8) ANOVA. The inferential statistics for the relevant main effects and interactions are presented in Table 2. The main effect of congruency indicates that the frontal slow wave was more negative for incongruent trials, $M = -0.51$ μV, $SD = 0.92$, than for congruent trials, $M = -0.29$ μV, $SD = 0.81$. The Congruency × Hemisphere interaction indicates that the difference between incongruent and congruent trials was greater over the left hemisphere, $M = -0.65$ μV, $SD = 1.10$, than over the right hemisphere, $M = 0.20$ μV, $SD = 1.05$.

To characterize the marginal Group × Congruency × Epoch interaction and the significant Group × Congruency × Epoch × RSI interaction, separate analyses were performed for the high and low gamers. For the low gamers the main effect of congruency was significant, $F(1,25) = 7.91$, $p = .009$, $\eta_p^2 = .24$, reflecting greater negativity for incongruent trials, $M = -0.55$ μV, $SD = 1.00$, than for congruent trials, $M = -0.10$ μV, $SD = 0.79$. The Congruency × Epoch interaction was not significant, $F < 1.00$, $\eta_p^2 = .03$, indicating that the amplitude of the frontal slow wave was consistent between 800 and 2000 ms after stimulus onset in the low gamers (Figure 3b). In the high gamers the main effect of congruency was not significant, $F < 1.00$, $\eta_p^2 = .001$, and the Congruency × Epoch interaction was significant, $F(2,48) = 7.17$, $p = .005$, $\eta_p^2 = .23$, $\varepsilon = .77$. This latter effect indicates that the amplitude of the frontal slow wave decreased over time in the higher gamers (Figure 3b). Additionally, the amplitude of the frontal slow wave was similar in low and high gamers between 800 and 1000 ms after stimulus set, $t(49) = 0.97$, $p = .34$, and

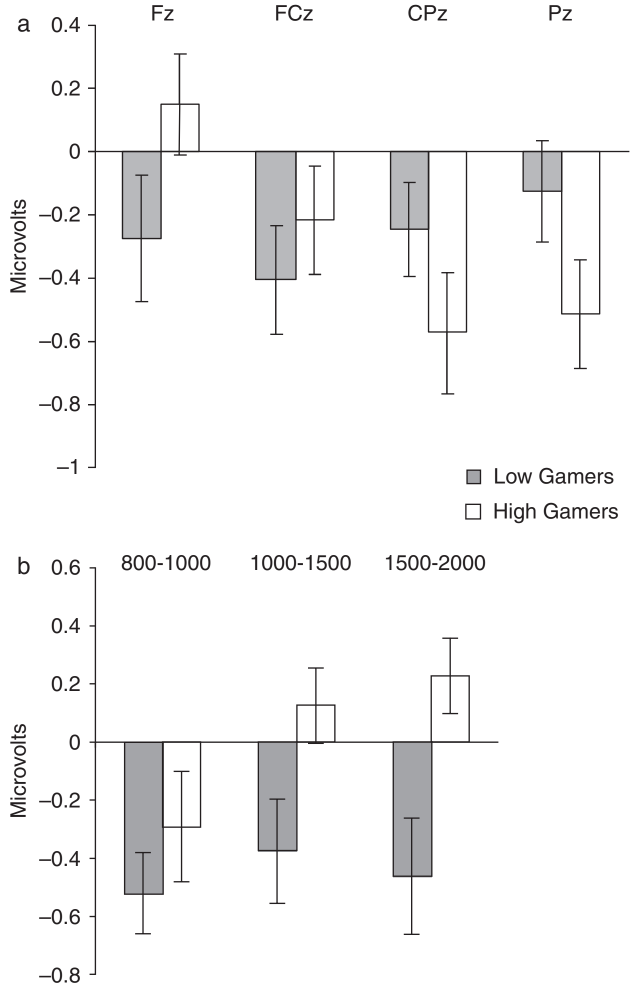

Figure 3. Mean voltage differences (incongruent − congruent) for the MFN demonstrating the Group × Congruency × Electrode interaction (a) and for the frontal slow wave demonstrating the Group × Congruency × Epoch interaction (b). The frontal slow wave was measured in three epochs (800–1000 ms, 1000–1500 ms, and 1500–2000 ms). The error bars represent one standard error of the mean.

differed between low and high gamers thereafter: 1000–1500 ms, $t(49) = 2.13$, $p = .01$; 1500–2000 ms, $t(49) = 2.82$, $p = .007$. The results of these analyses may indicate that high gamers can recruit proactive control, but that they may have difficulty maintaining this type of control over time.

Table 2. *Summary of Relevant Main Effects and Interactions Involving Group and Stimulus Congruency for the Primary Analysis of the Frontal Slow Wave*

	F	*df*	*p*	η_p^2
Congruency	4.34	1,49	.04	.08
Group × Congruency	5.21	1,49	.03	.10
Congruency × Epoch	5.73	2,98	.01	.11
Group × Congruency × Epoch	2.84	2,98	.07	.06
Congruency × Hemisphere	15.99	1,49	.01	.25
Group × Congruency × Epoch × RSI	3.40	2,98	.05	.07

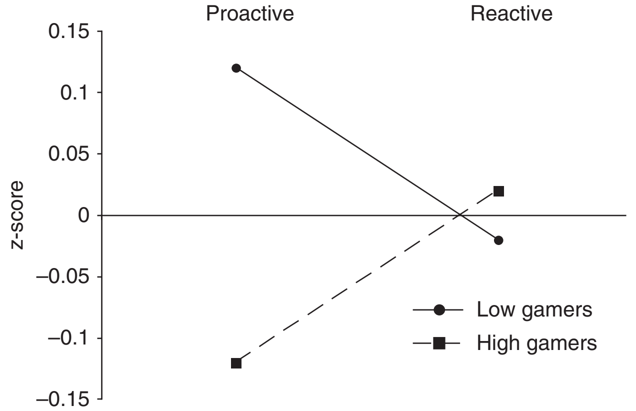

Figure 4. Mean *z*-scores in low and high gamers for the combined analysis of the behavioral and neural measures of proactive and reactive cognitive control. The error bars represent one standard error of the mean.

A final test was designed to examine the association between video game experience and cognitive control at the behavioral and neural levels in a single analysis. To this end, a 2 (group) × 2 (type of control: proactive or reactive) × 2 (index: behavioral or neural) × 2 (RSI) ANOVA was performed where the dependent measures represented *z*-scores for the conflict adaptation effect, the Stroop interference effect, the combined amplitude of the MFN at electrode FCz and frontal slow wave at electrodes F5 and F7 (1000–2000 ms after stimulus onset),[2] and the conflict SP at electrodes PO3, POz, and PO4. For the MFN-frontal slow wave measure the *z*-scores were reversed so that greater amplitude represented positive values. The relevant data are portrayed in Figure 4. In this analysis the Group × Type of Control interaction was not significant, $F(1,49) = 2.51$, $p = .12$, $\eta_p^2 = .05$. However, the effect of group was significant for proactive control, $t(49) = 2.06$, $p = .045$, and not for reactive control, $t < 1.00$, $p = .78$. The results of these analyses complement the separate analyses of the behavioral and ERP data, possibly revealing a selective influence of video game experience on proactive cognitive control.

Discussion

The current study was motivated by evidence indicating that video game experience may be negatively associated with cognitive control in the Stroop task (Kronenberger et al., 2005; Mathews et al., 2005). We were particularly interested in whether video game experience might be differentially related to proactive and reactive components of cognitive control. The behavioral and ERP data from the current study revealed that indices of proactive control were negatively associated with variation in video game experience; in contrast, indices of reactive control appeared to be insensitive to variation in video game experience.

All three indices of proactive cognitive control were sensitive to video game experience. The influence of video game experience on the conflict adaptation effect interacted with the RSI. In the short RSI condition the magnitude of this effect was similar in high and low gamers; in contrast, in the long RSI condition the magnitude of the conflict adaptation effect was greater for low gamers than for high gamers. This finding may indicate that the

---

[2] The composite for the MFN and frontal slow wave was calculate as $(\text{zMFN}+(\text{zfrontal slow wave}_{1000-1500}+\text{zfrontal slow wave}_{1500-2000})/2)/2$.

initial recruitment of proactive control was similar in high and low gamers, but that the high gamers were unable to maintain proactive control over the delay in the long RSI condition. The influence of video game experience on the MFN over the frontal and central regions and the frontal slow wave supports this suggestion. The amplitude of the MFN was attenuated in high gamers relative to low gamers, indicating that video game experience may be associated with the underrecruitment of anterior cingulate cortex (Mathews et al., 2005). The amplitude of the frontal slow wave was similar for high and low gamers between 800 and 1000 ms after stimulus onset. Additionally, in the low gamers the amplitude of the frontal slow wave was similar from 800 to 2000 ms after stimulus onset. In contrast, in the high gamers the amplitude of the frontal slow wave was attenuated beyond 1000 ms after stimulus onset. These findings converge with the behavioral data and may indicate that video game experience was associated with a reduction in the ability to maintain the recruitment of the lateral frontal cortex over time in the service of proactive cognitive control (DePisapia & Braver, 2006; Mathews et al., 2005). The negative association between video game experience and proactive cognitive control is interesting in the context of recent evidence demonstrating a similar correlation between video game experience and self-reported measures of attention deficits and hyperactivity (Swing, 2008). Together, these data may indicate that the video game experience is associated with a decrease in the efficiency of proactive cognitive control that supports one's ability to maintain goal-directed action when the environment is not intrinsically engaging.

In contrast to the measures of proactive control, indices of reactive cognitive control appeared to be insensitive to variation in video game experience. The magnitude of the interference effect for response time and response accuracy did not differ between low and high gamers, and the amplitude of the conflict SP was similar in these two groups. These findings are consistent with recent evidence from a larger scale study examining the relationship between individual differences in media exposure, symptoms of attention deficits and hyperactivity, and laboratory-based measures of sustained attention (i.e., continuous performance task) and selective attention (i.e., flanker task; Swing, 2008). In that study interference in the flanker task was not correlated with video game experience. Based on our findings and those of Swing, it does not appear that video game experience influences the ability to overcome interference from task irrelevant information within a given trial.

One unanticipated finding was the differential influence of video game experience on the amplitude of the MFN over the frontal region and parietal region of the scalp. In the low gamers the difference in amplitude between congruent and incongruent trials was similar from the frontal to the parietal region of the scalp; in the high gamers the voltage difference between congruent and incongruent trials was only significant over the central-parietal and parietal regions of the scalp. The extension of the MFN to the parietal region of the scalp is a common finding in studies using ERPs to examine the neural correlates of conflict processing in the Stroop and similar tasks (McNeely et al., 2003; West & Alain, 2000; West et al., 2005). However, the distribution of the MFN typically reflects a fairly continuous voltage gradient from the frontal-central to the parietal region of the scalp. The current findings may indicate that the MFN arises from the activity of multiple neural generators that are differentially sensitive to individual or group differences. Supporting this idea, the MFN reported by McNeely et al. (2003, Figure 2) was greater in amplitude for controls than for patients with schizophrenia at electrode Cz and appears to be more similar in amplitude in patients and controls at electrode Pz. Analyses of the MFN in the study by McNeely et al. were limited to the central electrodes, so it is not clear whether the Group × Region interaction might have been significant. The influence of individual differences in video game experience on the MFN may indicate that this modulation of the ERPs arises from the activity of multiple neural generators that are distinctly related to signaling the need for proactive and reactive cognitive control. This suggestion is consistent with the architecture of a recent computational model applying the Dual Mechanisms of Cognitive Control Theory to behavioral and functional neuroimaging data from the Stroop task (DePisapia & Braver, 2006).

There are two limitations of the current study worth noting. First, the influence of video game experience on proactive control was measured as an individual difference variable rather than being induced in a controlled training study. This makes it impossible to know for certain whether video game experience or some other factor caused the observed group differences. It could be that preexisting differences in executive control cause greater (or lesser) attraction to video games. Two issues need to be addressed before accepting this alternative explanation: First, one would need to specify the preconditions that lead individuals with lower levels of proactive control to consume higher levels of video games than individuals with higher levels of proactive control; second, one would also need to identify why this effect is specific to the consumption of video games and not other forms of media. This latter constraint follows from the findings of Swing (2008), who demonstrated that exposure to television and films, but not video game experience, may influence performance on both the flanker and continuous performance tasks that could be viewed as indices of reactive and proactive cognitive control, respectively. One way of addressing the issue of causality would be to examine the effect of video game experience on proactive and reactive cognitive control in training studies similar to those implemented in the literature demonstrating positive effects of video game experience on visuospatial attention (Feng et al., 2007; Green & Bavelier, 2003).

The second limitation applies to our study as well as to this domain of research more generally. Existing studies of the influence of video game experience on attention and cognitive control have focused on a fairly small number of tasks that arguably tap a limited set of attention and cognitive control processes. Therefore, an important avenue of future research will be to examine a broader range of tasks that are dependent on other control processes.

In conclusion, our results may serve to constrain the claims of some scholars, game manufacturers, and journalists who have suggested that playing action video games "improves attention" (e.g., Green & Bavelier, 2006). Clearly some types of video games produce positive educational and therapeutic outcomes (Barlett, Anderson, & Swing, 2009; Pope & Bogart, 1996). However, our data converge with other recent evidence (e.g., Bioulac et al., 2008; Swing, 2008) leading to the suggestion that high levels of video game experience may be associated with a reduction in the efficiency of processes supporting proactive cognitive control that allow one to maintain goal-directed information processing in contexts that do not naturally hold one's attention. Additional research on a broader range of attention and cognitive control tasks will not only improve our understanding of attention and cognitive control, but will also help move the debate beyond the simple "video games are good" versus "video games are bad" dichotomy (cf. Gentile & Stone, 2005).

REFERENCES

Barlett, C. P., Anderson, C. A., & Swing, E. L. (2009). Video game effects—Confirmed, suspected and speculative: A review of the evidence. *Simulation & Gaming*, *40*, 377–403.

Belchior, P. (2007). Cognitive training with video games to improve driving skills and driving safety among older adults. *Dissertation Abstracts International*, *68*(9-B), 5897.

Bioulac, S., Arfi, L., & Bouvard, M. P. (2008). Attention deficit/hyperactivity disorder and video games: A comparative study of hyperactive and control children. *European Psychiatry*, *23*, 134–141.

Botvinick, M. M., Braver, T. S., Barch, D. M., Carter, C. S., & Cohen, J. D. (2001). Conflict monitoring and cognitive control. *Psychological Review*, *108*, 624–652.

Botvinick, M. M., Cohen, J. D., & Carter, C. S. (2004). Conflict monitoring and anterior cingulate cortex: An update. *Trends in Cognitive Science*, *8*, 539–546.

Braver, T. S., Gray, J. R., & Burgess, G. C. (2007). Explaining the many varieties of working memory variation: Dual mechanisms of cognitive control. In A. R. Conway, C. Jarrold, M. J. Kane, A. Miyake, & J. N. Towse (Eds.), *Variation in working memory* (pp. 76–106). New York: Oxford.

Braver, T. S., & Hoyer, C. M. (2006). *Neural mechanisms or proactive and reactive cognitive control*. Unpublished manuscript.

Buchmann, D. D., & Funk, J. B. (1996). Video and computer games in the '90s: Children's time commitment and game preference. *Children Today*, *24*, 12–15.

DePisapia, N., & Braver, T. S. (2006). A model of dual control mechanisms through anterior cingulate and prefrontal cortex interactions. *Neurocomputing*, *69*, 1322–1326.

Duncan-Johnson, C. C., & Kopell, B. C. (1981). The Stroop effect: Brain potentials localize the source of interference. *Science*, *214*, 938–940.

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science*, *18*, 850–855.

Gentile, D. A., & Anderson, C. A. (2003). Violent video games: The newest media violence hazard. In D. Gentile (Ed.), *Media violence and children* (pp. 131–152). Westport, CT: Praeger.

Gentile, D. A., & Stone, W. (2005). Violent video game effects on children and adolescents: A review of the literature. *Minerva Pediatrica*, *57*, 337–358.

Gratton, G., Coles, M. G., & Donchin, E. (1992). Optimizing the use of information: Strategic control of activation of responses. *Journal of Experimental Psychology: General*, *121*, 480–506.

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, *423*, 534–537.

Green, C. S., & Bavelier, D. (2006). The cognitive neuroscience of video games. In L. Humphreys & P. Messaris (Eds.), *Digital media: Transformations in human communication* (pp. 211–223). New York: Peter Lang.

Hanslmayr, S., Pastötter, B., Bäuml, K.-H., Gruber, S., Wimber, M., & Klimesch, W. (2008). The electrophysiological dynamics of interference during the Stroop task. *Journal of Cognitive Neuroscience*, *20*, 215–225.

Huynh, H., & Feldt, L. S. (1976). Estimation of the Box correction for degrees of freedom from sample data in randomized block and split-plot designs. *Journal of Educational Statistics*, *1*, 69–82.

Kerns, J. G., Cohen, J. D., MacDonald, A. W. 3rd, Cho, R. Y., Stenger, V. A., & Carter, C. S. (2004). Anterior cingulated conflict monitoring and adjustments in control. *Science*, *303*, 969–970.

Kronenberger, W. G., Matthews, V. P., Dunn, D. W., Wang, Y., Wood, E. A., Giauque, A. L., et al. (2005). Media violence exposure and executive functioning in aggressive and control adolescents. *Journal of Clinical Psychology*, *61*, 725–737.

Liotti, M., Woldorff, M. G., Perez, R., & Mayberg, H. S. (2000). An ERP study of the temporal course of the Stroop color-word interference effect. *Neuropsychologia*, *38*, 701–711.

Mathews, V. P., Kronenberger, W. G., Wang, Y., Lurito, J. T., Lowe, M. J., & Dunn, D. W. (2005). Media violence exposure and frontal lobe activation measured by functional magnetic resonance imaging in aggressive and nonaggressive adolescents. *Journal of Computer Assisted Tomography*, *29*, 287–292.

McNeely, H. E., West, R., Christensen, B. K., & Alain, C. (2003). Neurophysiological evidence for disturbances of conflict processing in patients with schizophrenia. *Journal of Abnormal Psychology*, *112*, 679–688.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia*, *9*, 97–113.

Paxton, J. L., Barch, D. M., Racine, C. A., & Braver, T. S. (2008). Cognitive control, goal maintenance, and prefrontal function in healthy aging. *Cerebral Cortex*, *18*, 1010–1028.

Pope, A. T., & Bogart, E. H. (1996). Extended attention span training system: Video game neurotherapy for attention deficit disorder. *Child Study Journal*, *26*, 39–51.

Rosser, J. C. Jr., Lynch, P. J., Cuddihy, L., Gentile, G. A., Klonsky, J., & Merrell, R. (2007). The impact of video games on training surgeons in the 21st century. *Archives of Surgery*, *142*, 181–186.

Speer, N. K., Jacoby, L. L., & Braver, T. S. (2003). Strategy-dependent changes in memory: Effects on brain activity and behavior. *Cognitive, Affective, & Behavioral Neuroscience*, *3*, 155–167.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology*, *18*, 643–662.

Swing, E. L. (2008). *Attention abilities, media exposure, school performance, personality, and aggression*. Unpublished master's thesis. Ames, Iowa: Iowa State University.

West, R. (2003). Neural correlates of cognitive control and conflict detection in the Stroop and digit-location tasks. *Neuropsychologia*, *41*, 1122–1135.

West, R. (2007, November). *The shifting sands of conflict processing*. Paper presented at the Psychonomic Society, Long Beach, CA.

West, R., & Alain, C. (2000). Effect of task context and fluctuations of attention on neural activity supporting performance of the Stroop task. *Brain Research*, *873*, 102–111.

West, R., & Baylis, G. C. (1998). Effects of increased response dominance and contextual disintegration on the Stroop interference effect in older adults. *Psychology and Aging*, *13*, 206–217.

West, R., Jakubek, K., Wymbs, N., Perry, M., & Moore, K. (2005). Neural correlates of conflict processing. *Experimental Brain Research*, *167*, 38–48.

West, R., & Schwarb, H. (2006). The influence of aging and frontal function on the neural correlates of regulative and evaluative aspects of cognitive control. *Neuropsychology*, *20*, 468–481.

West, R., & Travers, S. (2008). Tracking the temporal dynamics of updating cognitive control: An examination of error processing. *Cerebral Cortex*, *18*, 1112–1124.

(Received July 29, 2008; Accepted April 1, 2009)