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Acta Psychologica 119 (2005) 217–230

acta psychologica

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The effects of action video game experience on the time course of inhibition of return and the efficiency of visual search

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Received 10 August 2004; received in revised form 10 February 2005; accepted 11 February 2005
Available online 23 March 2005

Abstract

The ability to efficiently search the visual environment is a critical function of the visual system, and recent research has shown that experience playing action video games can influence visual selective attention. The present research examined the similarities and differences between video game players (VGPs) and non-video game players (NVGPs) in terms of the ability to inhibit attention from returning to previously attended locations, and the efficiency of visual search in easy and more demanding search environments. Both groups were equally good at inhibiting the return of attention to previously cued locations, although VGPs displayed overall faster reaction times to detect targets. VGPs also showed overall faster response time for easy and difficult visual search tasks compared to NVGPs, largely attributed to faster stimulus-response mapping. The findings suggest that relative to NVGPs, VGPs rely on similar types of visual processing strategies but possess faster stimulus-response mappings in visual attention tasks.

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0001-6918/$ - see front matter
doi:10.1016/j.actpsy.2005.02.004

PsycINFO classification: 2346; 2340; 2323

Keywords: Visual attention; Inhibition of return; Visual search; Expertise; Cognitive control; Video games

1. Introduction

The ability to efficiently search the visual environment in order to locate certain objects or features is a critical component of the visual system. The manner in which one allocates attention to certain objects or features is influenced by a number of variables, some relating to the characteristics of the objects and the search display, and others relating to the prior experience of the individual. The sparse amount of previous research that has examined how video game playing influences information processing has shown that the reaction times in color and shape discrimination tasks by children who have had some experience playing video game were significantly faster than those of non-players (Yuji, 1996). Other research has shown that video game players have significantly better eye-hand motor coordination on a pursuit rotor, although no relationship was found between an individual's eye-hand motor coordination and the amount of time spent weekly playing video games or the length of experience with video games (Griffith, Voloschin, Gibb, & Bailey, 1983). More recently, Green and Bavelier (2003) demonstrated that people who have experience playing action video games display enhanced attentional capacity and control of selective attention, suggesting that experience with playing video games may alter and improve the attentional system.

In order to examine the attentional ability of action video game players (VGPs) and non-video game players (NVGPs), Green and Bavelier (2003) employed several attentional paradigms that measured attentional resources and the distribution of visual attention. In order to examine how the VGP process distracts information presented in the visual environment, Green and Bavelier measured reaction times (RTs) for target detection in situations in which a distracting "flanker" was present in the periphery. The flanker object was presented just outside the search environment, and was either compatible with the target (it was the same shape as the target) or incompatible with the target (it differed from the target in terms of shape). Participants completed this task either easily (no other distracters present in the search environment) or with difficulty (distracters were present in the search environment). The notion is that as the search display becomes more difficult, participants will be better at ignoring the flanker as they are focusing all attentional resources on the target (e.g., Lavie & Cox, 1997). However, when the task is easier, the flanker will have a distracting effect because there are residual available attentional resources under these search conditions. Green and Bavelier measured the degree to which the presence of distracting objects (either compatible or incompatible with the actual target) in the periphery influenced response times in easy and hard search displays. What was found was that NVGPs displayed less distraction at high levels of difficulty, while VGPs had greater residual attentional resources at these same high levels of difficulty. Thus, the VGPs actually showed more of a distraction effect in difficult search displays suggesting that these individuals had greater residual attentional resources to process compatible distractor items. On the other hand, NVGPs had already exhausted attentional resources under similar conditions and did not show this effect. This finding suggests that the difficult target task was less demanding for the VGPs, and this resulted in higher levels of residual attentional resources than NVGPs under similar conditions. In accordance with these findings, Green and Bavelier also found that VGPs could subitize more items that appeared briefly on a screen at increasing levels of eccentricities relative to NVGPs. It was also found that that VGPs show less of an "attentional blink" for rapid sequentially presented items, showing that the advantage displayed by VGPs is not restricted to spatial forms of visual attention.

The striking findings from the Green and Bavelier (2003) study strongly suggest that VGPs are better at detecting information in the visual environment, but it remains unclear whether VGPs carry out attentionally demanding tasks in a similar (but more efficient) manner than NVGPs, or if both populations rely on similar mechanisms and processes with VGPs engaging and completing each stage of processing at a faster rate. It may be that VGPs rely on different kinds or more efficient types of processing of the visual environment, and that speeded perception enhances visual processing and faster stimulus-response mappings lead to optimal performance. Thus, it may be the case that VGPs have greater control over attentional resources as well as respond faster to the presence or absence of targets in the visual environment. The present study seeks to examine the mechanisms and processes that are relied on by VGPs, and whether they differ qualitatively and/or quantitatively from those of NVGPs. In order to examine this in more detail, two experiments were conducted in order to obtain a better understanding of how VGPs carry out visual search and inhibit attention from returning to previously attended locations, and examine the similarities and differences between VGPs and NVGPs in terms of the ability to efficiently control and allocate visual attention.

2. Experiment 1

One paradigm which has been used extensively to examine the operation of the visual attention system involves measuring reactions times to cued and uncued regions of space. Posner and Cohen (1984) have demonstrated that if attention is captured at a cued peripheral location and then moved to a different location, the time to detect a target at the initially cued location is facilitated, but after a delay of 200 ms or more between the onset of the cue and the target, target detection then becomes faster at the uncued location. This effect has been referred to as inhibition of return, or IOR (Posner, Rafal, Choate, & Vaughan, 1985), and it has been suggested that IOR ensures efficient visual search by biasing the orienting of attention (as well as gaze direction and spatial responses) from previously searched locations (see Klein, 2000, for a review).

It may be the case that VGPs are better at inhibiting attention from a previously cued location, suggesting that the time course of attentional processes are enhanced as a result of habitually playing action video games. In line with this, it has been shown that younger adults are better than older adults at disengaging attention from cued locations in space, but that both age groups can inhibit previously attended locations after a certain period of time has elapsed between the onset of the cue and the onset of the target (Castel, Chasteen, Scialfa, & Pratt, 2003). If IOR is governed by an inhibitory mechanism that modifies and enhances the efficiency of visual search (e.g., Klein, 1988; Klein & MacInnes, 1999), then one might imagine that VGPs are better than NVGPs in terms of inhibiting these cued locations (i.e., VGPs would show an earlier onset of IOR, and the amount of IOR might be greater for VGPs). On the other hand, if IOR biases attention in a non-strategic manner, then perhaps VGPs would not show IOR at all and remain equally efficient at responding to both previously cued and uncued locations. Finally, if experience with action video games has little effect on the basic mechanisms that are involved in the allocation of focused visual attention, then both groups should show a similar pattern of results, with VGPs having faster overall reaction times but a similar trend and time course in terms of how attention is allocated to cued and uncued locations.

The present study was designed to examine the similarities and differences between VGPs and NVGPs in terms of the ability to disengage attention from cued locations, and later inhibit these locations. To closely determine the onset and time course of the facilitation and inhibition, the delay between the onset of the cue and the onset of the target (i.e., the stimulus onset asynchronies, or SOAs) was varied, ranging from 100 ms to 1000 ms. It was expected that both groups would show facilitation at early SOAs and IOR at the longer intervals. In addition, as mentioned earlier, of particular interest was that VGPs might show different times of onset and magnitude of IOR than NVGPs.

3. Method

3.1. Participants

Forty subjects aged between 18 and 34 years (mean age = 20.9 years) participated in the experiment, with 20 subjects (19 males and 1 female) making up both the videogame player (VGP) and non-videogame player (NVGP) experimental groups. The VGPs were selected on the criteria that they had played action videogames (a) at least four times a week for a minimum of 1 hour per day, and (b) had done so for the previous 6 months. Most VGPs played more frequently, however, for an average of 5.9 days and 12.9 hours per week. These games included *Super Mario*, *Max Payne*, *Unreal Tournament*, *Counter-Strike*, *NHL 2002*, *Zelda*, *Soul Calibur*, *Quake III*, *F-Zero*, and *Grand Theft Auto*3. The NVGPs had very little (less than 1 hour per month), and in most cases no, videogame playing experience. All participants were undergraduate students at the University of Toronto and all were compensated for their time; some were paid ten dollars and some received credit for a psychology course they were taking at the University.

3.2. Apparatus

Participants were seated at a computer in a dimly lit room for the duration of the experiment. The viewing distance between their eyes and the computer monitor was kept a constant 44 cm with the aid of an adjustable head/chin rest. Participants responded to stimuli displayed on the monitor by pressing the space bar on the computer keyboard, which was placed directly in front of them. A central cross (0.1° by 0.1°) displayed on the computer screen provided a fixation point and participants were instructed to refrain from moving their eyes from this cross at all times. Participants were visually monitored by the experimenter for eye movements throughout the experiment, and verbal feedback was given on the rare occasion that fixation was not maintained. The visual monitoring was accomplished through the use of a closed circuit TV system, with a camera mounted below the computer monitor.

3.3. Procedure

The sequence of events for each trial is shown in Fig. 1, although the actual experiment used white stimuli presented on a black background. The initial display consisted of the central cross and two placeholder boxes; the boxes, which were 1° square, were centered at 5° to the left and right of the cross. The initial display was presented for 1000 ms, and then one of the boxes was cued by outlining the perimeter for 50 ms. One of six SOAs (100, 200, 400, 600, 800, or 1000 ms), assigned at random, followed the onset of the cue. A target circle (0.7°) appeared in one of the two boxes following the variable SOA in 80% of the trials; the remaining 20% were catch trials and no target was presented. Participants were instructed that the location of the cue was unrelated to the location of the upcoming target and that they should respond to the appearance of the target by pressing the space bar as quickly

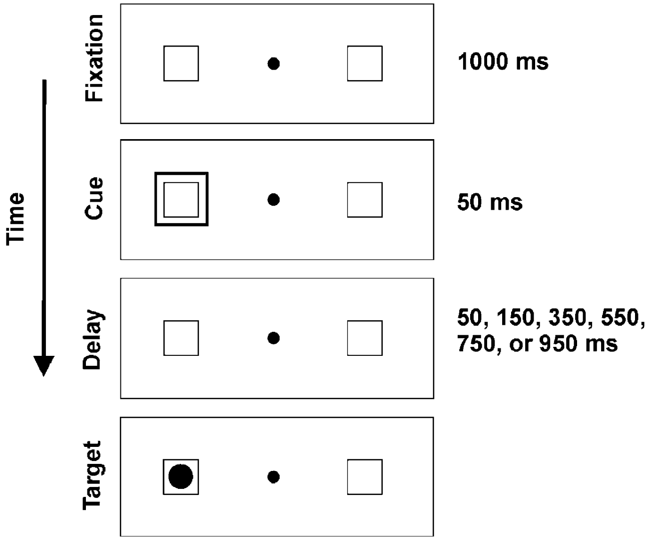

Fig. 1. Sample trial sequence from Experiment 1. The cue and target were equally likely to appear in the left and right placeholders.

as possible. A delay of 500 ms separated the end of one trial from the beginning of the next.

The experiment consisted of 450 trials in total, with all SOAs equally represented and with the cues and targets being equally likely to occur at the left or right box locations. The experiment took approximately 30 min to complete, and participants were given a short break after every 150 trials.

4. Results and discussion

The mean RTs from each group are displayed in Fig. 2. An analysis of variance (ANOVA) was carried out on the mean RTs for the correct trials with trial type (cued or uncued), SOA (100, 200, 400, 600, 800, 1000 ms), and group (i.e., those participants with video-game experience (VGPs) or non-video game players (NVGPs)) as factors. All three main effects were found. The within-subjects main effects were for trial type, $F(1,38) = 78.6$, $p < .0001$ (cued trials = 353 ms, uncued trials = 338 ms), and for SOA, $F(5,190) = 14.2$, $p < .0001$ (RTs were slower at the shorter SOAs). The between-subjects group effect showed that videogame players had significantly faster RTs than their non-videogame playing counterparts, $F(1,38) = 7.3$, $p < .01$ (VGPs = 328 ms, NVGPs = 363 ms).

The only interaction that reached significance was the two-way interaction between trial type and SOA, $F(5, 190) = 19.4$, $p < .0001$. As expected, RTs on cued trials were faster than uncued trials at the shortest SOAs, whereas the opposite occurred at the longer SOAs. The remaining two-way interactions, trial type by group, and SOA by search condition, did not approach significance, $F(1,38) < 1$, and $F(5,190) < 1$, respectively. Of particular note, the three-way interaction (trial type by SOA by group) was not significant, $F(5,190) < 1$, showing that the video

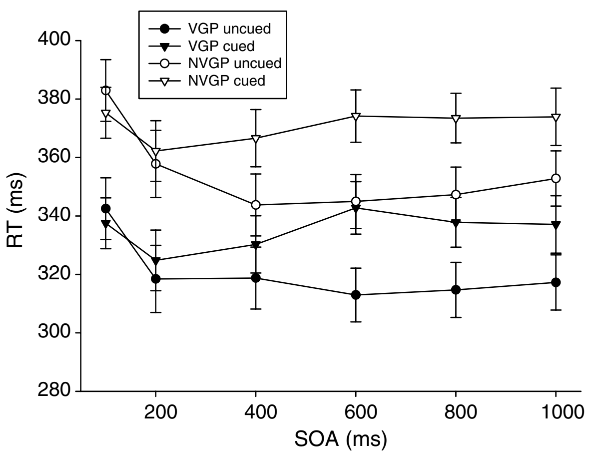

Fig. 2. Mean RTs from cued and uncued trials for both video game players (VGP) and non-video game player (NVGP) groups in Experiment 1.

game players were not significantly different from non-video game players in the pattern of early facilitation and late inhibition they exhibited.

Errors were divided into anticipations (RT < 100 ms), misses (RT > 1000 ms), and false alarms (responses on catch trials). No misses or false alarms were produced by either group of subjects, and anticipations were made on fewer than 2% of the trials. No differences were found among the error rates except for a group main effect with anticipations, $F(1,38) = 38.6$, $p < .001$, as VGPs had a higher anticipation rate (1.97%) than the NVGPs (1.85%).

There are two main results that are important in terms of examining and explaining the similarities and differences in the allocation of visual attention by VGPs and NVGPs. First, VGPs displayed faster RTs in general, suggesting that this group is faster at detecting and responding to the presence of targets in the visual environment that involves the external capture of attention via onset cues. The second, more interesting finding is that both groups showed a very similar pattern of results in terms of displaying early facilitation (i.e., a cueing effect at early SOAs) followed by inhibition to the cued location at later SOAs. Furthermore, both groups showed a similar magnitude of IOR at these later SOAs, indicating that similar inhibitory mechanisms are relied on and activated by both VGPs and NVGPs. Thus, in terms of the timecourse of facilitation and IOR, there are no marked differences between the two groups in the manner in which attention is shifted from cued to uncued locations in space.

5. Experiment 2

One reason that a similar overall pattern of results was obtained for both groups in Experiment 1 may have been that the target detection task (with only two locations) was relatively simple. Also, it may be the case then when attention is captured by abrupt-onset cues, this eliminates any advantage in attentional control that might normally be displayed by VGPs relative to NVGPs, relative to free visual search conditions that are not dictated by onset cues. Green and Bavelier (2003) found that in certain tasks, it was only in the most demanding conditions in which there were differences between VGPs and NVGPs, thus it may be the case that one needs to examine situations that are not influenced by the reflexive orienting of attention (i.e., onset cues in the periphery) and involve more complex visual search tasks.

In order to further determine the similarities and differences between VGPs and NVGPs, we examined how VGPs and NVGPs performed in visual search tasks that involve finding a target letter among various distractor letters. Given that Green and Bavelier often found a VGP advantage in difficult selective attention tasks, two levels of search task difficulty were included in this experiment. One visual search task involved detecting a target among a *constant* set of distractors (an "easy" search) while another more demanding task involved detecting a target among a set of *variable* distractors (a "difficult" search) (see Wolfe, 1994, for a description of how attention may be distributed in these types of tasks). We were interested in how the two groups would perform at the different levels of search difficulty, and if there would be a VGP advantage in terms of the efficiency of searching for targets. In these types of tasks, it may be that VGPs display faster search times per item in demanding visual search environments relative to NVGPs, whereas in terms of more basic, exogenously controlled shifts of attention (i.e., Experiment 1), there are no differences between the two groups.

6. Method

6.1. Participants

Twenty participants (19 male and 1 female) participated in this experiment, with 10 subjects comprising each experimental group (VGPs and NVGPs). These participants had participated in Experiment 1 originally and then elected, upon request, to participate in a second experiment at a later date. These participants were not selected based on performance in Experiment 1, and the experiment was run approximately 8 weeks after the completion of Experiment 1. The NVGPs were comparable to the NVGPs in Experiment 1 in terms of having little to no experience playing video games. As in the previous experiment, the participants were paid ten dollars for participation.

6.2. Apparatus

The apparatus was very similar to that of Experiment 1. Note that for the present experiment the central cross (0.1° by 0.1°) appeared in red and although participants were told to initially fixate the cross they were permitted to move their eyes to search for the target.

6.3. Procedure

The experiment consisted of two visual searches, one easy and one hard (see Fig. 3). In each case, participants had to search for a "b" or a "d" among distractor letters; for the easy search all distracters were the letter "k" while for the hard search. distracters included the letters p, y, g, j, l, and h. Both target and distractor letters were randomly located on an imaginary 10×10 grid surrounding the central cross, where each of the 100 cells was 1.0° high and 0.75° wide. Letters (0.75° high $\times$ 0.5° wide) were all lowercase, in *Courier New* font, and were presented in white (on a black background). For both the easy and hard search, there were four set sizes of 4, 10, 18, or 26 (distracters plus the target letter).

The sequence of events for each trial was as follows. The central cross appeared for 500 ms and was followed by one of the two target letters (randomly selected) plus the distracters for that trial. Participants indicated which target letter they saw by pressing the f-key (labeled "b") on the keyboard for a "b" and the j-key (labeled "d") for a "d". The trial ended after a response from the participant or after 6000 ms if no response had been registered. If participants made a mistake, the computer emitted a tone indicating that an error had been made. The next trial started 1000 ms later.

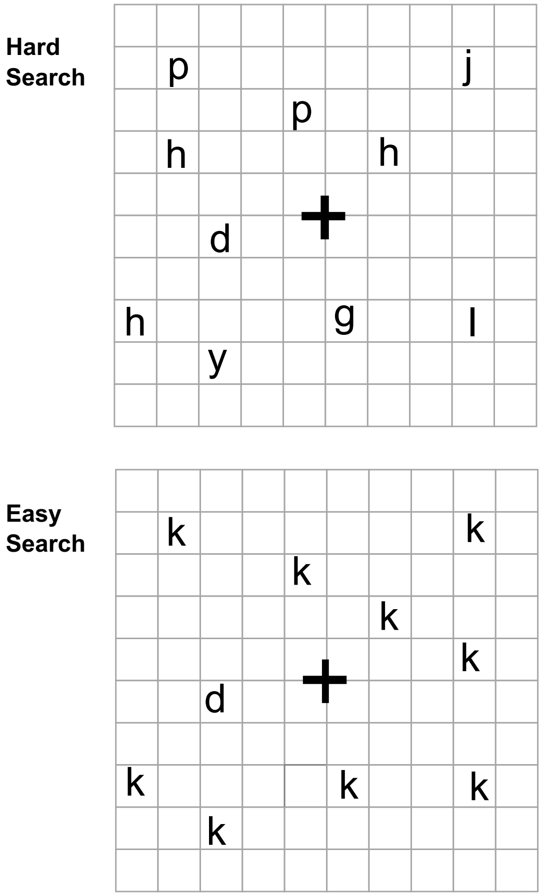

Fig. 3. Sample search displays (10 items; 9 distractors plus 1 target) from the easy and hard search conditions in Experiment 2. The gridlines were not visible in the experiment.

The easy and hard visual searches were blocked (counterbalanced across subjects) and each consisted of 180 trials in total; with half having a "b" as the target and half having a "d". Set size was also equally distributed across the 180 trials, and the letters used for the hard search distracters were randomized on each trial. Participants were given two short breaks per condition and took about thirty minutes to complete both conditions.

7. Results and discussion

The mean reaction times (RT) for the two groups in the easy and hard search condition are shown in Fig. 4. An analysis of variance (ANOVA) was carried out on the mean RTs for correct trials with task (easy or hard search), set size (4, 10, 18, or 26

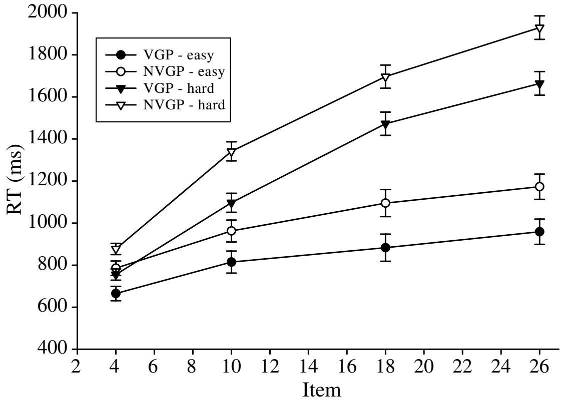

Fig. 4. Mean RTs from the easy and hard visual search tasks for both video game players (VGP) and non-video game player (NVGP) groups in Experiment 2.

items) and group (VGPs or NVGPs) as factors. Three main effects were found. As expected, within-subject main effects were found for task, $F(1,18) = 229.5$, $p < .0001$ (easy search = 917 ms, hard search = 1354 ms) and for set size, $F(3,54) = 417.8$, $p < .0001$ (RTs increase with larger set sizes). As in Experiment 1, the between-subjects group main effect showed that VGPs had significantly faster overall reaction times than their NVGP counterparts, $F(1,18) = 12.0$, $p < .0001$ (VGPs = 1038 ms, NVGPs = 1234 ms).

Two two-way interactions were significant, task by set size, $F(3,54) = 100.2$, $p < .0001$, and set size by group, $F(3,54) = 3.3$, $p = .03$. The former interaction shows that, as expected, search efficiency was greater in the easy search than the hard search. The later interaction indicates that videogame players are more efficient in searching through the displays than the non-videogame players. The remaining two-way interaction of task by group did not approach significance, $F(1,18) < 1$, nor did the three-way interaction of group by task by set size, $F(3,54) < 1$.

The error data was consistent with the RT data. A task by set size by group ANOVA showed main effects for task, $F(1,18) = 229.0$, $p < .001$ and set size, $F(3,54) = 417.8$, $p < .0001$. As expected from the RT data, there were more errors in the hard than the easy task, and the fewest errors occurred with the smallest set size (see Table 1). In addition, there was an interaction between task and set size, $F(3,54) = 3.1$, $p < .04$. Importantly, no main effect was found for group, $F(1,18) < 1$, nor were any other interactions found (ps > .12).

The findings from the present experiment show that experience with action video games results in faster response times to the presence of a target in a visual search task. This is consistent with the findings from Green and Bavelier (2003) in that VGPs show an advantage in terms of the speed in which responses are made to the presence or absence of targets in a visual search task, and this generalizes to different levels of task difficulty. Unlike what was found by Green and Bavelier, however, there was no clear evidence that VGPs display different or more efficient visual

Table 1
Errors rates (%) from the easy and hard search tasks for the video game players (VGP) and non-video game player (NVGP) groups in Experiment 2

# Items	Easy search		Hard search	
	VGP	NVGP	VGP	NVGP
4	13.0	16.4	14.8	10.4
10	11.2	8.2	14.6	12.2
18	11.2	11.0	13.2	10.4
26	12.4	15.2	23.6	27

search strategies relative to NVGPs. It is important to note that the critical interaction between group and set size may likely be driven by the small differences between the two groups at the smallest set size, relative to the somewhat larger differences at the larger set sizes. This may be the result of a floor effect for RTs at the smallest set size (i.e., RTs for both groups might be close to the fastest possible RT),[1] and to examine this further, a follow up ANOVA was conducted that excluded the smallest set size. This ANOVA did not yield a significant group by set size effect, $F(2,36) < 1$, nor a group by task by set size effect, $F(2,36) < 1$, confirming that the previously reported interaction was in fact driven by observations from the smallest set size. The lack of an interaction at larger set sizes could be interpreted as a constantly faster mapping of a detected target to the corresponding key in the VGPs, relative to NVGPs, and is discussed in more detail in the following section.

8. General discussion

The findings from the present experiments confirm earlier findings that there are clear differences in performance between VGPs and NVGPs in visual attention tasks. However, there are also some interesting and important similarities between the two groups that may suggest that similar attentional processing is used in certain situations. In Experiment 1, VGPs displayed faster overall target detection RTs relative to NVGPs, but both groups showed a similar cueing effect at early SOAs, followed by the standard IOR effect at later SOAs. This pattern of results mirrors other time-course analyses of cueing and IOR effects in normal younger adults (see Castel, Pratt, Chasteen, & Scialfa, in press, 2003; Samuel & Kat, 2003). The observation that VGPs display IOR indicates that this inhibitory effect may be related to a rather basic foraging mechanism that is not attenuated as a result of habitual video game playing. Thus, under these circumstances (reflexive cueing and simple target detection), experience with action video games has little effect on the basic mechanisms that are involved in the inhibition and allocation of focused visual attention. Thus, somewhat counter to the conclusions of Green and Bavelier (2003), the present data

[1] We would like to thank an anonymous reviewer for suggesting an alternative way to analyze the data, and that VGPs likely possess faster stimulus-response mappings.

suggest that VGPs and NVGPs rely on similar mechanisms to guide visual attention, but that VGPs posses faster stimulus-response mappings that lead to rapid execution of responses to the presence of targets in the visual environment.

In terms of visual search tasks that are more under the participant's control (a "free-viewing" task without any reflexive cues), some differences between VGPs and NVGPs were observed in both easy and more demanding visual search settings. In these situations, VGPs displayed faster RTs when discriminating a target letter from a varying set of distractors, possibly reflecting more efficient visual search behavior. Given that VGPs frequently need to make rapid responses to the presence of stimuli in a video game environment, it seems plausible that these individuals develop strong associations between the presence of a stimulus and a response output. The accelerated stimulus-response mappings in VGPs may be developed in order to perform well and "survive" in hostile and rapidly changing virtual environments[1]. This may be related to better executive control over the allocation of attention in situations that require the rapid processing of many items. Green and Bavelier (2003) suggest that VGPs may have better management of central executive processes such that when tasks become more demanding and complex, they can efficiently control and allocate attentional resources. Thus, although there may be minimal differences between the two groups in terms of focused attention in various visual attention tasks, VGPs do show an advantage in terms of being able to rapidly encode and respond to targets in both easy and more demanding visual search tasks. Thus, unlike the hypothesis that differences would emerge between VGPs and NVGPs in tasks that involve the endogenous control of attention (i.e., visual search), it seems that VGPs display an overall RT advantage due to stronger associations between the detection of a stimulus and the production of an appropriate response.

It is interesting to note that VGPs and NVGPs did not differ in terms of the time-course of facilitation and IOR, especially in light of the differences in attentional capacity that have been reported by Green and Bavelier (2003). It may be the case that there are no differences in terms of inhibiting attention from returning to previously searched locations (i.e., a spatial-based frame of reference for IOR effects), but that differences exist when examining IOR in terms of object-based frame of reference (e.g., Leek, Reppa, & Tipper, 2003). This distinction between object-based and spatial-based IOR may be especially important in terms of the various kinds of video-game search situations. Thus, for videogames (and unlike the present IOR experiment which used a rather sparse search environment), specific objects have a high impact on action selection and are therefore likely to attract attention. Indeed, Tipper, Driver, and Weaver (1991); also Tipper, Weaver, Jerreat, and Burak (1994) have showed that IOR effects could move with objects that change in their spatial locations. Thus, it would therefore be interesting to see whether VGPs show a different or enhanced tendency for applying inhibition to moving objects (or several objects simultaneously), which may be more applicable to the kinds of situations that are encountered in complex video game search environments.

Finally, one of the clearest findings from the present study was that VGPs consistently produced faster RTs relative to NVGPs, and this is important to consider in terms of the long-term effects of video game playing on the motor system. Similar findings of expertise influencing rate of motor responses have been found with people who, even after considerable experience with rolling cigars (1,000,000 + cigars), continued to improve their rolling performance (Crossman, 1959), as well as in a variety of other cognitive tasks that involve expertise in specific domains (Hambrick & Engle, 2002; Kramer & Willis, 2003). McCarley, Kramer, Wickens, Vidoni, and Boot (2004) found that sensitivity and response times improved reliably as a result of practice in a simulated luggage-screening task. In the present context, it may be that visual search tasks lead to higher levels of arousal and greater vigilance for VGPs due to constant experience with responding frequently to events in the visual environment. This may translate into the activation of response codes that lead to very fast motor responses. The rapid activation of response codes in the presence of visual targets may be related to the notion that VGPs possess greater control over executive function and response control, an idea that is consistent with the observations of Green and Bavelier (2003).

Given how popular and complex video games have become, and that both children and adults spend increasingly more time playing video games, it is important to gain a better understanding of the effects they may, and may not, have on the visual, attentional, and motor systems. The present study has shown some similarities and differences in visual attention performance for people who engage in habitual video game playing and people who spend very little time playing video games. These findings are important in order to develop accurate models and theories of visual attention and neural plasticity, and if frequent video game playing really does have profound effects of the visual system and motor responses, then this can also be incorporated into rehabilitation techniques.

Acknowledgement

This research was supported by a Natural Sciences and Engineering Research Council (NSERC) grant to Jay Pratt and an NSERC post-graduate scholarship to Alan Castel.

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