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LI, Renjie, *et al.*

Abstract

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Reducing backward masking through action game training

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Action video game play enhances basic visual skills such as crowding acuity and contrast sensitivity (C. S. Green & D. Bavelier, 2007; R. Li, U. Polat, W. Makous, & D. Bavelier, 2009). Here, we ask whether the dynamics of perception may also be altered as a result of playing action games. A backward masking paradigm was used to test the hypothesis that action video game play also alters the temporal dynamics of vision. As predicted, action gamers showed reduced backward masking and an accompanying training study established the causal role of action game play in this enhancement. Implications of this result are discussed in the context of the faster reaction times and enhanced sensitivity also documented after action game play.

Keywords: video game, backward masking, plasticity, temporal processing

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Introduction

Video game play can have substantial positive effects on visual skills (see Green & Bavelier, 2006c for a review). Previous studies of fast-paced video games have shown that video game players have faster visual reaction times (Bialystok, 2006; Clark, Lanphear, & Riddick, 1987; Goldstein et al., 1997; Orosyfiles & Allan, 1989; Yuji, 1996; see Dye, Green, & Bavelier, 2009 for a review) and enhanced visuomotor coordination (Drew & Waters, 1986; Griffith, Voloschin, Gibb, & Bailey, 1983). A number of video game training regimens have produced enhancements in skills such as spatial visualization, mental rotation, and distinguishing between trajectories of moving objects (Dorval & Pepin, 1986; Gagnon, 1985; Mcclurg & Chaille, 1987; Subrahmanyam & Greenfield, 1994). Finally, action video game play enhances various aspects of attention, such as the number of objects that can be simultaneously attended, the spatial and temporal distribution of visual selective attention, and the ability to divide attention (Feng,

Spence, & Pratt, 2007; Green & Bavelier, 2003; Green & Bavelier, 2006a, 2006b, 2007; Greenfield, de Winstanley, Kilpatrick, & Kaye, 1994). Importantly, these enhancements may lead to some real-world benefits, as pilots and laparoscopic surgeons trained on video games have been reported to outperform their peers (Gopher, Weil, & Bareket, 1994; Rosenberg, Landsittel, & Averch, 2005).

A framework for understanding these changes holds that video game play alters the spatiotemporal resolution of visual processing. In accordance with this view, Green and Bavelier (2007) have shown that action video game play results in enhancements in the spatial resolution of visual processing, in the form of reduced crowding. Action video game players (VGPs) could maintain 79% threshold performance with flankers brought nearer to the target than non-action game players (NVGPs). Greater temporal resolution of visual processing is supported by findings that VGPs have a reduced Attentional Blink. Yet, interpretations of the Attentional Blink paradigm are complex as attentional and perceptual factors are known to be at play in the Attentional Blink performance, and some studies have

failed to find Attentional Blink differences in gamers (Boot, Kramer, Simons, Fabiani, & Gratton, 2008). Our goal here is to evaluate the proposal that action video game playing changes the temporal dynamics of visual processing. To do so, we assessed the effect of gaming on the temporal dynamics of lateral visual masking.

Experiment 1: Lateral masking in VGPs and NVGPs

To investigate the temporal dynamics of visual processing, a lateral masking paradigm was used (Figure 1). Participants had to decide in which of two intervals a central Gabor patch (GP) was presented. We compared how high the contrast of this central GP had to be for detection when it was accompanied by a lateral mask—two lateral Gabor patches—versus in isolation. Increase in contrast in the presence of the lateral mask as compared to in isolation provides a direct measure of the strength of masking. Such a lateral masking effect is determined by a spatial–temporal combination of several factors including the processing time of the target, the order of presentation of the target and the mask, and the spatial arrangement of the target and the mask (Polat & Sagi, 2006; Polat, Sterkin, & Yehezkel, 2007). A masking effect is observed when

the mask is positioned within a short spatial range of the lateral masks (2 wavelengths, λ or less) and when the temporal separation between the target and the mask is short. In contrast, facilitation—the fact that the target is more visible in the presence of the lateral mask—is observed when the mask is presented at a larger spatial separation from the lateral masks (3λ) and also when presented simultaneously with or before the target (Polat & Sagi, 2006). Computational models suggest that these lateral masking effects, either inhibitory or facilitatory, can be captured through integration in the spatial and temporal domains of the feed-forward response to the target and of the lateral responses evoked by the mask (excitatory and/or inhibitory; Polat et al., 2007). The present paper focuses on the lateral masking effects that resemble more closely typical meta-contrast masking whereby the visibility of a target is reduced by a temporally succeeding and spatially non-overlapping mask (Alpern, 1953; Breitmeyer et al., 2006).

Meta-contrast masking has been extensively studied and a few landmark properties of the effect have been identified (Francis, 1997). Among these, three are most relevant for our purpose. First, masking is strongest when the mask follows the target (backward masking) rather than preceding it (forward masking). Second, the exact shape of the masking function changes as the target luminance is varied. Third, when the target luminance is

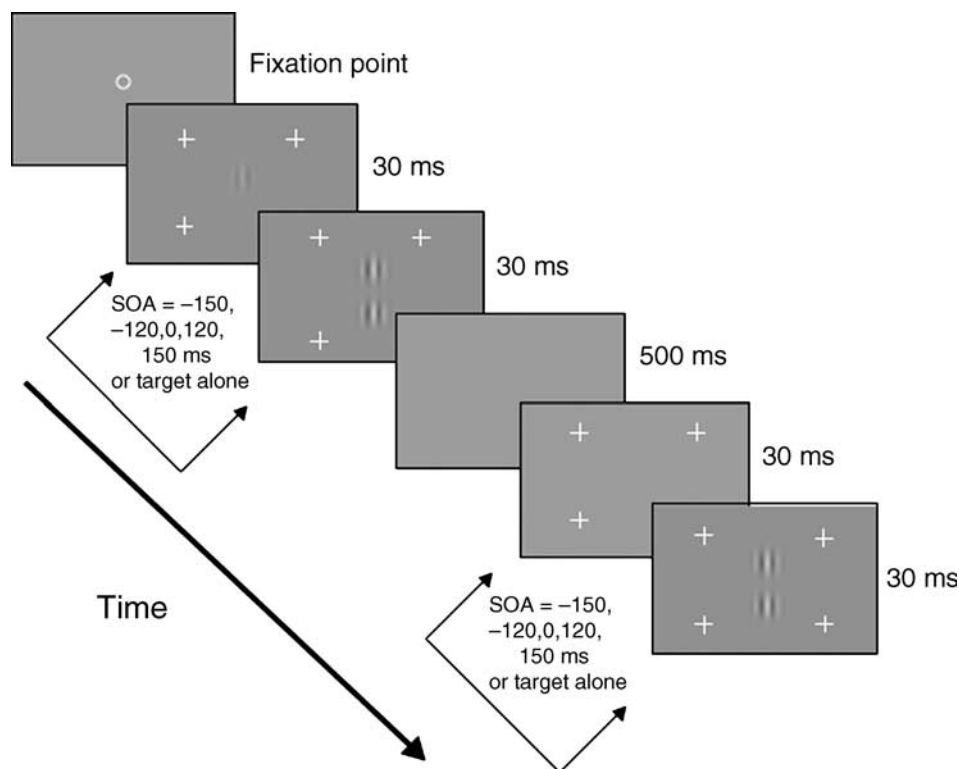


Figure 1. The lateral masking paradigm: Participants are required to decide in which interval (first or second—marked by four peripheral crosshairs) the central Gabor target (GP) has been presented. The contrast of the central GP is adjusted adaptively to reach the 79% correct threshold. Higher levels of contrast correspond to stronger masking effect.

low and the spatial structure of target and masks are the same, the strength of backward masking varies as SOAs increase, with a characteristic U-shape function whereby backward masking is strongest at intermediate SOAs (Rogowitz, 1983). The goal of [Experiment 1](#) was to measure and compare the strength of forward, simultaneous, and backward masking in VGPs and NVGPs to characterize the dynamic properties of early visual processing as a function of action game experience. The lateral masking paradigm selected for this purpose has several advantages. First, there is common agreement that it measures masking strength as a result of low-level interactions (Sterkin, Yehezkel, Bonneh, Norcia, & Polat, 2009), in contrast to object substitution masking, which taps higher levels of processing (Enns & Di Lollo, 2000). It is therefore better suited for investigating changes in temporal dynamics of even early visual processes. Second, it assesses masking using levels of luminance that are functionally equivalent across groups. This was necessary to address the concern that VGPs and NVGPs vary in their contrast sensitivity (Li, Polat, Makous, & Bavelier, 2009). Thus rather than fixing the luminance level of the target stimulus, the procedure used here measures the amount of contrast that has to be added to the target for it to be detectable in the presence of a high luminance mask.

[Experiment 1](#) first asks whether lateral masking displays the same U-shape characteristics as meta-contrast masking as well as greater masking strength from backward vs. forward masks by considering the performance of NVGPs on this paradigm. Then, it looks at how masking strength is affected in action game players. Our hypothesis predicted that VGPs would suffer less from lateral masking than NVGPs.

Methods

Subjects

Subjects were screened through a video game playing questionnaire designed to establish the frequency of action video game usage in the 12 months prior to testing. For each video game that participants reported playing, they were asked how often they had played that game in the previous 12 months and for how long they had played it during a typical session. Subjects who played at least 5 h of action video game per week during the past year were classified as VGPs. Qualified action video games are those that have fast motion and intense visual stimuli and require monitoring of periphery and simultaneous tracking of multiple objects, for example, Unreal Tournament, Counter Strike, Halo, Call of Duty, etc. Not all games labeled Action by the Video Game Industry have these features—in particular games with too many subgames, for example, Grand Theft Auto, Prince of Persia, Tomb Raider, and God of War. Subjects that play those games typically also play the faster paced, divided attention games, and thus fall under the VGP category. Finally,

those subjects who had little to no action video game experience (<1 h per month) in their past year were classified as NVGPs; note that some NVGPs did play other kinds of games, such as board games, puzzle games, card games, strategy games, or social games. Ten male NVGPs (age range 22–31 years old, mean age 25.5) and nine male VGPs (age range 19–28 years old, mean age 23.0) were recruited for [Experiment 1](#). The average of action video game play in VGPs was 57 h/month with a range of 20–120 h/month. The average of action video game play in NVGPs was 0. All subjects had normal or corrected-to-normal vision and performed at 20/20 or better with the logarithmic visual acuity chart “2000.” All the subjects provided informed written consent before the experiments and were paid \$8/h.

Stimuli and procedure

Stimuli were displayed on a Mitsubishi Diamond Pro SB CRT monitor with 1280 * 1024 resolution and 100-Hz refresh rate using the Windows XP operating system. The subjects were tested in a dark room. The mean display luminance was 17 cd/m², and viewing distance was 1.5 m. Gamma was calibrated by fitting the best linearity between 10 different luminance levels (from 0 to 240) on the monitor (full field) and readings from a photometer (Minolta Chromameter, CS-100).

Stimuli and procedure were similar to those used in Polat and Sagi (2006). The stimuli consisted of a foveally viewed Gabor signal, which was either alone or masked collinearly by two vertically flanking Gabor signals ([Figure 1](#)). The luminance distribution of a Gabor signal is described by the following equation:

$$L(x, y|x_0, y_0) = \cos(2\pi/\lambda((x - x_0)\cos\theta + (y - y_0)\sin\theta)) \\ * \exp(-((x - x_0)^2 + (y - y_0)^2)/\sigma^2), \quad (1)$$

where x and y are the horizontal and vertical coordinates, respectively, θ is the orientation of the Gabor signal, λ is the wavelength, and σ is the standard deviation of the Gaussian envelop. In this experiment, target and masks had the same orientation ($\theta = 0$, vertical orientation) and the same spatial frequency ($\lambda = \sigma = 0.16$ deg) with a center-to-center separation of 2λ . Although Gabor signals do not have sharp boundaries, the size of a stimulus with $\lambda = \sigma = 0.16$ deg is about 0.38 deg * 0.38 deg. The contrast of masks was kept constant at 60%. Target and masks were presented for 30 ms each. In [Experiment 1](#), five SOAs were used (−150 ms, −120 ms, 0 ms, 120 ms, and 150 ms). All conditions (SOAs and target alone) were presented in a mixed design.

A typical trial is shown in [Figure 1](#). A two-alternative forced-choice interval paradigm was used. Before each trial, a small white fixation circle was presented at the

center of the screen, where the target GP was to be flashed. Trials were self-paced and initiated by pressing the space bar. Each trial consisted of two intervals, marked by four peripheral high-contrast crosses and separated by a 500-ms blank. In the mask trials, only one of the intervals contained the target; both intervals contained masks. In the target-alone trials, masks were not presented and only one interval contained the target. All six different conditions were interleaved (5 SOAs + target alone). Subjects indicated which interval had the target by key presses (1st versus 2nd interval). An auditory beep signaled an incorrect response. Target contrast increased by 0.1 log unit after one error and decreased by 0.1 log unit following three consecutive correct responses, following a 3-down 1-up adaptive staircase procedure. Several staircases were run in a mixed mode. All staircases continued until the program stopped, but, when computing thresholds, each staircase was considered as having converged after 8 reversals or 60 trials whichever was reached first. Contrast threshold, which is known to converge to 79% correct under such conditions (Levitt, 1971), was defined as the mean of the final six reversals or all the reversals but the first two if termination was triggered by reaching 60 trials. The masking effect was measured by computing the threshold elevation, that is, the difference between the contrast threshold of the target in the presence of masks and the contrast threshold of the target in isolation. We note that there was no major difference between the two groups regarding the number of trials or the time needed to converge, in this and the next experiments.

Results

Average threshold elevations for gamers and non-gamers are plotted in Figure 2.

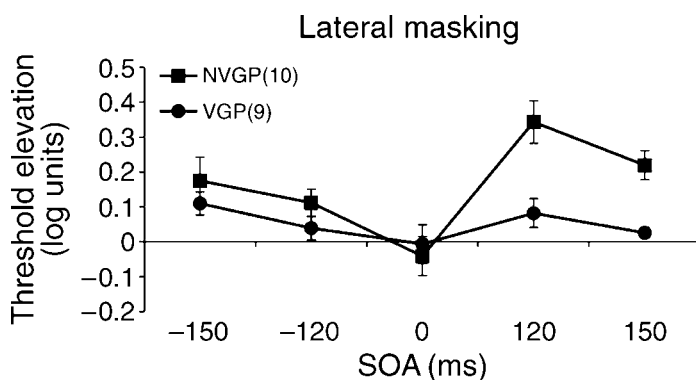


Figure 2. VGPs' and NVGPs' performances in lateral masking (SOA = -150, -120, 0, 120, and 150 ms). A significant group difference was observed in backward masking (SOA = 120, 150) but not in forward masking (SOA = -150, -120) or simultaneous masking (SOA = 0).

Omnibus ANOVA

A 2 * 5 ANOVA was carried out, with action game experience (VGPs/NVGPs) as a between-subject factor and SOA (-150, -120, 0, 120, 150 ms) as a within-subject factor using threshold elevation as the dependent variable. A main effect of SOA indicated that the size of the masking effect varied with SOA with the largest masking effect seen at backward masking ($F(4,68) = 7.737$, $p < 0.001$, $\eta_p^2 = 0.313$). Importantly, VGPs showed overall reduced masking as compared to NVGPs ($F(1,17) = 9.02$, $p < 0.01$, $\eta_p^2 = 0.35$). This reduction was especially remarkable for backward masking as indicated by an interaction between video game status and SOA ($F(4,68) = 3.39$, $p < 0.05$, $\eta_p^2 = 0.17$).

Separate analyses were carried out for forward, simultaneous, and backward masking to further qualify the interaction between SOA and video game status. An analysis of backward masking revealed a significant group difference ($F(1,17) = 16.75$, $p < 0.001$, $\eta_p^2 = 0.50$), whereas no such difference was found for either forward ($F(1,17) = 0.14$, $p > 0.70$, $\eta_p^2 = 0.01$) or simultaneous masking ($F(1,17) = 0.70$, $p > 0.40$, $\eta_p^2 = 0.04$).

Lateral masking in NVGPs

Finally, a separate analysis of NVGPs was carried out to characterize the properties of lateral masking, unconfounded with action game play. Using the 5 levels of SOA, a main effect of SOAs was found, indicating differences in strength of masking as SOA varies ($F(4,36) = 8.51$, $p < 0.001$, $\eta_p^2 = 0.49$). Separating the SOAs into backward and forward masking, larger effects for backward than for forward masking were found ($F(1,9) = 12.44$, $p < 0.01$, $\eta_p^2 = 0.58$). Simultaneous masking showed no facilitation as expected due to our choice of 2λ (Polat & Sagi, 1993, 2006).

Discussion

Experiment 1 assessed forward, simultaneous, and backward lateral masking in both non-action gamers and action gamers. Lateral masking in NVGPs was greater for backward than forward masking and showed an inverted U-shape for backward masking. This pattern of data adds to the existing literature on lateral masking (Polat & Sagi, 2006) and closely mirrors masking in general (Breitmeyer, 1984; Breitmeyer & Ogmen, 2000; Enns & Di Lollo, 2000). In addition, reduced backward masking was found in action gamers, with little to no changes in forward and simultaneous masking.

The proposal that the temporal dynamics of visual processing are altered in action gamers was confirmed as VGPs displayed overall reduced lateral masking as compared to NVGPs. This effect was most marked for backward masking supporting the proposal that action gaming results primarily in changes in the dynamics of

cortical networks. Indeed, forward masking is known to rely more heavily on peripheral, eye-related factors than backward masking (Greenspoon & Eriksen, 1968; Smith & Schiller, 1966; Turvey, 1973). This contention is further supported by the finding that schizophrenic patients who have cortical deficits also show changes in backward masking despite intact forward masking. Schizophrenic patients exhibit larger backward masking in the face of unchanged forward masking, in accord with the view that backward masking but not forward masking is primarily centrally mediated (Saccuzzo, Cadenhead, & Braff, 1996).

At the target–mask distance used here (2λ), simultaneous masking did not differ across populations. This may seem surprising given that higher crowding acuity has been reported in VGPs as compared to NVGPs (Green & Bavelier, 2007). It remains unclear whether changes in simultaneous masking between these two populations may be found at other target–mask distances or whether changes in crowding acuity reported in past work may index changes in the processing resolution of attention, rather than the relatively early stages of visual processing believed to be under study here (He, Cavanagh, & Intriligator, 1996). This is an issue that remains to be resolved.

Experiment 2: Collinear and orthogonal backward masking

To further characterize the change in temporal dynamics noted in Experiment 1, Experiment 2 focused exclusively on backward masking where differences were noted between the two groups. The goal of Experiment 2 was twofold. First, it aimed at more precisely characterizing the temporal time course of backward masking (Breitmeyer & Ganz, 1976). To do so, masking was assessed across groups at the following SOAs (0, 30, 60, 90, 120, 150 ms). Second, Experiment 2 aimed to confirm the orientation dependence of the masking effect by using both collinear and orthogonal masks. In previous studies,

masking was demonstrated to be sensitive to the orientation of target and masks at least in the case of simultaneous masking (Polat & Sagi, 1993). The fact that the nature of the interaction between target and masks may change as a function of the orientation of the masks is indicative of a mechanism for masking that is sensitive to the orientation of receptive fields. Although not diagnostic of a given cortical level of processing, such changes indicate that the organization of early visual cortex has an impact on the masking effect. The aim of Experiment 2 was to determine the respective effects of collinear and orthogonal masks on backward masking in VGPs and NVGPs.

Methods

Subjects

Eleven male NVGPs (age range 19–31 years old, mean age 25, three of whom participated in E1) and nine male VGPs (age range 22–29 years old, mean age 23.6, six of whom also participated in E1) were recruited by the same criterion as in Experiment 1. The average of action video game play in VGPs is 45 h/month with a range of 20–90 h/month. The average of action video game play in NVGPs is 0.

Stimuli and procedure

The stimuli and procedure were identical to those of Experiment 1 except that two kinds of masks were used (collinear or orthogonal to the target) and that only simultaneous and backward masking were tested, albeit with more SOAs (0, 30, 60, 90, 120, 150 ms). Collinear and orthogonal masks were tested in separate blocks. In each block, the seven conditions were mixed.

Results

Average threshold elevations for collinear and orthogonal masks are plotted in Figures 3a and 3b, respectively.

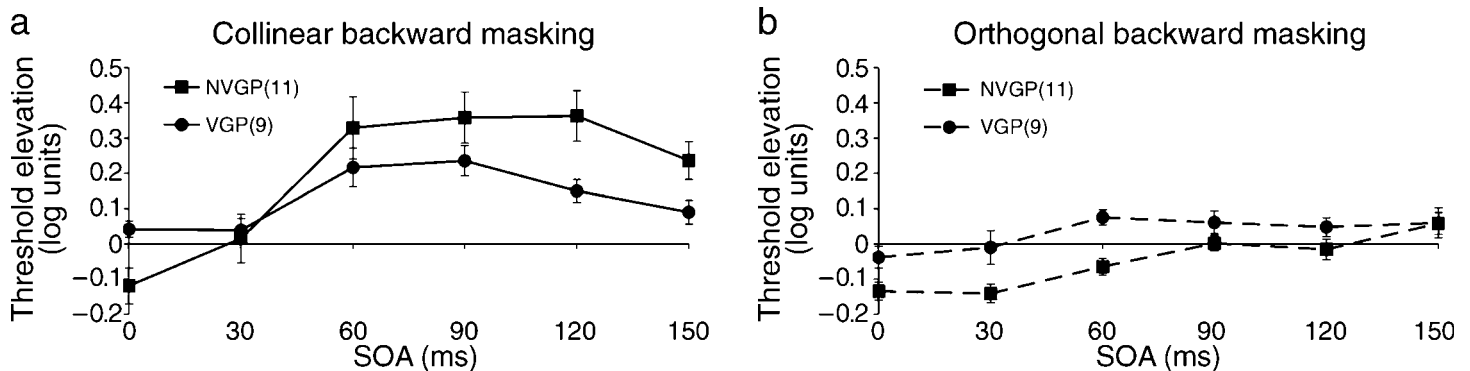


Figure 3. (a) VGPs' and NVGPs' performances in collinear backward masking. (b) VGPs' and NVGPs' performances in orthogonal backward masking.

Omnibus ANOVA

A $2 \times 2 \times 6$ ANOVA with action game experience (VGP/NVGP), mask orientation (collinear/orthogonal), and SOA (0, 30, 60, 90, 120, 150 ms) as factors and threshold elevation as the dependent variable was carried out. As expected, a main effect of SOA ($F(5,90) = 20.27$, $p < 0.001$, $\eta^2 = 0.53$) was observed, reflecting the inverted U-shape curve of the masking effect as a function of SOA (Breitmeyer & Ganz, 1976). An effect of mask orientation ($F(1,18) = 89.71$, $p < 0.001$, $\eta^2 = 0.83$) confirmed a greater masking effect from collinear than orthogonal masks. The effect of mask orientation interacted with action game experience ($F(1,18) = 17.27$, $p < 0.001$, $\eta^2 = 0.49$), indicating different sensitivities to the mask orientation between VGPs and NVGPs (Figure 4). The effect of mask orientation also interacted with SOA ($F(5,90) = 4.75$, $p < 0.001$, $\eta^2 = 0.21$). The effect of collinear masks was greater at intermediate SOAs whereas those of orthogonal mask were greater at early SOAs (Figure 3). Finally, an interaction between action game experience and SOA ($F(5,90) = 3.80$, $p < 0.01$, $\eta^2 = 0.17$) suggested different sensitivities to SOA across groups. These interactions led us to perform additional analyses on mask orientation and gaming group separately.

Effect of mask orientation

The effect of mask orientation was further investigated by performing 2×6 ANOVAs with mask orientation (collinear/orthogonal) and SOA (0, 30, 60, 90, 120, 150 ms) as factors in NVGPs and VGPs separately. As expected, NVGPs showed a difference between collinear and orthogonal masks ($F(1,10) = 82.11$, $p < 0.001$, $\eta^2 = 0.89$, Figure 4). This effect was dependent on SOA ($F(5,50) = 4.46$, $p < 0.01$, $\eta^2 = 0.31$). VGPs also showed a significant difference between collinear and orthogonal masks, albeit a less robust difference ($F(1,8) = 18.91$, $p < 0.01$, $\eta^2 = 0.70$, Figure 4). No interaction of mask orientation with

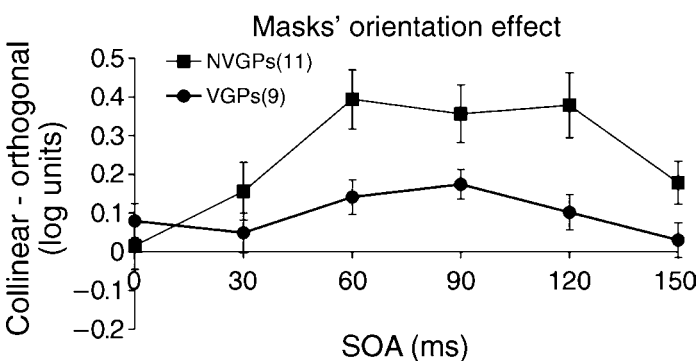


Figure 4. Effect of masks' orientation in VGPs and NVGPs. Y-axis represents the difference between masking with collinear versus orthogonal masks. NVGPs exhibited a greater sensitivity to the orientation of the mask as compared to VGPs ($F(5,90) = 17.27$, $p < 0.001$, $\eta^2 = 0.49$).

SOA was observed for VGPs ($F(5,40) = 1.63$, $p > 0.17$, $\eta^2 = 0.17$).

VGPs vs. NVGPs for collinear and orthogonal masks

Separate 2×6 ANOVAs with action game experience (VGP/NVGP) and SOA (0, 30, 60, 90, 120, 150 ms) as factors were carried out for collinear and orthogonal backward masking separately.

The 2×6 ANOVA for collinear masks indicated a main effect of SOA ($F(5,90) = 11.54$, $p < 0.001$, $\eta^2 = 0.39$), with an inverted U-shape function as previously reported in the literature. A marginal effect of action game experience ($F(1,18) = 3.35$, $p = 0.08$, $\eta^2 = 0.16$) was observed as well as an interaction between SOA and action game experience ($F(5,90) = 2.74$, $p < 0.05$, $\eta^2 = 0.13$). As expected, VGPs showed less backward masking than NVGPs at long SOAs replicating Experiment 1; this group difference was less marked at shorter SOAs as illustrated by the SOA by action game experience interaction.

The 2×6 ANOVA for orthogonal masks revealed main effects of SOA ($F(5,90) = 16.95$, $p < 0.001$, $\eta^2 = 0.49$) and of action game experience ($F(1,18) = 5.82$, $p < 0.05$, $\eta^2 = 0.24$) as well as an interaction between these two factors ($F(5,90) = 3.22$, $p < 0.01$, $\eta^2 = 0.15$). NVGPs exhibited weak facilitation at short SOAs, which disappeared at longer SOAs. In contrast, VGPs showed overall little sensitivity to the masks (post-hoc *t*-test at each SOA indicated no difference from 0, except for a small inhibitory effect at 60-ms SOA).

Discussion

Experiment 2 examined the temporal dynamics of lateral masking by adding more SOAs, complementing the work of Polat and Sagi (2006), which focused on just one forward and one backward SOA. Experiment 2 shows a clear inverted U-shape of backward masking for collinear masks (Figure 3a). This inverted U-shape curve is consistent with the classic finding of meta-contrast masking (Enns & Di Lollo, 2000) and replicates closely Experiment 1. Experiment 2 also replicates Experiment 1 in that VGPs showed again reduced backward masking as compared to NVGPs, with this effect being strongest at SOAs of 90 ms and more.

Mask orientation plays an important role in lateral masking, with orthogonal masks hindering target detection to a lesser extent than collinear masks. Although it was reported previously that simultaneous masking, and thus spatial lateral interactions between target and masks, is sensitive to orientation (Polat, Mizobe, Pettet, Kasamatsu, & Norcia, 1998; Polat & Sagi, 1993), the present study extends this result by showing that lateral backward masking is also orientation specific. This overall result

was observed in both VGPs and NVGPs indicating sensitivity to orientation in both groups. Such sensitivity to orientation supports the view that the mechanisms under study are cortical in nature and tap representations early enough in the visual processing hierarchy to be sensitive to orientation.

Importantly, the effect of maskers, whether collinear or orthogonal, was overall larger in NVGPs than VGPs. The present experiment replicates and extends [Experiment 1](#) showing lesser hindrance from backward collinear masks in VGPs than NVGPs. Additionally, orthogonal masks led mostly to a facilitatory effect, whereby, in contrast to the typical backward masking effect, the presence of the masks facilitated target processing. This facilitatory effect was especially marked at short SOAs in NVGPs; in contrast, VGPs displayed little sensitivity to the orthogonal maskers.

Overall, the presence of masks in VGPs had a lesser impact on target processing. This held true whether the masks hindered or facilitated target processing, suggesting a shorter temporal range of interaction between target and masks in VGPs than NVGPs. Models of lateral interactions designed to capture the basic phenomenon of masking and facilitation within the lateral masking paradigm provide additional pointers to the mechanisms at play (Adini & Sagi, 2001; Adini, Sagi, & Tsodyks, 1997; Polat, 1999). In such models, reduced lateral backward masking may be achieved through faster excitatory lateral interactions (or feedback) leading to lesser inhibitory local mechanisms. Alternatively, reduced inhibition and/or a shorter time constant for inhibition (Polat & Sagi, 2006; Sterkin et al., 2009) may also allow the more slowly developing excitation to take place. These proposals will have to be further tested with modeling work.

Experiment 3: Training study

[Experiments 1](#) and [2](#) indicate a much reduced backward masking in VGPs as compared to NVGPs, suggesting a change in the temporal dynamics of visual processing in VGPs. While our hypothesis is that extensive action video game experience is at the root of the observed reduction in backward masking, it may be the case that individuals with better perceptual skills are more inclined to become VGPs. Indeed, individuals with reduced masking may have an advantage when playing and thus may become more keen players. To establish the causal effect of action gaming, an intensive training study (50 h over 9 weeks) was conducted on a small sample of NVGPs.

Methods

Subjects

Twenty-five naive NVGPs were recruited using the same criterion as in [Experiment 1](#). Participants were

randomly assigned to one of two groups: the action group played fast-paced action video games (*Unreal Tournament 2004* and *Call of Duty 2*) while the control group played a non-action video game (*The Sims 2*). The action trainees included 14 participants (7 males and 7 females, 20–30 years old, mean age 26.0 years old). The control trainees included 11 participants (4 males, 7 females, 22–28 years old, mean age 24.7 years old). One subject in the action group and one in the control group were excluded from this study, because their pre-test performance were more than 2 standard deviations from the mean.

Stimuli and procedure

A few days before and after the training period, participants' masking functions were assessed. The stimuli and procedure were identical to [Experiment 1](#) except for the two following changes: to further characterize the change in temporal dynamics, six SOAs were used (−120 ms, −60 ms, 0 ms, 60 ms, 120 ms, and 150 ms); to get better threshold estimates, each subject performed the task twice on the same day in both pre- and post-tests.

Video game training

For both groups, training consisted of playing a video game for 50 total hours. The subjects were allowed to play a maximum of 2 h per day and a maximum of 10 h per week. No minimum amount of game play per week was enforced, but subjects were required to finish the 50-h training in no more than 9 weeks. The subjects completed the 50 h in an average of 44 days. The training games for both the action and the control conditions covered the entirety of the screen (a visual angle of approximately 15° height × 18° width).

The control group played *The Sims 2* (2004, Electronic Arts). *The Sims 2* is a simulation-style game, wherein the player takes complete control over the life of a character, which involves everything from everyday activities (eating, bathing, etc.) to going to work, managing relationships with other characters, getting married, having and raising children, and eventually growing old and dying. As characters are added to the household, the player takes control of those characters as well. Our trainees took control of an average of 10 different characters during the 50 h of training.

Participants in the action group played games similar to those played by our VGPs in [Experiments 1](#) and [2](#). During the first half of training, the action group played the game *Unreal Tournament 2004* (Epic Games) in Death Match mode, where the goal is for the player to kill as many of the computer-controlled characters as possible, while minimizing the number of times the player dies. During piloting of the training regimen, we noticed that the difficulty level changes non-linearly in that game such that, after about 25 h, trainees reach a level that is too hard for anyone with that level of experience to play.

Unfortunately, the next level down was clearly too easy for these trainees. In an attempt to minimize the difference with the control game trainees who kept experiencing new and rewarding situations, the action group played the game *Call of Duty 2* (Activision) during the second half of training. This game puts the player into fictionalized World War II combat situations, with the primary goal again being to kill as many computer-controlled characters as possible while minimizing the player's own deaths. Subjects were retested on all levels of *Unreal Tournament 2004* at the end of training in order to assess improvement in skill. It should be noted that even by asking the action group to play two games, the control group trainees played five times as many characters, had more variable goals, and were exposed to more diversity in their environment than the action group trainees. We chose to keep the action game trainees at a disadvantage for these factors to ensure that amount of stimulating situations encountered could not be used to explain any improvements in the action group beyond what is seen in the control group. Assignment of the subjects to the two groups was random.

Each group was requested to log their performance regularly (control game: accumulated wealth; experimental game: ratio of kills to death). In addition, the experimental group was told to reach a ratio of two kills for one death before advancing to a harder level. This ensured that players progressed through the game smoothly, avoiding long period of frustration because the game was too hard or boredom because it was too easy. This was not an issue in the control game, which progresses automatically through more and more advanced situations.

Results

The results of both groups are plotted in Figure 5.

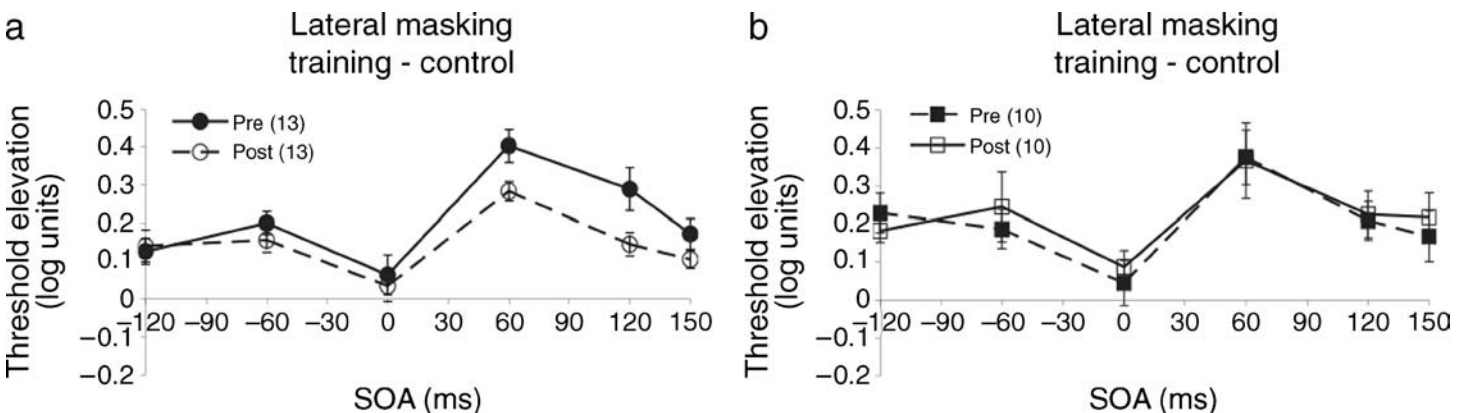


Figure 5. Results in training study. (a) Reduced lateral masking after training in action group. (b) No change in lateral masking after training in control group.

Omnibus ANOVA

We first confirmed that the two groups were comparable at pre-test. A 2 (control/action) * 6 (6 SOAs) ANOVA was carried on pre-test measurements and no effect of group was noted ($F(1,21) = 0.015$, $p = 0.905$, $\eta^2 = 0.001$).

A 2 * 2 * 2 * 6 ANOVA with threshold elevation as the dependent variable and training game (action/control), test (pre/post), run (1st/2nd), and SOA as factors was then carried out. No main effect of run was found ($F(1,21) = 2.434$, $p > 0.13$, $\eta^2 = 0.104$) nor did this factor interact with any other factors; it will not be discussed further. As expected, a main effect of SOA was observed ($F(5,105) = 22.988$, $p < 0.001$, $\eta^2 = 0.523$), indicating that the size of the masking effect varied with SOA. A marginally significant interaction between training game (action/control), test (pre/post), and SOA ($F(5,105) = 2.033$, $p < 0.08$, $\eta^2 = 0.088$) led us to carry out separate ANOVAs for the three different types of masking (forward, simultaneous, and backward).

A 2 (pre/post) * 2 (control/action) * 3 (SOA: 60, 120 and 150 ms) ANOVA was performed to assess the effect of training on backward masking. The action-trained group showed a greater decrease in backward masking from pre- to post-training than the control group (pre/post * control/action interaction: $F(1,21) = 6.84$, $p < 0.02$, $\eta_p^2 = 0.25$, Figure 5a), establishing the causal effect of playing action video games in reducing lateral backward masking. There was no group difference in forward (pre/post * control/action interaction: $F(1,21) = 0.18$, $p > 0.65$, $\eta_p^2 = 0.01$) or simultaneous masking (pre/post * control/action interaction: $F(1,21) = 0.88$, $p > 0.35$, $\eta_p^2 = 0.04$) from pre- to post-training between action and control groups. Additional analyses for each group confirmed a reduced backward masking effect after training in the action group (pre/post effect for backward masking: $F(1,12) = 7.02$, $p < 0.05$, $\eta^2 = 0.37$) and no such difference in the control group (pre/post effect for backward masking: $F(1,9) = 1.62$, $p > 0.24$, $\eta^2 = 0.15$, Figure 5b).

Discussion

This pattern of results confirms the causal role of action game playing in changing the dynamics of backward masking and rules out any explanation in terms of differences in genetic endowment between those that play action games and those who do not. This training study also makes clear that not all video games have an effect on backward masking. While control trainees did play engrossing video games, they did not show any changes in masking strength. The use of fast-paced, embodied games such as action video games seems to be required to reduce backward masking, at least in young individuals with normal or corrected-to-normal vision. The inclusion of control trainees also allows us to rule out alternative explanations for the effect of action game training such as test–retest improvements and social attention effects such as the Hawthorne effect (whereby individuals that are attended to tend to perform better). Finally, it is worth noting that only backward masking was affected by training. Forward and simultaneous masking remained unchanged, rendering explanations of the group differences in terms of motivational, attentional, or arousal factors extremely unlikely.

General discussion

Visual masking is a classic and powerful tool for studying changes in processing speed. It has the advantage over reaction times of providing measures of processing that are not confounded with execution or motor selection issues. Additionally, it is often used as a robust predictor of susceptibility to cognitive dysfunction since larger backward masking is typically associated with lower functioning, a finding noted in schizophrenics (Green & Nuechterlein, 1999; McClure, 2001; Saccuzzo et al., 1996), dyslexics (Di Lollo, Hanson, & McIntyre, 1983; Lovegrove & Brown, 1978; Williams & Lecluyse, 1990), and older adults (Di Lollo, Arnett, & Kruk, 1982; Waszak, Schneider, Li, & Hommel, 2009). Here we show that action video game experience can change visual backward masking, but in this case for the better. A lateral masking paradigm was used to characterize the temporal dynamics of visual processing in VGPs and NVGPs and confirmed the proposal that VGPs suffer less from backward masking. Our training study excluded the possibility of self-selection and established the causal role of playing action video games in this change. Although there are some reports showing that the strength of backward masking weakens with practice (Hogben & Di Lollo, 1984; Ventura, 1980) and that expert tennis players showed reduced backward masking effects (Overney, Blanke, & Herzog, 2008), this is the first report to identify

a training regimen that can reduce visual backward masking. This work establishes that the dynamics of visual processing can be significantly altered even in adulthood.

The change induced by action game play appears to be best understood as arising from cortical dynamics rather than alterations of peripheral, eye-related factors. First, lateral masking was seen to decrease after action gaming when the masks followed the target (backward) but not when the mask preceded the target (forward). Backward masking is believed to depend on cortical dynamics to a greater extent than forward masking, which seems more dependent on eye-related factors (Greenspoon & Eriksen, 1968; Smith & Schiller, 1966; Turvey, 1973). Second, lateral masking is known to depend, at least in part, on the spatiotemporal dynamics of lateral interactions in the visual cortex (Polat & Sagi, 1993, 2006; Polat et al., 2007; Sterkin et al., 2009). The effect of backward masking is also under the control of higher level spatiotemporal interactions as demonstrated by the complex interplay between the processing time of the target, the order of presentation of the target and the mask, and the spatial arrangement of the target and the mask (Duangudom, Francis, & Herzog, 2007; Polat & Sagi, 2006; Polat et al., 2007; Sterkin et al., 2009). Thus, changes in dynamics in VGPs may occur in the visual cortex or in later, integrative areas such as the parietal cortex, or possibly both. This latter locus has been implicated in backward masking in schizophrenics (McClure, 2001) who exhibit a striking deficit in visual backward masking in the face of intact forward masking (Saccuzzo et al., 1996). Whether the mechanism at play in gamers is similar, albeit reversed, to that in schizophrenic patients, remains to be elucidated.

The role of attention in the advantage noted after action gaming is worth considering, as action gaming alters attention and attention enhances contrast perception (Carrasco, Ling, & Read, 2004) and reduces backward masking (Boyer & Ro, 2007; Ramachandran & Cobb, 1995). Could the reduced backward masking in action game trainees be explained by better attentional skills? We would argue that there is little ground for a purely attentional explanation of the findings presented here. First, attention improves contrast and reduces masking in the visual periphery, but whether it does so in the fovea as the present study shows remains unknown. Moreover, an attentional explanation predicts that forward and backward masking should be equally alleviated; this was not the case.

The proposal of altered cortical dynamics in VGPs finds further support in two recent reports in the literature. First, Donohue, Woldorff, and Mitroff (2010) have documented that, whereas NVGPs require a visual stimulus to come ahead of an auditory tone to perceive the two events as simultaneous, VGPs perceive visual and auditory stimuli as being simultaneous when they are closer to true,

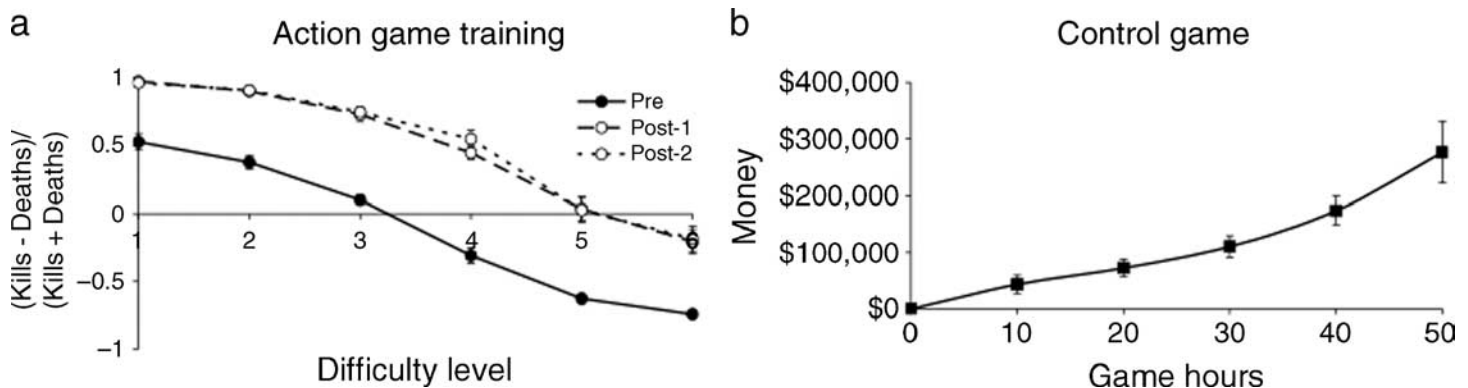


Figure A1. (a) Action group's gaming performance in Unreal Tournament in training study. (b) Control group's gaming performance in Sims 2 in training study.

physical simultaneity. VGPs may therefore have a more veridical perception of the timing of events, a skill consistent with shorter temporal windows of interactions in VGPs. Second, Green, Pouget, and Bavelier (2010) have recently established that action video game play increases perceptual sensitivity be it in the visual or auditory domains. VGPs were found to integrate information over time more efficiently, in accordance again with a change in cortical dynamics. The proposal of more efficient cortical dynamics in VGPs, as demonstrated here for visual processing, is appealing as it naturally captures the greater efficiency of gamers at processing visual information across a variety of tasks. Indeed, a change in the dynamics of visual processing also naturally accounts for other documented effects of action game play such as shorter critical duration (Green et al., 2010; Li et al., 2009), lesser attentional blink (Green & Bavelier, 2003), and faster choice reaction times in VGPs as compared to NVGPs (Dye et al., 2009; Green et al., 2010). The present finding of reduced backward masking in VGPs is therefore consistent with the working hypothesis proposed by Dye et al. (2009) and Green et al. (2010) that action video game play may enhance performance over a wide variety of visual skills and tasks by speeding up visual information processing, changing the rate at which information is integrated, possibly allowing VGPs to be less susceptible to the interference from maskers.

Appendix A

Gaming performance in training study

For the action game, kills and deaths in each block were used to calculate a skill metric $S = \frac{[\text{Kills} - \text{Deaths}]}{[\text{Kills} + \text{Deaths}]}$. Subjects were tested on this metric at all six difficulty levels prior to training. Subjects were reassessed at the 25th and 26th (after completing Unreal

Tournament) and 49th and 50th hour of training (to get a final value of performance on the same scale as used before training). All participants' gaming skills improved significantly after playing 24 h of Unreal Tournament (post-1) and continued to be excellent after playing 22 h of Call of Duty (post-2; Figure A1a).

For the control game, the amount of money accumulated (which increases with positive actions, such as being promoted or adding a member to one's household, and decreases with negative actions, such as burning down one's house or having a character die due to neglect) was a reliable measure of performance. All participants showed an exponential increase in accumulated wealth over the course of training. The time course of the accumulation was well fit by a polynomial function: $\text{wealth} = (77 * \text{training hour})^2 + (1319 * \text{training hour}) + 9191$, $r^2 = 98.85$ (Figure A1b).

These results demonstrated that both groups were engaged in their training and showed improvement on their respective training task.

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