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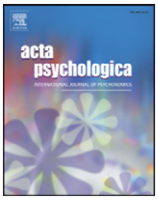

Enhanced change detection performance reveals improved strategy use in avid action video game players

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ABSTRACT

Recent research has shown that avid action video game players (VGPs) outperform non-video game players (NVGPs) on a variety of attentional and perceptual tasks. However, it remains unknown exactly why and how such differences arise; while some prior research has demonstrated that VGPs' improvements stem from enhanced basic perceptual processes, other work indicates that they can stem from enhanced attentional control. The current experiment used a change-detection task to explore whether top-down strategies can contribute to VGPs' improved abilities. Participants viewed alternating presentations of an image and a modified version of the image and were tasked with detecting and localizing the changed element. Consistent with prior claims of enhanced perceptual abilities, VGPs were able to detect the changes while requiring less exposure to the change than NVGPs. Further analyses revealed this improved change detection performance may result from altered strategy use; VGPs employed broader search patterns when scanning scenes for potential changes. These results complement prior demonstrations of VGPs' enhanced bottom-up perceptual benefits by providing new evidence of VGPs' potentially enhanced top-down strategic benefits.

1. Introduction

As our everyday lives become increasingly more complex with technological advancements, it becomes increasingly more necessary to understand how extensive experience with specific activities can affect cognitive and perceptual abilities. Recent findings have revealed that individuals with extensive action video game experience consistently demonstrate improved performance across a variety of visual and attentional tasks when compared to individuals who rarely play action video games. For example, compared to non-video game players (NVGPs), avid action video game players (VGPs) respond more rapidly (e.g., Castel, Pratt, & Drummond, 2005; Dye, Green, & Bavelier, 2009; Orosy-Filders & Allan, 1989; Yuji, 1996), have improved spatial abilities (e.g., Okagaki & Frensch, 1994; Quaiser-Pohl, Geiser, & Lehmann, 2006; Terlecki & Newcombe, 2005), have enhanced temporal abilities (e.g., Donohue, Woldorff, & Mitroff, 2010; Green & Bavelier, 2003, 2006b, 2007; West, Stevens, Pun, & Pratt, 2008), can enumerate briefly displayed items more quickly (Green & Bavelier, 2006b), can switch between tasks faster (e.g., Karle, Watter, & Shedden, 2010), and have enhanced eye–hand coordination (Griffith, Voloschin, & Gibb, 1983). Further, VGPs demonstrate improved "low-level" visual abilities, or bottom-up processing, as seen in increased visual acuity (Green & Bavelier, 2007) and contrast sensitivity (Caplovitz & Kastner, 2009; Li, Polat, Makous, & Bavelier, 2009), as well as improved "higher-level" visual abilities, such as enhanced top-down attentional control (Chisholm, Hickey, Theeuwes, & Kingston, 2010; Hubert-Wallander, Green, & Bavelier, 2010). Here we define "low-level" and "bottom-up" improvements as performance benefits involving physical changes in basic visual abilities (e.g., contrast sensitivity; Li et al., 2009) and "higher-level" and "top-down" improvements as performance benefits involving changes to higher cognitive processes such as shifts in attentional allocation (e.g., Chisholm et al., 2010) or strategy use.

From the broad array of prior video game research, it appears that action video game exposure may heighten and hone attentional abilities (Hubert-Wallander et al., 2010), thus guiding and enhancing performance in visually demanding tasks. An important question that often arises in regard to these striking benefits is about causality — are VGPs better than NVGPs because they have engaged in extensive action video game play or are they better because individuals with a pre-disposition to heightened attentional and perceptual abilities may be more likely to play such fast-paced, action packed video games? This issue has been addressed head-on by training studies in which NVGPs were exposed to video games and their subsequent performance approached that of VGPs (e.g., Green & Bavelier, 2003). Many studies have shown that trained NVGPs do reveal enhanced performance, which suggests a causal role of video game playing (e.g.,De Lisi & Cammarano, 1996; De Lisi & Wolford, 2002; Dorval & Pepin, 1986; Green & Bavelier, 2003, 2006a,b, 2007; McClurg &

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Chaille, 1987; Okagaki & Frensch, 1994; however, see Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Gagnon, 1985; Rosenberg, Landsittel, & Averch, 2005; Sims & Mayer, 2002 for lack of training effects; and Nelson & Strachan, 2009 for more nuanced training effects). The issue of causality explores an important mechanistic explanation of VGPs' benefits, but regardless of the causal nature of such benefits, differences between VGPs and NVGPs have been reliably demonstrated. The aim of the current study is to address an equally critical mechanistic question: can video game players excel in visual tasks, at least in part, because of enhanced strategy use?

Despite the myriad of VGP benefits, it remains unknown *how* VGPs outperform NVGPs. There are two feasible hypotheses that are not mutually exclusive. The bottom-up hypothesis suggests that action video game exposure develops low-level differences that allow for better "vision" and "attention," honing basic abilities (e.g., Dye et al., 2009; Green & Bavelier, 2006a, 2007; Li et al., 2009; West et al., 2008). According to this hypothesis, VGPs may have an increased capacity to process visual information compared to NVGPs. Alternatively, the top-down hypothesis suggests that video game playing leads to the development of enhanced higher-level abilities such as attentional control (Chisholm et al., 2010) for generalized use across a variety of visually demanding tasks. For example, Chisholm et al. (2010) found that enhanced attentional control in VGPs can modulate the potentially negative effects of bottom-up attentional capture in spatial orienting. In line with this hypothesis, VGPs need not necessarily have an increased information-processing capacity but rather could be better able to use what resources they have to process perceptual information (e.g., Colzato, van Leeuwen, van den Wildenberg, & Hommel, 2010). Further, the top-down hypothesis suggests that VGPs may be better able to select (and adjust) their current strategies given the situation and their short- and long-term goals. Though strategy differences in long-term VGPs have yet to be explored fully, short-term exposure to video games has been found to influence speed/accuracy trade-off strategies in visual tasks (Nelson & Strachan, 2009). Here, we look to investigate how differences in strategies employed by long-term VGPs and NVGPs may relate to their improved abilities. While strong evidence exists in support of the bottom-up hypothesis (e.g., Green & Bavelier, 2007; Li et al., 2009), and some evidence supports the role of top-down attention control (e.g., Chisholm et al., 2010), we hypothesized that extensive action video game play may also work to develop enhanced top-down strategies in VGPs. The role of strategy has been proposed before — a prior research project used the classic Posner cuing paradigm to investigate the possibility of reduced attentional costs in VGPs (Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994). While there was mention of possible enhanced strategy use in VGPs, the data were ambiguous, as the paradigm provided no information about the process participants used to complete the task.

Here we use a change detection task to investigate whether improved use of top-down strategy can contribute to the benefits seen in video game players. Change detection is a commonly used visual task in which participants attempt to identify a visual change between two scenes temporally separated by a disruption (see Simons & Rensink, 2005 for a recent review). Change detection provides a powerful tool for exploring issues of visual attention and perception since successfully noticing a visual change across a disruption requires forming, maintaining, and comparing visual representations (e.g., Mitroff, Simons, & Levin, 2004; Simons, 1996). These three necessary components of successful change detection tap into aspects of visual perception, attention, and memory, and each of these processes has been found to be enhanced in VGPs.

Change detection offers a nice tool for the current question since prior change detection studies have isolated various aspects of the detection process to examine the nature of visual processing. For example, change detection has been used to explore the contents of visual memory (e.g., Hollingworth & Henderson, 2004; Rensink, 2002; Simons, 1996) and the role of focused attention (e.g., Rensink, O'Regan, & Clark, 1997; Scholl, 2000). Further, failures to successfully detect a change have been used as evidence that 1) not all information is properly encoded (e.g., O'Regan & Noë, 2002), 2) even when information is encoded, it can be subsequently overwritten by new information (e.g., Beck & Levin, 2003; Levin, Simons, Angelone, & Chabris, 2002), and 3) even if information is not overwritten, two viable representations need not necessarily be compared to one another (e.g., Angelone, Levin, & Simons, 2003; Hollingworth, 2003; Mitroff et al., 2004; Wang & Mitroff, 2009). Moreover, it has been argued that explicit processes may be necessary for the ultimate detection of a change (e.g., Mitroff & Simons, 2002; Mitroff, Simons, & Franconeri, 2002), which allows for us to focus the current questions at the level of perception with awareness.

A commonly used change detection paradigm is the "flicker" task (Rensink et al., 1997). In this task an image and a modified version of the image continuously alternate (with a blank display in between) until the participant finds the change between the two images. For the current goal of exploring *how* VGPs perform differently from NVGPs, we will employ a variant of the flicker task that allows for a step-by-step examination of the change detection process (Mitroff & Simons, 2002). This modified task has previously been used to look at group differences (young vs. older adults, Costello, Madden, Mitroff, & Whiting, 2010), making it especially compelling for the current goals. In this modified paradigm, individuated presentations of pre-change and post-change image pairs are presented one at a time and then the participants attempt to localize the change. The benefit of this design is that it slows down the change detection process and makes it possible to acquire multiple localization responses for each specific trial leading up the eventual detection (or non-detection) of a change (Mitroff & Simons, 2002).

2. Methods

2.1. Participants

35 male participants (VGP: $N = 15$, mean age = 19.93,[1] SD = 1.69; NVGP: $N = 20$, mean age = 23.05, SD = 5.87; $t(32) = 1.93$, $p = 0.063$) from the Duke University community received either course credit or $10 for a single 60-minute testing session. All participants had normal or corrected-to-normal vision.

Three additional participants (2 NVGPs, 1VGP) incorrectly reported seeing a change on more than 25% of the no-change trials, and their data were excluded from all further analyses. Participants completed a video game questionnaire that assessed their experiences with several video game genres (e.g., first-person shooters, role-playing, puzzle) over several time frames and their responses were used to classify them as VGPs, NVGPs, or neither (participants that did not qualify as a VGP or NVGP were not included in this study). Those with extensive action video game playing experience were classified as VGPs. These participants played action video games (primarily first-person shooter games) for more than 6 h per week over the 6-month period prior to testing. Participants with no action video game experience and little to no experience with other video games in their lifetimes were classified as NVGPs. Prior to their testing session, many of the participants completed a condensed version of our video game questionnaire as part of a large test battery and we used their responses to selectively recruit VGPs and NVGPs while not revealing why they were being recruited. After the completion of the experiment, all participants completed our full questionnaire, and these responses were used to determine their status as VGPs and NVGPs. As in previous studies (e.g., Green & Bavelier, 2006b), female

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[1] Represents mean age in years for 14 of the 15 VGP participants. As the result of a clerical error, one subject's age information is missing.

participants were not included since few meet the criteria for being classified as a VGP.

2.2. Apparatus and stimuli

The experiment was run in a dimly lit room on a Dell Dimension E520 with a 19-inch CRT monitor with a 1024 × 768 pixel resolution and a screen refresh rate of 60 Hz. Participants were seated at a viewing distance of approximately 57 cm without head restraint. Stimuli were presented and responses were collected with Matlab 7 software and the Psychophysics Toolbox (Brainard, 1997).

The stimulus set has been used in previous papers (Costello et al., 2010; Mitroff & Simons, 2002; Simons, Franconeri, & Reimer, 2000), and a detailed explanation of its construction can be found in Simons et al., 2000. The stimuli consisted of 64 photographs of natural scenes that subtended a visual angle of 18.97° × 12.71°. The stimuli were presented at the center of the screen and were surrounded by a black background that filled the remainder of the monitor. Each photograph was modified with Photoshop to either add or remove one item/region to create an original and modified version of each image with only one change between the two. The average size of the change was 3.35% of the total area of the image and the change sizes ranged from 0.43% to 14.46%. Across the 64 image pairs used in the current experiment, the change was equally distributed in each quadrant of the image (i.e., 25% of the changes occurred in the upper-left quadrant). Forty-eight of the image pairs were used for the change trials and the remaining 16 were used for the no-change trials. Only one image from each image pair was presented on the no-change trials, with half using the image that contained the modified item and half using the image that did not contain the modified item.

2.3. Procedures

Note that the experimental procedures were based closely on those of Mitroff and Simons (2002) and Costello et al. (2010). All participants were given written and oral instructions prior to the start of the experiment. They completed four practice trials with feedback, all of which contained a change. The images displayed during the practice trials were not used in the experimental trials. Participants were not informed prior to participation whether or not there would be a change in every trial.

Each trial began with a single white fixation cross presented on a black background for 500 ms. Following the fixation, the first presentation cycle was presented. A single cycle consisted of the first image of the scene pair displayed for 250 ms, a blank gray screen replacing the image for 100 ms, the second image of the scene pair displayed for 250 ms, and finally, a blank gray screen that matched the size of the images that remained until response (see Fig. 1). Participants then used the computer mouse to make a localization response to indicate the location of the change between the two images. After the localization response, participants were to indicate their level of certainty with key-presses associated with the terms "Guess," "Verify," and "Saw." If the mouse click was a complete guess, as participants had not seen any change, they were to indicate "Guess." "Verify" was to be used if participants believed they saw a change but needed another presentation cycle to be certain. Participants were only to indicate "Saw" if they were confident they had seen the change and had clicked in the correct location. If the participant responded "Saw" the trial would end and they would move to the next trial. Otherwise, the entire presentation cycle would repeat and participants were to make another set of mouse click and key-press responses. If the change was not detected after 15 total cycles, the next trial began. Thus for no-change trails, participants viewed all 15 cycles unless they falsely reported "Saw." Participants were instructed to make their best localization guess at the end of each cycle (even if they did not see a change) and not to simply click the same location every time. Additionally, between cycles the mouse cursor was moved below the portion of the screen on which images were displayed to minimize haphazard responding.

The order of the 64 trials was uniquely randomized for each participant. Half of the change trials involved an *addition* within each presentation cycle (the changed item/region was present in the second image and not the first), and the other half involved a change *deletion* (the changed item/region was present in the first image and not the second). The changing region was defined as the smallest rectangular region that encompassed all changing pixels. For a few of the analyses below, we focused only on trials with a correct localization response, and for these, clicks within 30 pixels of the border of this rectangle were considered accurate. A 30-pixel window was

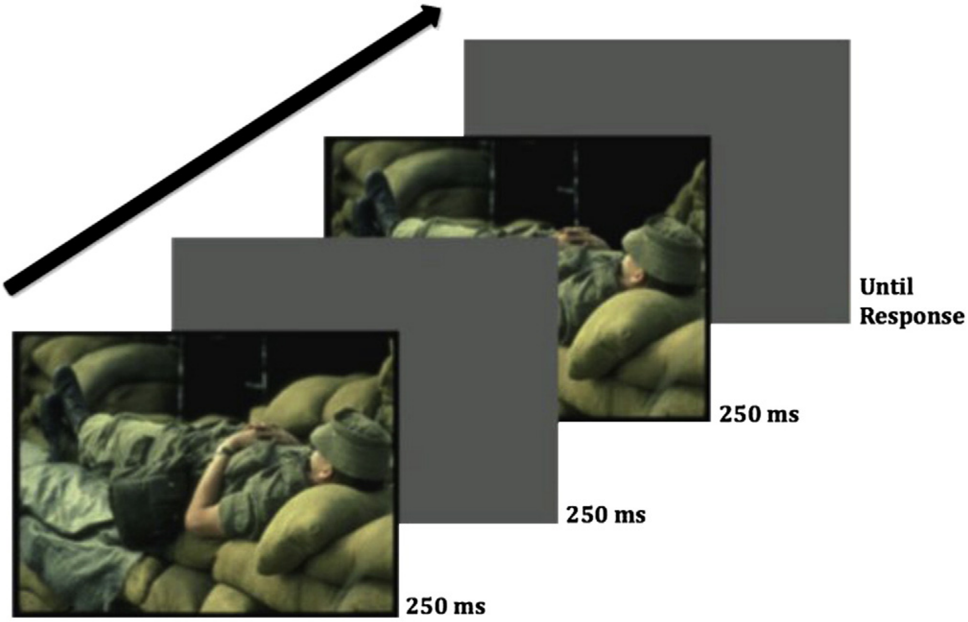

Fig. 1. Sample cycle on a "change" trial.

employed since participants were making mouse click responses on a blank gray screen, and therefore, may not have clicked in exactly the right location, despite having successfully located the change. Since the trial only ended when participants indicated that they "Saw" the change, this window did not increase the likelihood of a chance localization response influencing the data analyses.

3. Results

Overall performance was consistent with prior instantiations of this paradigm (e.g., Costello et al., 2010; Mitroff & Simons, 2002) with participants successfully finding 92.45% of the changes ($SD = 6.47\%$). False alarms on no-change trials (reports of "Saw") were minimal and did not differ between VGPs ($M = 3.75\%$, $SD = 9.97\%$) and NVGPs ($M = 5.95\%$, $SD = 11.09\%$; $t(33) = 0.61$, $p = 0.54$). The "Verify" response was seldom used, and there was no significant difference in its use between VGPs ($M = 0.34$ times per trial, $SD = 0.19$) and NVGPs ($M = 0.33$, $SD = 0.19$; $t(33) = 0.11$, $p = 0.92$).

Several differences arose between VGPs and NVGPs and the primary findings are presented in Table 1. On change trials, VGPs took significantly fewer cycles to find the change than NVGPs (see Table 1 row A). While this result reflects that VGPs are better able to detect changes, four additional analyses offer insight into *how* VGPs were able to detect changes in fewer cycles than NVGPs, revealing that VGPs employed a broader search strategy in conducting their search.

The first three of these analyses were performed on mouse click response data from the no-change trials[2] in which participants correctly viewed all 15 cycles without reporting "Saw" (no-change trials without a false alarm). First, VGPs' successive localization responses were further apart than NVGPs' (see Table 1 row B); from one localization guess to the next, VGPs made mouse click responses that were a significantly greater distance from their previous mouse click response than did NVGPs. Second, VGPs were more likely to make a localization guess in all four quadrants of the images (see Table 1 row C), suggesting they were more likely to search the entirety of the display. Third, VGPs were less likely than the NVGPs to perseverate in a single quadrant — on average, the NVGPs had a larger maximum number of localization responses within one quadrant (see Table 1 row D).

A fourth analysis that was conducted on data from change trials in which the change was correctly detected, VGPs made localization responses across a significantly wider area of the image than the NVGPs (calculated as the area of the rectangle formed by the minimum and maximum clicks on the x- and y-axes, see Table 1 row E). To ensure comparable data, we limited this analysis to the first 5 cycles on trials in which participants took 6 or more cycles to accurately locate a present change.

The above analyses show clear differences between VGPs and NVGPs; however, they are consistent with both the bottom-up and the top-down hypotheses. On one hand, and in line with the bottom-up hypothesis, VGPs may have been able to process more visual information during each fixation. This would explain why VGPs search more broadly by suggesting that during each cycle they were able to "eliminate" larger areas on the image as not containing a change, as they were able to process more visual information. On the other hand, and consistent with the top-down hypothesis, VGPs may have chosen to strategically employ a broader search strategy when looking for the changes. For these sorts of change detection tasks, participants are more likely to notice a change if they search the display broadly than if they perseverate in a given region. To differentiate between these competing explanations we examined what we termed "unrealized correct localizations" — trials on which participants successfully clicked on a change but failed to realize they had done so. Such occurrences were defined as the number of trials in which participants successfully made a localization mouse click on the change location, reported that the click represented a "Guess," and then continued to search elsewhere for at least the next two cycles. On change trials, VGPs and NVGPs were not significantly different in their number of "unrealized correct localizations" (see Table 1 row F). There was no group difference in terms of when, within a trial, the unrealized correct localizations occurred (VGP: $M = 3.54$ cycles into the trial, $SD = 3.68$; NVGP: $M = 3.95$, $SD = 1.97$ cycles, $t(33) = 0.45$, $p = 0.65$).

Table 1
Means of each measure, by group, with standard deviations in parentheses.

	Primary analyses	Video game players (VGPs)	Non-video game players (NVGPs)	Statistical tests
A	Number of cycles required to find change (*change trials*)	4.51 cycles (1.02)	5.32 cycles (1.05)	$t(33) = 2.31$ $p = 0.028$
B	Distance jumped from click to click (*no-change trials*)	7.77° (1.02°)	6.65° (1.73°)	$t(33) = 2.20$ $p = 0.035$
C	Tendency to cover all four quadrants (*no-change trials*)	14.00 trials (2.04)	10.90 trials (5.17)	$t(33) = 2.19$ $p = 0.035$
D	Maximum number of clicks per quadrant (*no-change trials*)	6.44 clicks (0.76)	7.51 clicks (1.89)	$t(33) = 2.07$ $p = 0.046$
E	Area covered in first-five clicks (*change trials*)	$93.87^{\circ 2}$ ($39.14^{\circ 2}$)	$78.71^{\circ 2}$ ($41.27^{\circ 2}$)	$t(33) = 2.07$ $p = 0.047$
F	Number of "undetected changes" (*change trials*)	8.20 trials (2.93)	8.19 trials (3.41)	$t(33) = 0.01$ $p = 0.993$

4. Discussion

Previous work has shown that VGPs outperform NVGPs on a variety of attentional and perceptual tasks and the current study sought to reveal *how*. It is informative to know that extensive action video game playing is associated with enhanced processing, but for this to become a viable research tool, we must understand what aspects of performance can be affected (e.g., Hubert-Wallander et al., 2010). Recent findings have offered support for "low-level" visual benefits in that VGPs show superior visual acuity and contrast sensitivity (e.g., Green & Bavelier, 2007; Li et al., 2009). Other work has suggested a possible "higher-level" benefit in the form of attentional control (e.g., Chisholm et al., 2010), but the role of top-down strategy had not been thoroughly investigated. Here we find additional evidence for higher-level claims in the specific form of strategy benefits and possibly reveal one manner in which VGPs can outperform NVGPs.

As predicted, and in line with prior work showing enhanced visual attention abilities in VGPs (e.g., Green & Bavelier, 2003, 2006a,b; Greenfield et al., 1994; Hubert-Wallander et al., 2010; West et al., 2008), VGPs performed better than NVGPs on our change detection task. When searching between two scenes for a change introduced during a disruption, VGPs required fewer exposures to the changing stimulus to detect its presence. Interestingly, the current results do not support a prior study that revealed no differences in change detection performance between VGPs and NVGPs (Durlach, Kring, & Bowens, 2009). While it is not clear what led to these differing results, the current paradigm provides an arguably more sensitive means to tease apart how VGPs and NVGPs differed by slowing down the change detection process and collecting successive localization data leading up to the eventual detection (or miss) of a change.

The primary finding of the current experiment is the differences in search patterns between VGPs and NVGPs when searching for visual changes. VGPs exhibited broader search strategies, and in doing so, covered significantly more visual area. However, at first blush, these

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[2] We can glean useful information from the no-change trials as these trials yielded a consistently large data set for each participant, as participants were likely to view all 15 cycles since there was no change to be found, and false alarms were rare.

differences could be consistent with both a bottom-up and a top-down explanation: They could reveal that VGPs have better visual abilities and can encode more visual information on a given fixation (i.e., Green & Bavelier, 2007), or they could reveal enhanced change detection search strategies, such that VGPs make better use of the processed visual information, in that they choose to employ a broader search (i.e., Chisholm et al., 2010; Greenfield et al., 1994). In other words, VGPs make larger moves from one localization response to the next, for example, because either they can process more visual details than NVGPs from a given fixation (bottom-up) or because they choose to engage a broader endogenous search strategy (top-down). The results from our "unrealized correct localizations" analysis provide insight into this key explanatory issue. *Unrealized correct localizations* occurred when a participant made a localization mouse click on the changed region of the image, but indicated the response to be a "Guess," and then continued to search elsewhere. These occurrences reflect how often participants accidentally found the change and failed to realize that they had done so. If VGPs' better visual abilities allowed them to take in more information on a given fixation, we would expect them to have a significantly lower number of unrealized correct localizations. If, however, a higher-level, broader search strategy is the driving force behind VGPs' enhanced change detection performance, we would not expect a difference between VGPs and NVGPs on the number of unrealized correct localizations. The VGPs and the NVGPs did not differ in their rate of undetected changes ($p = 0.99$), which suggests a strategy difference.

An assumption underlying several of the interpretations is that the mouse click data reveal the participants' attentional allocation. While these mouseclicks do not provide a definite measure of attention, several factors suggest they are a useful proxy. First, participants reported post-experiment that they used the "Guess" mouseclicks to indicate where they planned to search on the next cycle of the trial. Second, the previous instantiation of this paradigm in Mitroff and Simons (2002) used a variety of permutations across experiments to reveal that participants used the mouseclicks to report their next locus of attention. Regardless, the different mouse click patterns between VGPs and NVGPs nevertheless reveal differences in strategy between the groups.

Both basic bottom-up visual abilities and top-down strategy choices are likely to be enhanced in VGPs, and the current results offer evidence for a top-down strategy contribution. This conclusion is consistent with other recent claims (e.g., Chisholm et al., 2010; Colzato et al., 2010) and reveals a generalizable VGP benefit that may not be tied to specific visual skills or paradigms. An exciting suggestion from the current study is that strategies obtained through extensive action video game playing may be a driving force in VGPs' benefits in visual attention tasks. The finding here that VGPs employ a broader search strategy for change detection raises the possibility that video game playing may introduce generalized training that can increase performance broadly. VGPs may learn to approach tasks more optimally and flexibly adjust their global strategies to meet the task at hand.

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