

# Playing a First-person Shooter Video Game Induces Neuroplastic Change

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## Abstract

■ Playing a first-person shooter (FPS) video game alters the neural processes that support spatial selective attention. Our experiment establishes a causal relationship between playing an FPS game and neuroplastic change. Twenty-five participants completed an attentional visual field task while we measured ERPs before and after playing an FPS video game for a cumulative total of 10 hr. Early visual ERPs sensitive to bottom-up attentional processes were little affected by video game playing for

only 10 hr. However, participants who played the FPS video game and also showed the greatest improvement on the attentional visual field task displayed increased amplitudes in the later visual ERPs. These potentials are thought to index top-down enhancement of spatial selective attention via increased inhibition of distractors. Individual variations in learning were observed, and these differences show that not all video game players benefit equally, either behaviorally or in terms of neural change. ■

## INTRODUCTION

Several visual attentional, perceptual, and cognitive skills have been shown to improve after playing first-person shooter (FPS) video games. These include attentional capacities in central and peripheral vision (Green & Bavelier, 2003), perceptual abilities in low-level vision (Li, Polat, Makous, & Bavelier, 2009; Green & Bavelier, 2007), and high-level visuospatial cognition (Feng, Spence, & Pratt, 2007). Other enhancements include increased speed of processing (Dye, Green, & Bavelier, 2009b) and improved decision-making (Green, Pouget, & Bavelier, 2010). In applied contexts, visual acuity, positional acuity, and stereopsis in adults with amblyopia showed improvement after playing action games (Li, Ngo, Nguyen, & Levi, 2011) and video game training improved surgical performance in virtual reality endoscopic simulators (Schlickum, Hedman, Enochsson, Kjellin, & Felländer-Tsai, 2009). Training with an FPS game yields large behavioral changes for those who have not previously played an FPS game (Dye et al., 2009b; Li et al., 2009; Spence, Yu, Feng, & Marshman, 2009; Feng et al., 2007; Green & Bavelier, 2003, 2007), ruling out the possibility that observed differences between players and nonplayers are solely a consequence of self-selection. Although it is intriguing that playing an FPS video game can improve attentional and perceptual skills, the neurophysiological mechanisms are only just beginning to be understood (Bavelier, Achtman, Mani, & Föcker, 2011; Mishra, Zinni, Bavelier, & Hillyard, 2011).

Recently, action video game players were found to be superior to nonplayers in their ability to suppress irrelevant distractors during an attention-demanding task (Mishra et al., 2011). Concomitantly, the players showed greater suppression of steady state visual-evoked potential amplitudes in response to unattended stimuli, suggesting that players possess a superior attentional ability to suppress irrelevant information; they also exhibited larger amplitudes of the target-elicited P3 (450–470 msec) wave, which Mishra et al. (2011) interpreted as reflecting improved perceptual decision-making processes. Further evidence of better early filtering of irrelevant information by players (relative to nonplayers) was recently obtained in an fMRI study, where players exhibited less activation of the visual motion-sensitive middle temporal area/medial superior temporal area while viewing irrelevant moving distractors (Bavelier et al., 2011). However, although strongly suggestive, there is still no direct evidence that playing action video games is the cause of observed differences in neural activity between players and nonplayers.

Our study sought to resolve the issue of whether playing an FPS game directly alters the neural activities that are known to support visual attentional processing. We used scalp recording of ERPs to investigate the possible neuroplastic changes associated with playing an FPS game. We recorded visual ERPs during an attentional visual field (AVF) task, which assesses the ability to detect a target among distractors over a wide visual field, before and after playing an FPS video game for a cumulative total of 10 hr (cf. Spence et al., 2009; Feng et al., 2007; Green & Bavelier, 2003). We also included a control group whose participants played a 3-D puzzle game that has little effect on spatial

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selective attention (Feng et al., 2007). None of the participants in either group had previously played FPS games.

Although behavioral improvements in attentional and perceptual skills have been observed in several studies (Dye et al., 2009b; Li et al., 2009; Spence et al., 2009; Feng et al., 2007; Green & Bavelier, 2003, 2007), there is some evidence that playing action video games does not always lead to improved performance (Boot, Kramer, Simons, Fabiani, & Gratton, 2008). The amount of video game training, in conjunction with individual differences in learning trajectories, may be partially responsible for the observed variability in performance gains (Spence et al., 2009). Furthermore, good and poor learners seem to differ in the patterns and level of activity in the dorsal striatum, and these differences are correlated with performance gains (Erickson et al., 2010). Therefore, our study was particularly attentive to the amount and nature of individual variation in performance and the possible associated changes in neural activity after playing the game.

## METHODS

### Participants

Thirty-five right-handed university students who had not played video games in the previous 4 years were recruited and randomly assigned to two video game training groups: an FPS group and a nonaction game control group. Data from 10 participants were subsequently excluded because of failure to complete the study ( $n = 3$ ), equipment problems ( $n = 1$ ), and excessive noise levels or other unreliabilities in the ERP data ( $n = 6$ ), leaving 16 participants (seven men and nine women, aged 18–27 years,  $M = 21.3$  years) in the FPS group and 9 participants (four men and five women, aged 19–28 years,  $M = 22$  years) in the control group.

### Stimuli and Procedures

The participants completed a pretraining test on an AVF task. Then they played a video game under experimenter supervision for a cumulative total of 10 hr with no individual session longer than 2 hr (cf. Spence et al., 2009; Feng et al., 2007; Green & Bavelier, 2003). Finally, they completed a posttraining test on the AVF task. An EEG was recorded during the AVF task before playing the video game and again after the video game playing sessions had been completed. Participants viewed the AVF stimulus display binocularly with the head positioned on a chin rest at a distance of 10 inches from a 20-in. CRT monitor in a dimly lit room.

Each trial of the AVF task began with a fixation cross ( $2^\circ \times 2^\circ$ ) located in the center of the screen for 300 msec. The fixation screen was followed by a blank screen (500 msec) and then by the stimulus screen (14 msec). The stimulus consisted of a target and 24 distractors, presented in dark gray on a light gray background in an area ( $34^\circ \times 34^\circ$ ) centered in the display. One object was located at the center

of the screen, and the remaining 24 objects were arranged circularly around the center in the cardinal and intercardinal directions, forming three concentric rings at  $10^\circ$ ,  $20^\circ$ , and  $30^\circ$  eccentricities. The distractors were unfilled squares with dark gray borders ( $3^\circ \times 3^\circ$ ), and the target was a dark gray filled circle centered in an unfilled square with a dark gray border ( $3^\circ \times 3^\circ$ ). The stimulus display was comparable with those previously used in similar studies (Spence et al., 2009; Feng et al., 2007; Green & Bavelier, 2003); however, no mask was presented after the stimulus to avoid contaminating the ERP response. On each trial, the target occupied 1 of the 16 locations at  $20^\circ$  and  $30^\circ$  eccentricities; targets never appeared in the central position or at  $10^\circ$  eccentricity, because performance at these locations would have been close to 100% without a mask. Immediately after the stimulus disappeared, the participants indicated the direction of the target relative to the center of the display by pressing the key on the number keypad that lay in the same direction as the target relative to the central “5” key (e.g., “2” for *south* and “1” for *southwest*). A new trial began 1000 msec after the response or after 6000 msec if no response was made.

There were 640 trials grouped in five blocks of 128 trials, with a short rest between blocks. All combinations of target eccentricity ( $20^\circ$  and  $30^\circ$ ) and target direction were equally represented and presented in a pseudorandom order. Participants completed 32 practice trials before the experimental blocks of trials to familiarize themselves with the response keys and the experimental procedures. The practice trials were identical to the experimental trials, except for a supplemental intertrial screen that provided feedback regarding the correctness of the response, the running average accuracy rate, and the average response time. The task was completed in 50 min or less.

### Electrophysiological Recording

During the task, the EEG was digitized continuously (sampling rate, 512 Hz; band-pass of 0.01–100 Hz) from 64 scalp locations using Advanced Source Analysis software (ASA, ANT Software BV, Enschede, the Netherlands) and stored for off-line analysis. The electrooculogram was recorded from electrodes located at the superior and inferior orbit and lateral to the outer canthi of each eye to monitor horizontal and lateral eye movements. During recording, each electrode was referenced to an average of all the electrodes.

The EEGs were filtered using a band-pass of 0.03–30 Hz. The analysis epoch was set to 100 msec of prestimulus activity and 900 msec of poststimulus activity. All experimental files for each participant were scanned for artifacts with all epochs containing deflections exceeding  $150 \mu\text{V}$  marked as artifacts. All non-ocular-related artifacts were excluded by visual inspection. Ocular artifacts, such as blinks, saccades, and lateral movements, were corrected by ocular source components using a PCA. The processed waves were then averaged across the trials with

correct responses on the AVF task, for each electrode site and target eccentricity. Each average was baseline-corrected with respect to the prestimulus interval. All analyses were performed using EEProbe software (ANT Software BV).

### The Video Games

Participants played a video game for a cumulative total of 10 hr in sessions of 1 or 2 hr under experimenter supervision within a maximum period of 3 weeks. The experimental group played the FPS game *Medal of Honor: Pacific Assault* (Electronic Arts; Spence et al., 2009; Feng et al., 2007), and the control group played the three-dimensional puzzle game *Ballance* (Atari; Feng et al., 2007). Both games become more difficult as the player progresses in the game. At the end of each session, the participant's progress was recorded, and the game was continued from that point in the following session. Participants completed the initial scenarios of the games on two occasions, at the beginning and at the end of the video game training, to assess how well they had learned to play the game.

## RESULTS

### Performance in the Video Games

Both groups achieved substantial mastery of the games after playing for 10 hr. Participants in the FPS group improved in shooting accuracy by killing more enemies (mean  $\pm$  SEM: from  $11.3 \pm 1.3$  to  $16.4 \pm 1.1$ ;  $n = 16$ ) during a repetition of the initial scenario of the FPS game,  $t_{FPS}(15) = 4.11, p < .001$ , two-tailed (paired  $t$ ). Participants in the control group achieved higher game scores (mean  $\pm$  SEM: improving from  $2807 \pm 295$  to  $3655 \pm 218$ ;  $n = 9$ ), taking less time and making fewer mistakes while repeating the initial scenario of the 3-D puzzle game,  $t_{Control}(8) = 4.22, p = .003$ , two-tailed (paired  $t$ ).

### AVF Accuracy

We compared the AVF accuracy between the FPS and control groups using ANOVA: Group [FPS, control]  $\times$  Session [pre, post]  $\times$  Eccentricity [ $20^\circ$ ,  $30^\circ$ ], with the first factor between participants and the other two factors within participants. Accuracy (percent correct target detections) was higher at  $20^\circ$  (mean  $\pm$  SEM:  $64 \pm 3\%$ ;  $n = 25$ ) than at  $30^\circ$  eccentricity (mean  $\pm$  SEM:  $49 \pm 3\%$ ;  $n = 25$ ),  $F(1, 23) = 29.70, p < .001, \eta_p^2 = .56$ . Accuracy was also higher after playing the video games (mean  $\pm$  SEM:  $52 \pm 3\%$  to  $60 \pm 3\%$ ;  $n = 25$ ),  $F(1, 23) = 15.33, p < .001, \eta_p^2 = .40$ , and the improvement was greater at  $20^\circ$  than at  $30^\circ$  eccentricity (mean  $\pm$  SEM:  $10 \pm 2\%$  vs.  $6 \pm 2\%$ ;  $n = 25$ ),  $F(1, 23) = 5.83, p = .02, \eta_p^2 = .20$ . Only the FPS group (mean  $\pm$  SEM:  $12 \pm 3\%$ ;  $n = 16$ ) and not the control group (mean  $\pm$  SEM:  $7 \pm 3\%$ ;  $n = 9$ ) improved at  $20^\circ$

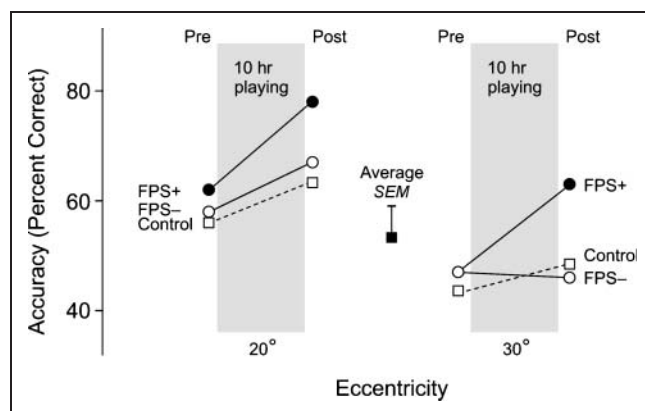
eccentricity after playing the video games:  $F_{FPS}(1, 23) = 13.62, p = .001, \eta_p^2 = .37$ ;  $F_{Control}(1, 23) = 2.55, p = ns$ . Similarly, only the FPS group (mean  $\pm$  SEM:  $7 \pm 3\%$ ;  $n = 16$ ), and not the control group (mean  $\pm$  SEM:  $4 \pm 2\%$ ;  $n = 9$ ), showed improvement at  $30^\circ$  eccentricity:  $F_{FPS}(1, 23) = 4.12, p = .05, \eta_p^2 = .15$ ;  $F_{Control}(1, 23) = .78, p = ns$ .

For subsequent analyses, we divided the participants in the FPS group into high and low performers according to their accuracy on the AVF test. Participants who improved more than the FPS mean (7%) at  $30^\circ$  eccentricity (the more difficult condition) were categorized as FPS+ ( $n = 7$ ), whereas the others were categorized as FPS- ( $n = 9$ ). We made this subdivision because we noted (see below) that the FPS participants who performed best on the AVF test had distinctly different average P2 and P3 waves than the other FPS participants or the control participants. Figure 1 shows the pre- and posttraining accuracies on the AVF test for the three categories of participant.

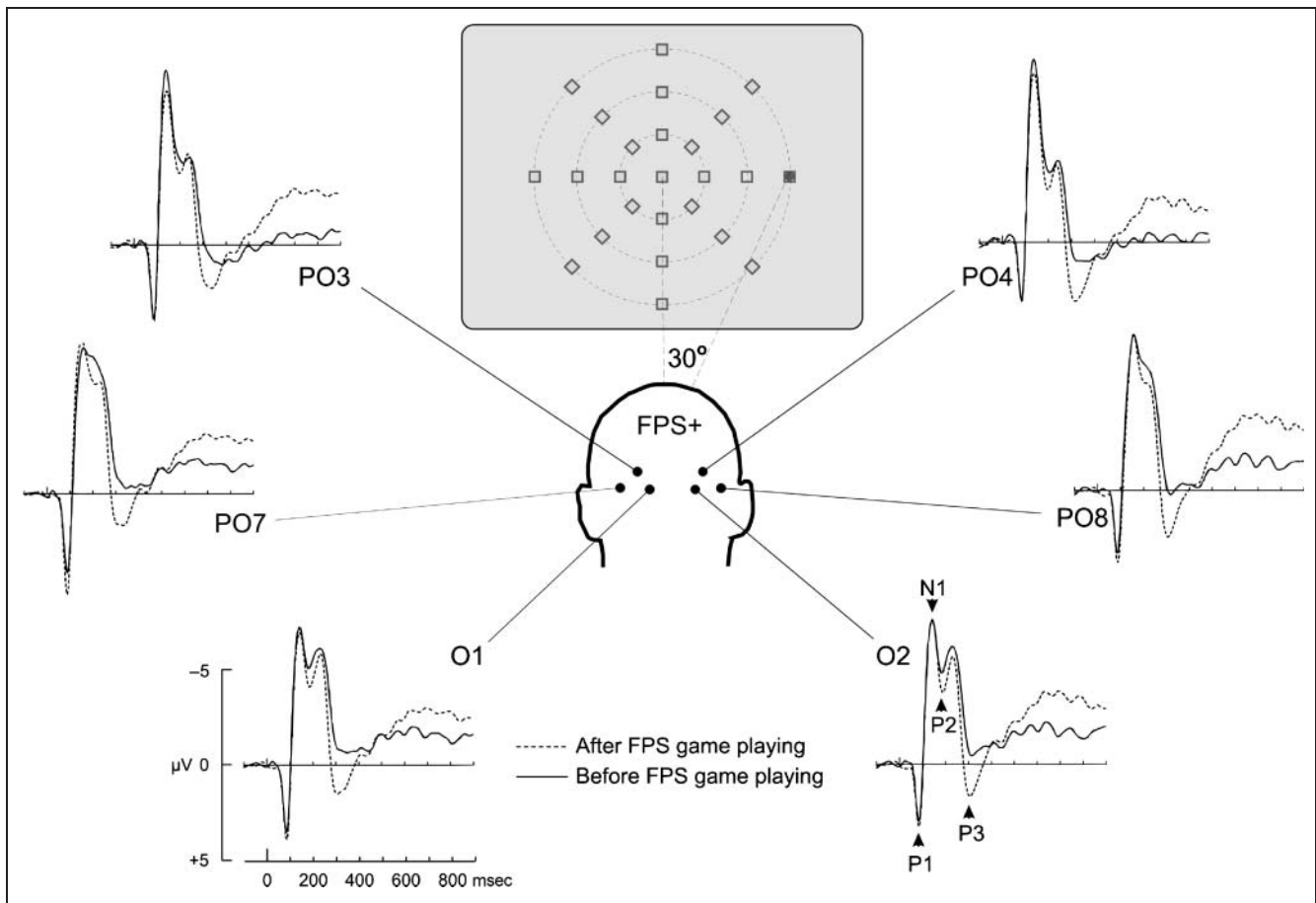
### EEG/ERP

Grand-averaged ERP waves were computed and examined for all sites and participant categories; for example, Figure 2 shows the averaged occipital and occipito-parietal ERPs for participants in the FPS+ category. P1 and N1 waves were evident at all occipital and occipito-parietal sites. The N1 deflection was followed by a small P2 wave peaking at about 200 msec after stimulus onset. Following the P2 wave, there was a small N2 and a subsequent P3 deflection peaking at about 300 msec, followed by a slow sustained negative potential.

The P1 and N1 amplitudes and latencies were not different before and after playing the video games. Because top-down endogenous attention, but not exogenous attention, is improved after playing an action video game (Hubert-Wallander, Green, & Bavelier, 2011; Chisholm, Hickey, Theeuwes, & Kingstone, 2010), our analysis



**Figure 1.** Accuracies on the AVF task at  $20^\circ$  and  $30^\circ$  eccentricities for high- (FPS+;  $n = 7$ ) and low- (FPS-;  $n = 9$ ) performing participants before and after playing an FPS video game and also for the control group ( $n = 9$ ) that played a nonaction game. Standard error bars are not shown to avoid cluttering the display; these varied between 4.8 and 6.7 with a mean of 5.8 (shown in the glyph at center).



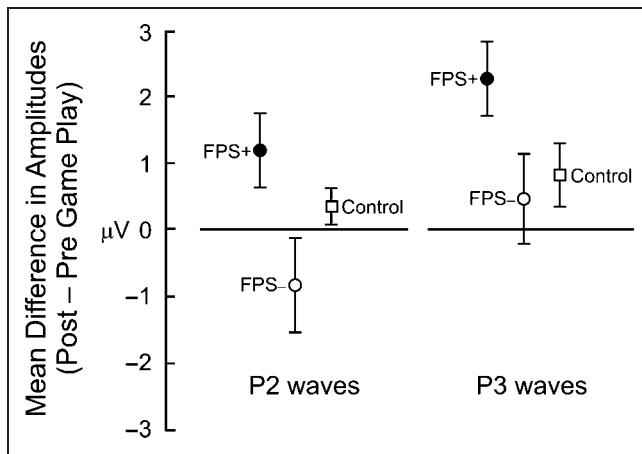
**Figure 2.** Grand-averaged ERPs obtained during trials of the AVF task, before and after playing a video game, for high-performing FPS participants (FPS+;  $n = 7$ ). The locations of the P1, N1, P2, and P3 waves are indicated for electrode site O2 and are similarly located for other sites. The P2 and P3 waves, peaking near 200 and 300 msec, respectively, exhibit increased amplitudes after playing the FPS game. The P1 and N1 waves, peaking near 100 and 150 msec, respectively, show little change. Similar patterns are present in the waves at each of the other electrode sites. Dotted lines in the stimulus display indicate eccentricities and target visual angle; these were not visible in the actual display.

focused on the P2 and P3 waves (Straube & Fahle, 2010; AnilloVento & Hillyard, 1996; Johnson, 1988; Squires, Hillyard, & Lindsay, 1973) at occipital and occipito-parietal sites (O1, O2, PO3, PO4, PO7, PO8). We compared the mean amplitude differences (before and after playing the video game) of P2 (175–225 msec) and P3 (250–350 msec) waves using ANOVA. The factors were: Category [FPS+, FPS–, control]  $\times$  Session [pre, post]  $\times$  Hemisphere [left, right]  $\times$  Channel (hemisphere) [O1, PO3, PO7 (left), O2, PO4, PO8 (right)]  $\times$  Eccentricity [20°, 30°], with the first factor between participants and the other four factors within participants (Channel was nested within Hemisphere).

The first apparent difference in the ERP waves began about 200 msec after stimulus onset and was characterized by an increase in the P2 amplitude. However, the three categories of participant exhibited different levels of modulation of the P2 amplitudes (175–225 msec) after playing the video games. Only the FPS+ participants showed a P2 amplitude difference larger than zero,  $F(1, 22) = 3.89, p = .06, \eta_p^2 = .15$ ; the FPS– and control amplitude differences were not significantly different from zero (Figure 3).

The next obvious difference was an increase in the P3 amplitude about 300 msec after stimulus onset (Figure 3). On average, the P3 wave amplitude (250–350 msec) was larger after playing the video game,  $F(1, 22) = 12.26, p = .002, \eta_p^2 = .36$ . Only the FPS+ participants showed a P3 amplitude difference that was significantly larger than zero,  $F(1, 22) = 12.78, p < .002, \eta_p^2 = .37$ , whereas the FPS– and control category differences were not.

We constructed two scatterplots (Figures 4 and 5) to examine the question of whether the observed changes in the P2 and P3 waves were related to improvements in AVF scores. We plotted the changes in amplitude against the changes in accuracy at 30° eccentricity because that was the more difficult of the two eccentricity conditions and also the one where the FPS+ participants achieved the greatest gains. These plots reveal strongly suggestive relationships within the three categories. The sample size is too small to support the fitting and statistical comparison of parametric (nonlinear) regressions to test whether these within-category relationships differ; however, only the FPS+ participants appear to show a positive relationship. We visually highlighted the associations by fitting



**Figure 3.** Mean amplitude differences in the P2 and P3 waves before and after playing a video game for the three categories of participant (FPS+:  $n = 7$ , FPS-:  $n = 9$ , control:  $n = 9$ ). Error bars represent standard errors of the mean amplitude differences. Only the FPS+ participants showed enhancement of P2 and P3 amplitudes significantly greater than zero.

separate LOESS (locally weighted scatterplot smoothing) curves to the data in each of the three categories (Cleveland, 1979). Only the FPS+ participants show change in both P2 and P3 amplitudes as a function of gains in AVF performance. Neither the controls nor the FPS- participants show a similar association. The controls are flat across the range, and the FPS- participants are almost indistinguishable from the controls, with the exception of one or two outliers.

## DISCUSSION

Our results demonstrate a direct causal relationship between playing an FPS video game and the neural activity that supports spatial selective attention. In addition to behavioral improvement, the electrophysiological substrates of spatial selective attention were modified, but only in high-performing FPS players, after playing the video game. The effects occurred at a relatively late stage of visual information processing (around 200 msec or later, after stimulus onset) during the allocation of attentional resources (Luck, Woodman, & Vogel, 2000). Playing the FPS game probably enhanced attentional performance by improving top-down allocation of attentional resources (Straube & Fahle, 2010; AnilloVento & Hillyard, 1996; Johnson, 1988; Squires et al., 1973), likely mediated by changes in activity in intraparietal cortex (Corbetta & Shulman, 2002; Kastner & Ungerleider, 2000).

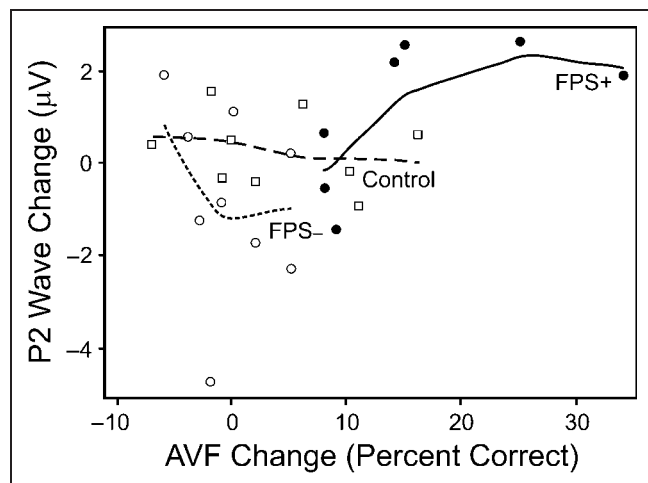
During the AVF task, multiple objects (1 target and 24 distractors) compete for limited visual processing resources (Kastner & Ungerleider, 2000; Reynolds, Chelazzi, & Desimone, 1999; Kastner, De Weerd, Desimone, & Ungerleider, 1998). This competition can be biased by a bottom-up input (e.g., the saliency of a particular object) or by a top-down input (e.g., attentional modulation; Kastner & Ungerleider, 2000). In our study, the P1 and

N1 waves were little affected, whereas the P2 and P3 amplitudes increased in individuals who showed superior AVF performance after playing the FPS game.

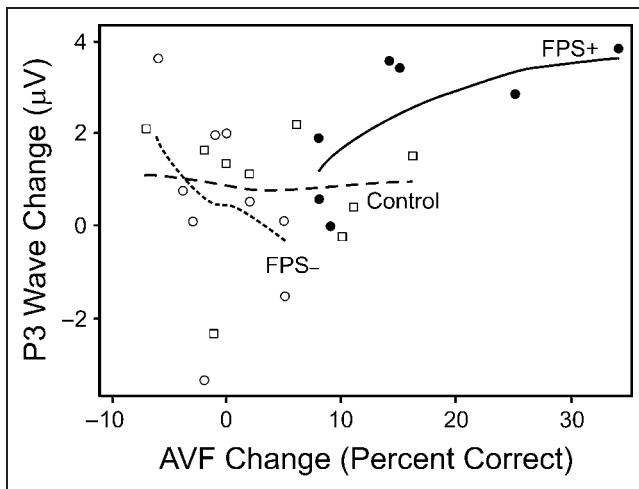
## The P1, N1, P2, and P3 Waves

Playing the FPS video game did not induce significant changes in early sensory ERPs (P1, N1). Hence, it appears that playing a video game for 10 hr has little impact on the deployment of selective attention at an early stage of processing in either a bottom-up manner (Schiff et al., 2006; Mangun, Hillyard, & Luck, 1993; Hillyard & Munte, 1984) or via the allocation of spatial attention before stimulus onset (Mangun, Buonocore, Girelli, & Jha, 1998). Indeed, we did not expect to see early-stage ERP differences between the FPS and control groups because, behaviorally, players and nonplayers have not previously been found to differ in the exogenous capture of attention (Green, Li, & Bavelier, 2010) or in the inhibition of return (Castel, Pratt, & Drummond, 2005). However, we cannot rule out the possibility that longer periods of play (e.g., 50 hr or more) might induce neural changes associated with bottom-up effects. Note that improvements in some fundamental perceptual skills have required extended periods of play (Mishra et al., 2011; Li et al., 2009; Green & Bavelier, 2007).

Evidence suggests that P2 is sensitive to task demands and that an increase in P2 amplitude may reflect adaptation to demands on attentional selection and attentional control (Fritzsche, Stahl, & Gibbons, 2011; Potts, Patel, & Azzam, 2004; Potts, Liotti, Tucker, & Posner, 1996). Also, P2 amplitude is directly correlated with the saliency of the stimulus (Mareschal, Kotsoni, Csibra, & Johnson, 2007); an increase P2 amplitude was observed when the stimuli were less salient (Straube & Fahle, 2010), presumably



**Figure 4.** Mean amplitude differences in individual P2 waves as a function of the mean differences in accuracy at 30° eccentricity on the AVF task for the three categories of participant (FPS+:  $n = 7$ , FPS-:  $n = 9$ , control:  $n = 9$ ). Individual LOESS curves have been fitted to each category to assist interpretation.



**Figure 5.** Mean amplitude differences in individual P3 waves as a function of the mean differences in accuracy at 30° eccentricity on the AVF task for the three categories of participant (FPS+:  $n = 7$ , FPS-:  $n = 9$ , control:  $n = 9$ ). Individual LOESS curves have been fitted to each category to assist interpretation.

requiring improved allocation of attention. Thus, the enhanced P2 amplitude in our high-performing FPS players might indicate that these participants have improved their attentional selection and control in the AVF task, possibly as the result of more efficient target–template matching (Mazza, Turatto, & Caramazza, 2009).

Many studies have associated P3 with the allocation of visual attention (Polich, 2007; Johnson, 1988) and have concluded that the amplitude of the P3 wave is an indicator of the amount of attention allocated to the task (Kok, 1997, 2001; AnlloVento & Hillyard, 1996; Kramer, Wickens, & Donchin, 1985; Wickens, Kramer, Vanasse, & Donchin, 1983; Isreal, Chesney, Wickens, & Donchin, 1980). Thus, the larger P3 amplitudes that we observed in high-performing participants after playing the FPS video game are probably associated with a top–down modulated increase in the allocation of attentional resources during the AVF task. This interpretation is reinforced by the positive association between the magnitude of change in P3 amplitudes and the improvements in spatial selective attention as measured by the AVF task scores.

The top–down modulation probably includes the filtering of unwanted information associated with nearby distractors (Kastner & Ungerleider, 2000; Reynolds et al., 1999; Kastner et al., 1998; Luck, Chelazzi, Hillyard, & Desimone, 1997). Enhancements in spatial selective attention, accompanied by greater P3 wave amplitudes, are frequently the result of an improved ability to inhibit processing of distractors (Sawaki & Luck, 2010; Bledowski, Prvulovic, Goebel, Zanella, & Linden, 2004; Barcelo, Perianez, & Knight, 2002). Furthermore, when the attentional demand increases during a visual search task, action video game players show less recruitment of a fronto-parietal network than nonplayers and less activation of the middle temporal/medial superior temporal area, in the presence

of irrelevant moving distractors. This suggests that players may achieve more efficient and automatic top–down allocation of attention, possibly facilitating more efficient early filtering of irrelevant information (Bavelier et al., 2011). The increased P3 amplitudes in the FPS+ participants may indicate that they improved their ability to suppress the processing of distractors over a wide field of view, at eccentricities as great as 20° or 30°, under top–down influence (Sawaki & Luck, 2010; Lauritzen, D’Esposito, Heeger, & Silver, 2009; Kastner & Ungerleider, 2000).

In a comparison of experienced action video game players with nonplayers, Mishra et al. (2011) observed an analogous effect to the increase in P3 amplitude that we found: experienced action video game players exhibited a larger target-elicited P3 wave than nonplayers. Mishra et al. (2011) proposed a novel explanation: They attributed the larger P3 amplitude to more effective perceptual decision-making on the part of the video game players. If this is correct, it is possible that playing an action video game enhances not only the allocation of resources in spatial selective attention but also improves the player’s ability to make perceptual decisions.

### Individual Differences in Learning

Both our behavioral and electrophysiological results show that not everyone who plays an FPS video game will realize the same gains in spatial selective attention or experience the same neural changes after playing the game for only 10 hr. Fairly large individual differences have been observed in previous studies (Spence et al., 2009; Feng et al., 2007), and it is likely that improvements in attentional performance depend not only on the time spent playing the game but also on the players’ latent potential for improvement (Erickson et al., 2010). Different participants will follow different learning trajectories, with some acquiring the skill more quickly than others (Spence et al., 2009). In our study, participants in the FPS+ category showed substantial improvement on the AVF task and significant changes in the amplitude of the P2 and P3 waves. Although the FPS- participants may have realized some benefit (at 20° eccentricity) from repeatedly performing the AVF task during the testing sessions (cf. Ball, Beard, Roenker, Miller, & Griggs, 1988) and also possibly by playing the FPS video game, they showed no significant overall change in their ERP waves. Ten hours of FPS video game playing may not be enough for all players to achieve changes as large as those in the FPS+ category.

It might be argued that practice on the AVF task itself (Ball et al., 1988) is responsible for the observed differences in neural activity between the FPS+ and FPS- categories and that playing the FPS video game has contributed nothing. However, if the type of game is unimportant and the changes in the FPS+ participants are solely because of practice on the AVF task, we should observe a similar result

if we compare high and low performers in the control group. Participants in the control group who improved more than the control group mean (4%) at 30° eccentricity were categorized as C+ ( $n = 4$ ), whereas the others were categorized as C- ( $n = 5$ ). However, the two subgroups did not exhibit amplitude differences significantly different from zero in either the P2 or P3 waves nor did the two subgroups differ from each other. This suggests that the changes in neural activity observed in the FPS+ category are a consequence of playing the FPS video game alone and are not a result of the practice obtained during the 1280 trials of the AVF task. Playing the FPS video game is the cause of the neuroplastic changes observed in the FPS+ participants.

## Conclusions

Playing an FPS video game can be an effective training tool to improve a range of attentional and perceptual skills (Spence & Feng, 2010; Dye, Green, & Bavelier, 2009a; Feng et al., 2007; Green & Bavelier, 2003). Our data show that playing an FPS video game can improve spatial attentional skills and can modify the neural processes in the brain associated with the allocation of visual attention. The modulation of the P2 and P3 waves in those FPS players who improved most on the AVF task suggests that they extended their visual selective attentional skills by enhancing top-down allocation of attentional resources and suppressing the processing of distractors. It is also possible that perceptual decision-making processes may have been improved (Mishra et al., 2011). However, it is important to note that neuroplastic change occurred only in those individuals who realized significant behavioral improvement. Not all FPS video game players demonstrated substantial neural and behavioral change after only 10 hr of play. The starting positions and shapes of individual learning trajectories (Spence et al., 2009) will influence the training time required to induce significant behavioral improvement and neuroplastic change.

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