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Neural bases of selective attention in action video game players

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ABSTRACT

Over the past few years, the very act of playing action video games has been shown to enhance several different aspects of visual selective attention, yet little is known about the neural mechanisms that mediate such attentional benefits. A review of the aspects of attention enhanced in action game players suggests there are changes in the mechanisms that control attention allocation and its efficiency (Hubert-Wallander, Green, & Bavelier, 2010). The present study used brain imaging to test this hypothesis by comparing attentional network recruitment and distractor processing in action gamers versus non-gamers as attentional demands increased. Moving distractors were found to elicit lesser activation of the visual motion-sensitive area (MT/MST) in gamers as compared to non-gamers, suggestive of a better early filtering of irrelevant information in gamers. As expected, a fronto-parietal network of areas showed greater recruitment as attentional demands increased in non-gamers. In contrast, gamers barely engaged this network as attentional demands increased. This reduced activity in the fronto-parietal network that is hypothesized to control the flexible allocation of top-down attention is compatible with the proposal that action game players may allocate attentional resources more automatically, possibly allowing more efficient early filtering of irrelevant information.

1. Introduction

Selective attention is fundamental to allowing task-relevant information to guide behavior, while reducing the impact of irrelevant or distracting information. Many paradigms have been developed with the goal of quantitatively measuring visual selective attention (Carrasco & Yeshurun, 1998; Eckstein, Pham, & Shimozaki, 2004; Eriksen & Eriksen, 1974; Lavie, 1997; Treisman & Gelade, 1980). These paradigms range from visual search to flanker compatibility, measuring the efficiency with which targets are selected and irrelevant, potentially distracting, stimuli are ignored. Recently, playing fast-paced action video games has been shown to enhance several different aspects of selective visual attention as compared to control games (Green & Bavelier, 2003; Hubert-Wallander, Green, & Bavelier, 2010 for a review). The present study asks how such changes in behavior may be instantiated at the neural level by comparing action video game players (VGPs) to individuals who do not play such games (NVGPs). We first review the aspects of attention that have been shown to be modified in VGPs as the design of the present study was based on this body of work.

It was first demonstrated that VGPs outperform NVGPs in selective attention by using the Useful Field of View (UFOV) paradigm initially developed by Ball and collaborators. This task requires subjects to distribute their attention widely over the screen and locate a peripheral target while ignoring irrelevant distractors (Feng, Spence, & Pratt, 2007; Green & Bavelier, 2003; Sekuler & Ball, 1986; Spence et al., 2009). Enhanced spatial selective attention in gamers has been shown more recently using different types of search tasks, such as the Swimmer task (West et al., 2008) or difficult visual search tasks (Hubert-Wallander, Green, & Bavelier, 2010; but see Castel, Pratt, & Drummond, 2005 for a different result). Interestingly, some of these tasks include a condition where participants perform a peripheral localization task while simultaneously discriminating between two possible shapes located at fixation. This version of the task requires spatial selective attention as well as divided attention. Under such conditions, VGPs outperformed NVGPs on both the peripheral task and the central task (Green & Bavelier, 2006a). Thus, both selective attention over space as well as divided attention is enhanced in VGPs.

VGPs not only exhibit better selective attention over space, they also exhibit enhanced selective attention to objects. For example, VGPs can track a greater number of dynamic, moving objects as compared to NVGPs (Dye & Bavelier, 2010; Green & Bavelier, 2003, 2006b; Trick, Jaspers-Fayer, & Sethi, 2005). This skill requires the ability to allocate attention to several objects and to do so efficiently for several seconds. Another aspect of selective attention

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also found to change in VGPs is the deployment of attention in time, or the ability to select a target from distractors presented in a temporal sequence. Using an Attentional Blink paradigm (Shapiro, 1994), limits on the dynamic allocation of visual attention were compared in VGPs and NVGPs. VGPs exhibited much less of a blink than NVGPs, with a number of VGPs exhibiting no blink whatsoever, indicating that their attention recovers more quickly over time (Green & Bavelier, 2003).

Importantly, the causal effect of action game play on several of these aspects of visual selective attention has been established through training studies in which naïve subjects are required to play either action-packed, fast-paced video games or control games. Those asked to play action games showed greater attentional gains from pre-to post-test than those asked to play control games. This was shown when testing spatial selective attention (Feng et al., 2007; Green & Bavelier, 2003, 2006a; Spence et al., 2009), selective attention to objects (Cohen, Green, & Bavelier, 2007; Green & Bavelier, 2003, 2006b) as well as selective attention over time (Cohen, Green, & Bavelier, 2007; Green & Bavelier, 2003).

The attentional skills mentioned above primarily involve goal-directed, top-down attention. This begs the question of whether other aspects of attention may be equally modified by action game play. Although stimulus-driven, exogenous attention is certainly engaged while playing action games, it seems that the capacity and dynamics of exogenous attention are less susceptible to the effects of playing action video games. Exogenous cues were found to induce equivalent performance enhancement in VGPs and NVGPs leading to similar cue-validity effects and comparable inhibition of return[2] (Castel, Pratt, & Drummond, 2005; Hubert-Wallander, Green, Sugarman, & Bavelier, 2011). Thus, not all aspects of attention are equally modified in VGPs. Reports that VGPs show reduced attentional capture as compared to NVGPs could suggest less exogenous pull in VGPs; however, the available data are also consistent with the proposal that VGPs have better top-down attentional control allowing them to either limit or recover faster from the distracting effect of abrupt onsets (Chisholm et al., 2010; but see West et al., 2008 for a different view). In line with the proposal of greater top-down selective attention in VGPs, a recent electrophysiological study by Mishra et al. (2011) reported greater suppression of distracting, unattended information in VGPs. Participants were presented with four rapid serial visual presentation streams in a steady-state visually evoked potential design allowing one to recover the cortical responses to the task-relevant attended stream as well as to the distracting, unattended streams. Under these high load conditions, VGPs and NVGPs similarly processed the attended streams, but VGPs more efficiently suppressed the unattended streams. Notably, this greater suppression was associated with faster reaction times. Greater distractor suppression may be a possible mechanism for more efficient executive and attentional control (Clapp et al., 2011 in older adults; Serences et al., 2004; Toepper et al., 2010). The present work builds on the findings of these earlier studies to further our understanding of the mechanisms that may be at play in the attentional enhancements noted in VGPs.

The present study directly compares VGPs and NVGPs by using a visual search paradigm contrasting an easy versus a more difficult search, while concurrently measuring the impact of search difficulty on the processing of irrelevant motion information (Lavie, 2005). As most behavioral changes documented so far point to improvements in top-down attention after action gaming, we expected to observe changes in the dorsal fronto-parietal network, whose role in the control and regulation of attention is well-established (Corbetta & Shulman, 2002; Hopfinger, Buonocore, & Mangun, 2000). To recruit this network, the present design varies the difficulty of target selection using small search arrays under two different perceptual load conditions. In addition, the present study takes advantage of the well-documented attentional modulation of neural activity in visuo-perceptual areas such as MT/MST to compare distractor processing in action gamers and non-gamers (Rees, Frith, & Lavie, 1997).

Subjects were presented with a ring of shapes and asked to decide whether there was a square or a diamond among the shapes presented. On each trial, there could only be one target (either a square or a diamond). By manipulating the homogeneity of the other shapes in the ring, two levels of difficulty were used (see Fig. 1). In the low load condition, all non-target shapes were circles allowing the target to pop-out and thus be easily discriminated; in the higher load condition, three different filler shapes were used leading to a more heterogeneous display making the target discrimination more difficult. Under this high load condition, we expected increased recruitment of fronto-parietal networks as compared to the low load condition. Of interest was the difference between VGPs and NVGPs in recruiting this network as search difficulty increased. Importantly, we selected rather easy search tasks (the low load effectively corresponds to a pop-out situation and the high load is just slightly more difficult) as we were aiming for relatively comparable increase in reaction times across groups from low to high attentional load. Indeed, while it is the case that VGPs have faster search rates than NVGPs (Hubert-Wallander et al., 2011), relatively matched increase in RTs between two levels of difficulty can still be found when using very easy searches. By using the low load condition as the baseline, any group differences in BOLD signal between VGPs and NVGPs could then be attributed to their group status, rather than a significantly greater increase in difficulty from low to high load in one group and not the other.

Concurrent to this main search task, irrelevant patches of random dots (either moving or static) were presented to examine distractor suppression. Previous work from Lavie and collaborators has shown that as the perceptual load of the main search task increases, distractors receive fewer processing resources, thereby resulting in smaller activation of MT/MST by irrelevant moving patterns (Lavie, 2005; Rees, Frith, & Lavie, 1997). While this pattern of results was predicted for both VGPs and NVGPs, the amount of activation in MT/MST triggered by irrelevant moving stimuli was expected to differ across populations. Greater attentional control should allow more efficient suppression of task-irrelevant motion (see for example, Mishra et al., 2011). By contrasting the neural correlates of motion processing in MT/MST in VGPs and NVGPs, the present study allowed us to directly compare how much processing irrelevant distractors may undergo in each population.

2. Material and methods

2.1. Participants

Participants were 26 naïve males (18–26 years, mean age 20.5 years) who were trained on the task prior to the scanning session. Participants were placed in one of two groups, video game players (VGPs, $n = 12$) or non-video game players (NVGPs, $n = 14$), according to their responses to a questionnaire designed to establish the frequency of action video game usage in the 12 months prior to testing. For each video game which 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. The criterion to be considered a VGP was a minimum of 5 h per week (on average) of action video game play over the previous year. It is important to note that only experience with *action* video games counted towards this requirement. Action video games are played from the first-person perspective

[2] Speed and accuracy with which an object is detected are first briefly enhanced after the object is attended, and then hindered. This hindrance has been termed 'inhibition of return'.