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Effect of Action Video Games on the Spatial Distribution of Visuospatial Attention

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The authors investigated the effect of action gaming on the spatial distribution of attention. The authors used the flanker compatibility effect to separately assess center and peripheral attentional resources in gamers versus nongamers. Gamers exhibited an enhancement in attentional resources compared with nongamers, not only in the periphery but also in central vision. The authors then used a target localization task to unambiguously establish that gaming enhances the spatial distribution of visual attention over a wide field of view. Gamers were more accurate than nongamers at all eccentricities tested, and the advantage held even when a concurrent center task was added, ruling out a trade-off between central and peripheral attention. By establishing the causal role of gaming through training studies, the authors demonstrate that action gaming enhances visuospatial attention throughout the visual field.

Keywords: video games, attention, useful field of view

Visual acuity, or the ability to discriminate small changes in shape in central vision, is a key determinant of vision. Ask someone how good their vision is, and they will typically comment on their ability to read a sign, to recognize faces from afar, or to score 20/20 on an optometrist's eye chart. However, many of the visual tasks people complete on a day-to-day basis bear little relation to the ability to read the bottom line on an eye chart. For instance, driving does not require perfect acuity (many U.S. states require that one's vision be only 20/40 to receive a driver's license). Instead, the most common visual demands present while driving involve focusing attention on relevant stimuli, such as pedestrians, animals, and other cars, while ignoring the many irrelevant distractors that clutter the visual environment. The dichotomy between visual acuity and visual attention has been exemplified by many studies (Ball, Beard, Roenker, Miller, & Griggs, 1988; Ball & Owsley, 1991; Ball, Owsley, & Beard, 1990; Ball, Owsley, Sloane, Roenker, & Bruni, 1993; Intriligator & Cavanagh, 2001; Owsley & Ball, 1993; Owsley, Ball, & Keeton, 1995; Sekuler & Ball, 1986), with the general finding being that simple tests of visual acuity and perimetry are poor predictors of performance on tasks that demand effective visuospatial attention.

A number of paradigms have been developed with the goal of quantitatively measuring visual selective attention (Carrasco & Yeshurun, 1998; Eckstein, Pham, & Shimozaki, 2004; Eriksen & Eriksen, 1974; Lavie & Cox, 1997; Treisman & Gelade, 1980). In many of these paradigms, targets are presented simultaneously with distracting objects, and the influence of the distracting information on target processing is measured. Groups thought to have diminished attentional abilities, such as the elderly (Ball et al., 1988; Madden & Langley, 2003; Maylor & Lavie, 1998; Plude & Hoyer, 1986; Scialfa, Esau, & Joffe, 1998) and young children (Akhtar & Enns, 1989; Enns & Cameron, 1987; Enns & Girgus, 1985; Plude, Enns, & Brodeur, 1994; Rueda et al., 2004), typically demonstrate larger effects of distracting information on attentional tasks than normal adult controls, indicating an effect of age on the determinants of visual selective attention. Similarly, a host of data indicate that the control of visual selective attention decreases in most pathological populations, including frontal patients (Husain & Kennard, 1997), Alzheimer's patients (Levinoff, Li, Murtha, & Chertkow, 2004; Tales, Haworth, Nelson, Snowden, & Wilcock, 2005; Tales, Muir, Jones, Bayer, & Snowden, 2004), children with attention-deficit/hyperactivity disorder (Shalev & Tsal, 2003), and neglect patients (Russell, Malhotra, & Husain, 2004; Sprenger, Kompf, & Heide, 2002; Vivas, Humphreys, & Fuentes, 2003). Whereas most of the studies describing changes in visual selective attention document a decrease in performance as compared with normal healthy young adults, of interest to us was the possibility that this type of selective attention may be enhanced (rather than reduced) from the level typically observed in young adults.

Several researchers have noted enhancements in various aspects of visual attention as a result of video-game play (Castel, Pratt, & Drummond, 2005; Gopher, 1992; Gopher, Weil, & Bareket, 1994; Green & Bavelier, 2003; Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994; Trick, Jaspers-Fayer, & Sethi, 2005). Many of today's action video games are remarkably visually challenging. They regularly have unnaturally stringent attentional requirements, much more so than any everyday situation to which one may be exposed. For instance, in many video games, multiple items must be processed simultaneously, a task that would benefit from additional attentional resources across space. Additionally, many

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games require the efficient rejection of irrelevant objects, a process that would benefit from a more proficient selection process. The penalty for either failing to process a target or allowing nonessential information to interfere with the processing of potential targets is often great in video games; therefore, those who play should be especially motivated to develop both capabilities. Our goal with this study is to assess whether action video-game experience enhances visuospatial attention and its allocation over space.

Our previous work has led to the hypothesis that action video-game play results in an increase in the amount of available attentional resources as well as an increase in the selectivity of spatial processing (Green & Bavelier, 2003). It has remained unclear, however, whether the improvements noted were specific to the visual periphery, possibly occurring at the cost of central vision. The present study reports on two types of paradigms that test the distribution of attention over space and that contrast central and peripheral processing. The first, the perceptual load paradigm of Lavie and colleagues (Lavie, 1995; Lavie & Cox, 1997), offers a measure of the attentional resources available to both video-game players (VGPs) and non-video-game players (NVGPs) and was adapted to compare central and peripheral resources across populations. The second, the useful field of view (UFOV) paradigm developed by Ball and colleagues (Ball et al., 1988; Ball & Owsley, 1992), allows for a measure of the distribution and selectivity of visual attention across a wide field of view, while controlling for different levels of central load. Portions of Experiments 1 and 2 were presented in Green and Bavelier (2003).

Experiment 1: The Perceptual Load Paradigm

To gain a general understanding of the amount of attentional resources available to distribute across space in VGPs and NVGPs, we used the perceptual load paradigm (Lavie & Cox, 1997; Proksch & Bavelier, 2002). In this paradigm, the effect of task-irrelevant distractors on primary task performance is measured and used as an index of the degree to which these irrelevant distractors are processed. By contrasting central and peripheral distractors, this paradigm allows us to compare attentional resources across space in VGPs and NVGPs.

The effect of the distractors is measured using the compatibility effect, wherein the presence of distractors that lead to the same response as the target (response compatible) results in faster reaction times (RTs) than distractors that lead to a different response than the target (response incompatible) (Eriksen & Eriksen, 1974). Work by Lavie and colleagues (Lavie, 1995; Lavie & Cox, 1997; Lavie, Hirst, Viding, & de Fockert, 2004) has shown that the effect of extraneous distractors on RT is largely a function of the perceptual load of the target task display (perceptual load in this case roughly corresponds to the number of items in the visual search array). When the perceptual load is low (for instance, the visual search array contains only the target), the effect of an extraneous distractor on performance is great. However, when the perceptual load is high (the visual search array contains the target as well as several additional items), the effect of an extraneous distractor on performance is minimal.

This finding is incorporated in the load theory of selective attention and cognitive control (Lavie, 2005; Lavie et al., 2004). Relatively easy perceptual tasks do not require all of one's attentional resources to reach adequate behavioral performance. In this case, the resources left over from the task are not simply turned off but are instead distributed to adjacent locations or items, leading to a sizable compatibility effect. Conversely, challenging perceptual tasks demand a larger percentage of the available attentional resources, thereby leaving little to spread to nontask locations and items and resulting in little or no compatibility effect (Lavie, 1995; Lavie & Cox, 1997). Although the load theory posits that the distribution of attention is automatic, it is not the case that the exact distribution of attention is identical in all humans. Proksch and Bavelier (2002) have demonstrated that hearing individuals do typically allocate more attention to the area around fixation (central vision), but in contrast, deaf individuals appear to allocate more attention to the periphery. If action video-game play primarily affects peripheral visual attention, then VGPs may also exhibit a proportionally larger compatibility effect for peripheral distractors, as noted in deaf individuals. Conversely, if action video-game play similarly affects both central and peripheral vision, then the distribution should be similar to what is observed in normal hearing individuals—that is, greater allocation around fixation than peripherally (Beck & Lavie, 2005; Proksch & Bavelier, 2002). In Experiment 1, the compatibility effects induced by peripheral versus central distractors were compared in VGPs and in NVGPs to gain a measure of the amount of available attentional resources as a function of eccentricity in each population.

Method

Participants

Sixteen men with normal or corrected vision were placed into one of two groups, VGP or NVGP, according to their responses to a questionnaire given prior to the experiment. Because of the relative difficulty in the acquisition of women with sufficient video-game experience, only men underwent testing.

The criterion to be considered a VGP was a minimum of 3–4 days a week of action video-game usage for the previous 6 months. Eight right-handed men with a mean age of 20.9 years fell into this category. Of these men, 7 reported daily video-game usage for at least the previous 6 months, and the 8th reported playing several times a week for the same time span. It is important to note that only *action* video-game players were included in this and all subsequent experiments. Action video games are those that have fast motion, require vigilant monitoring of the visual periphery, and often require the simultaneous tracking of multiple targets. The following is a representative sample of the games participants reported having played that qualify as action games according to our criteria: Grand Theft Auto, Half-Life, Counter-Strike, Marvel vs. Capcom, Rogue Spear, and Super Mario Kart.

The criterion to be considered an NVGP was little, although preferably no, action video-game usage in the past 6 months. Eight men (6 right- and 2 left-handed) with a mean age of 21.6 years fell into this category. Of these men, 7 reported no video-game experience whatsoever in the past year, and the 8th reported a maximum of five instances of non-action-video-game play over the same time frame.

All participants were paid for their participation and provided informed consent in accordance with the guidelines set by the University of Rochester.

Stimuli

All stimuli and procedures were identical to those used in Proksch and Bavelier (2002). Stimuli were presented on a 21-in. Mitsubishi monitor from a standard PC equipped with a Matrox Millennium video card using

OpenGL routines. Each participant viewed the display at a test distance of 60 cm in a darkened room.

The stimuli consisted of three categories of items (target, filler, and distractor) presented in light gray on a black background (Figure 1). The target set consisted of a square and a diamond. The filler set was composed of a houselike shape, an upside-down house shape, a sideways trapezoid, a triangle pointing up, and a triangle pointing down. Both the target and the filler shapes subtended an average of 0.6° vertically and 0.4° horizontally, and they were always presented inside circular frames.

Throughout the experiment, the six circular frames were presented in the same location, arranged around the central fixation point at a distance of 2.1°. The distance between the centers of adjacent circular frames was also 2.1°. One, and only one, member of the target set (square or diamond) always appeared in one of the six circular frames. Random members of the filler set could occupy zero, one, three, or five of the remaining circular frames. The frames in which target and fillers appeared were randomly selected across trials. For all analyses and for the purposes of subsequent discussion, the two lowest levels of perceptual load (zero fillers or one filler) were grouped into a single *low-load* condition, and the two highest levels of perceptual load (three or five fillers) were grouped into a single *high-load* condition.

The distractor set consisted of a square, a diamond, and an elongated circle. One member of the distractor set was presented during each trial in one of four locations. The distractor could appear either centrally (0.5° to the right or left of fixation, which falls within the ring of circular frames) or peripherally (4.2° to the right or left of fixation, outside the ring of circular frames).

Although 4.2° from fixation is better described as parafoveal rather than peripheral, this location was chosen to ensure that peripheral and central distractors were presented at comparable distances from the target ring. This point is important if differences in effects between central and peripheral distractors are to be interpreted in terms of eccentricity (central vs. peripheral) rather than absolute distance (Miller, 1991). The size of the distractors was corrected for the known cortical magnification factor (Rovamo & Virsu, 1979). Accordingly, central distractors subtended 0.3° vertically and 0.2° horizontally, and peripheral distractors subtended 0.9° vertically and 0.5° horizontally.

The design was fully intermixed, with all combinations of target (square or diamond), perceptual load (zero, one, three, or five fillers), distractor compatibility (compatible, incompatible, or neutral), and distractor eccentricity (central or peripheral) being equally represented and presented in pseudorandom order.

Procedure

Each trial began with a 1-s fixation point followed by a 100-ms presentation of the trial shapes. The relative brevity of the presentation time was chosen to preclude eye movements as a potential source of differences.

The task of the participant was to identify which of the two potential target shapes (square or diamond) appeared in one of the six circular frames as quickly and accurately as possible. Participants were reminded to ignore any stimuli that did not appear in the circular frames (i.e., the distractor). Participants responded to the target by pressing the key labeled with the corresponding target shape. Feedback was given after each trial by a change in the color of the fixation point. Trials were grouped into two halves of 576 trials. Following each block of 48 trials, participants were given a resting screen that informed them of their performance over the previous block (RT and percentage correct). Participants were instructed to respond as quickly as possible and to aim for 90% correct.

Before testing began, participants were given two blocks of practice, during which time responses were monitored by the investigator to ensure comprehension of the task. Following successful training, the participants were left to complete the first half, followed by a short intermission, and the second half. The entire experiment lasted approximately 1.5 hr.

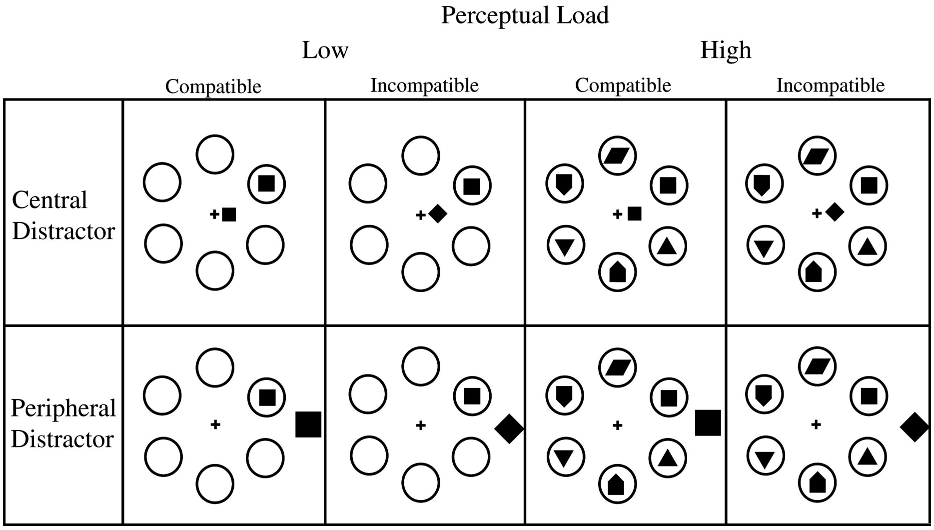

Figure 1. Perceptual load stimuli. The participants' task was to determine as quickly and accurately as possible which of two possible target shapes (square or diamond) appeared in one of the six circular frames. Task difficulty was manipulated by the addition of other shapes in the circular frames. Low loads correspond to displays with the target alone or with one other shape in the circular frame, whereas high loads correspond to displays with three or five shapes in addition to the target. The *distractor shape* is the shape that does not appear in one of the six circular frames. Participants were explicitly told to ignore the distractor shape, which could be either compatible (i.e., led to the same response as the target) or incompatible (i.e., led to the opposite response from the target). The distractor shapes could be presented either centrally, that is, appearing within the ring of circular frames, or peripherally, appearing outside of the ring.

Results

As in our past studies, all analyses focused on trials with incompatible or compatible distractors (Green & Bavelier, 2003; Proksch & Bavelier, 2002).

RT

For the RT analysis, incorrect trials were first removed (VGP: 12.1% ± 1.5; NVGP: 13.0% ± 1.6) as well as any trial with RTs greater than 1,800 ms or less than 300 ms (less than 2% of trials in both VGPs and NVGPs). Trials were then separated on the basis of distractor eccentricity (central vs. peripheral). For each participant, a mean and standard deviation was computed for each of the two eccentricities; any trial in which the RT was more than two standard deviations away from the mean was excluded (approximately 2% of trials for both VGPs and NVGPs). These filtered RT data were then analyzed in a 2 × 2 × 2 × 2 omnibus analysis of variance (ANOVA) with video-game experience (VGP vs. NVGP), perceptual load (low vs. high), distractor eccentricity (central vs. peripheral), and distractor compatibility (compatible vs. incompatible) as factors.

The standard main effects of perceptual load (low load: 629.2 ms ± 9.5; high load: 712.4 ms ± 11.2), $F(1, 14) = 119.4$, $p < .001$, reflecting an increase in task difficulty with increasing perceptual load, and distractor compatibility (compatible distractors: 664.1 ms ± 11.5; incompatible distractors: 677.5 ms ± 11.6), $F(1, 14) = 63.0$, $p < .001$, demonstrating the effect of distractor compatibility on RT, were observed. Also, as has been consistently reported, an interaction between load and compatibility was observed, $F(1, 14) = 7.0$, $p = .02$, with the RT difference between incompatible and compatible distractors decreasing with increasing perceptual load (Table 1).

In accord with our previous report (Green & Bavelier, 2003), a Video-Game Experience × Perceptual Load × Distractor Compatibility interaction, $F(1, 14) = 7.4$, $p = .02$, was also observed, with NVGPs showing a larger decrement in the size of the compatibility effect with increasing load than VGPs (Table 1). VGPs instead demonstrate a consistently high compatibility effect across perceptual load conditions. This indicates that the VGPs continued to process the extraneous distractor even at the highest loads, suggesting an increase in available attentional resources. Of note, this effect did not further interact with eccentricity, $F(1, 14) = 1.2$, $p > .30$, signifying that the effect of video-game experience was similar for both central and peripheral distractors (see also Figure 2). Finally, consistent with previous reports demonstrating greater attentional resources in central vision, a Perceptual Load × Distractor Compatibility × Distractor Eccentricity interaction, $F(1, 14) = 8.1$, $p = .01$, was observed, with the decrease in the size of the compatibility effect with increasing load being more pronounced for peripheral than for central distractors.

Because differences in baseline RTs between groups may produce interactions with within-subject measures that reflect only the magnitude of the baseline RT differences, it is important to note that although the mean VGP RT was approximately 37 ms faster than the mean NVGP RT, the main effect of gaming did not approach significance (VGP: 652.4 ms ± 13.5; NVGP: 689.2 ms ± 8.8), $F(1, 14) = 0.8$, $p > .30$, indicating relatively comparable overall RTs in VGPs and NVGPs.

To better assess the spatial distribution of attentional resources in VGPs and NVGPs, the two groups were separated and the size of the compatibility effect (i.e., incompatible minus compatible RTs) for each group was examined in 2 × 2 ANOVAs with perceptual load (low vs. high) and eccentricity (central vs. peripheral) as factors. In the NVGP group, only a main effect of load was found, with compatibility effects being larger for the low-load than for the high-load condition (low: 21.6 ms ± 4.3; high: −0.5 ms ± 4.4), $F(1, 7) = 28.4$, $p = .001$. As previously reported (Proksch & Bavelier, 2002), the compatibility effect was approximately double for central distractors as compared with peripheral distractors (central: 14.4 ms ± 4.4; peripheral: 7.0 ms ± 5.7); however, in this study the main effect was not statistically significant, $F(1, 7) = 0.6$, $p > .40$.

In the VGP group no effect of load was found (low: 15.2 ms ± 4.3; high: 15.5 ms ± 4.7), $F(1, 7) = 0.001$, $p > .90$. However, an Eccentricity × Load interaction was observed, $F(1, 7) = 8.1$, $p = .03$, with compatibility effects being greater for low load in the periphery and for high load in the center. This indicates that in the VGP population, the allocation of attention shifts from a more peripherally biased distribution under conditions of low load to a more centrally biased distribution under conditions of high load.

Accuracy

Error rates were analyzed in a 2 × 2 × 2 × 2 omnibus ANOVA with video-game experience (VGP vs. NVGP), perceptual load (low vs. high), distractor eccentricity (central vs. peripheral), and

Table 1
Reaction Times (and Standard Errors) in Milliseconds for Each of the Conditions of Experiment 1

	Center distractor				Peripheral distractor			
	Low load		High load		Low load		High load	
Condition	Incomp.	Comp.	Incomp.	Comp.	Incomp.	Comp.	Incomp.	Comp.
VGP	606 (20)	595 (22)	708 (31)	684 (28)	617 (26)	595 (22)	708 (28)	701 (26)
NVGP	665 (21)	642 (18)	727 (27)	719 (26)	665 (17)	644 (17)	720 (25)	729 (25)

Note. Non-video-game players (NVGPs) show a clear decrease in the size of the compatibility effect with increasing perceptual load for both central and peripheral distractors, whereas video-game players (VGPs) show a decrease in the size of the compatibility effect with increasing perceptual load only for the peripheral distractors. The opposite effect, an increase in the size of the compatibility effect with increasing perceptual load, is observed in the VGP population for the center distractor condition. Incomp. = incompatible; comp. = compatible.

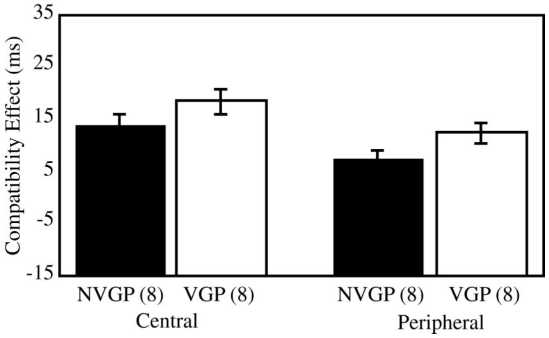

Figure 2. Results of Experiment 1: Size of compatibility effect (RT incompatible minus RT compatible) as a function of eccentricity. As in previous work, there is a trend for greater compatibility effects to be present for center distractors. Of note, video-game players (VGPs) show compatibility effects for both center and peripheral distractors, suggesting that the changes in the VGP population are not specific to the visual periphery. RT = reaction time.

distractor compatibility (compatible vs. incompatible) as factors. This analysis revealed only a main effect of perceptual load (low load: 94.3% ± 1.0; high load: 80.6% ± 1.3), $F(1, 4) = 221.5$, $p < .001$. No other main effects or interactions were significant, including the main effect of video-game experience, $F(1, 14) = 0.1$, $p > .70$. The increase in error rate with higher levels of perceptual load highlights the increase in task difficulty with increasing perceptual load. However, the lack of a main effect of or interactions with video-game experience suggests that the task was equally difficult for the VGP and the NVGP populations.

Discussion

Experiment 1 establishes that VGPs continue to be affected by distracting items at much higher perceptual loads than NVGPs. As previously discussed, the perceptual load at which compatibility effects disappear provides an estimate of the amount of available attentional resources. The higher the perceptual load of the task is when this occurs, the greater will be the attentional resources available. VGPs demonstrate a clear compatibility effect even under conditions of high load, whereas NVGPs cease to show an effect of the distractors at these loads. This indicates an increase in the attentional resources available in the VGP population.

Other potential alternative explanations for this result are not wholly consistent with the data. One may surmise, for instance, that the discrimination task is less perceptually demanding for the VGPs than for the NVGPs. It would then follow that the perceptual difficulty of, for instance, a load of four for an NVGP is equivalent to a load of eight for a VGP. However, although the VGPs do show a slight advantage in both percentage correct (VGPs approximately 1% more accurate) and simple RT (VGPs 37 ms faster), neither is significant, nor are there Video-Game Experience × Perceptual Load interactions for either dependent variable. Thus, behaviorally one must assume the tasks are similarly difficult for the two groups. Another possible explanation is that nontarget objects simply distract VGPs more easily than NVGPs. Although it is unintuitive that the "advantage" in attentional resources manifests itself through a greater effect of distractors (which would suggest poorer control of visual selective attention), it should be noted that at a load of one, which elicits the maximum compatibility effect from NVGPs, the VGP compatibility effect is, if anything, smaller than that of the NVGPs ($p = .10$). This issue is addressed more thoroughly in Experiments 2 and 3, but in all, the hypothesis most consistent with the data is that VGPs have an enhancement in attentional resources as compared with NVGPs.

Importantly for the question at hand, the spatial distribution of attention found in VGPs was similar to that seen in NVGPs. In accord with the previous literature (Beck & Lavie, 2005; Proksch & Bavelier, 2002), a bias was seen for central vision, with the size of the compatibility effect decreased more sharply with increasing load for peripheral than for central distractors, reflecting greater attentional resources in central than peripheral locations (Figure 2). It is also significant that the interaction between video-game experience, perceptual load, and distractor compatibility did not interact further with distractor eccentricity. This suggests that even as load increased, the VGPs continued to process both central and peripheral distractors to a greater degree than the NVGPs. Thus, enhanced attentional capacities in VGPs are not exclusive to the visual periphery but instead are present in both central and peripheral vision.

To more conclusively answer the question of whether VGPs can make the most of this attentional enhancement, we used a different type of paradigm. After all, in the perceptual load task distractors are processed, despite the fact that doing so could be detrimental to the successful completion of the primary task. The question then arises, are VGPs actually better at filtering out irrelevant items, which is really the hallmark of visual selective attention? To answer this question we turned to the UFOV paradigm, which allowed us to measure the effect of distracting information and changes in central task load on peripheral target localization.

Experiment 2: The UFOV Paradigm

The UFOV task (Ball et al., 1988; Ball & Owsley, 1992; Goode et al., 1998; Mazer, Sofer, Korner-Bitensky, & Gelinas, 2001; Myers, Ball, Kalina, Roth, & Goode, 2000; Sekuler, Bennett, & Mamelak, 2000) measures the ability to locate a target as a function of the eccentricity of the target, the amount of distracting elements in the display, and the presence of an added center task. Performance on the UFOV is poorly correlated with so-called "perceptual" visual attributes (contrast sensitivity, acuity, perimetry, etc.) and is instead thought to provide an index of the distribution of visual attention across the visual scene (Ball et al., 1990; Owsley et al., 1995). Previous results indicate that the ability to localize a peripheral target decreases with eccentricity, with distraction, and as a center task is made more difficult (Ball et al., 1988).

Three different target eccentricities (10°, 20°, and 30°) were used, allowing the distribution of visual attention to be mapped as a function of eccentricity. Because the peripheral stimulus in Experiment 1 was within the range of normal video-game playing, we were unable to assess the generality of the learning across space. In the UFOV paradigm, we can test the effect of action video-game experience within, at the border of, and beyond the eccentricity at which games are typically played (our players generally reported a viewing angle of 7.5°–10° from the center of the screen). If the effect of action video-game play is specific for trained parts of the visual field, there should be little to no effect of experience at 30°, whereas if action video-game play alters processing throughout the visual field, differences should be observed at all three eccentricities.

To better understand the effect of video-game playing on the allocation of attention over the visual field, we used a paradigm that included one condition without a center task and one with a center task. By contrasting performance with and without a concurrent center task, the UFOV allowed us to test whether enhanced peripheral localization performance in VGPs may be occurring at the cost of central performance. If VGPs indeed have greater attentional resources both centrally and peripherally, as suggested in Experiment 1, the detrimental effect of the center task on peripheral localization should be lesser in VGPs than in NVGPs (while maintaining equal accuracy on the central task). Alternatively, if enhanced peripheral performance in VGPs is at the cost of central attention, we may observe a larger trade-off between central and peripheral tasks in VGPs than in NVGPs.

Finally, the paradigm we used included displays with and without distractors. Participants were first asked to perform the task without distractors and then with distractors. Performance in the distractor condition is thought to reflect the same processes as in typical visual search; however, because block order was fixed, this design does not allow us to address the issue of whether there is a discriminative effect of distractor load. Thus, our paradigm is not suited to address the role of gaming on the rate of visual search.

Method

Participants

A total of 16 right-handed men with normal or corrected vision, none of whom had participated in Experiment 1, were classified as either VGPs or NVGPs according to the same requirements as those used in Experiment 1. Of these men, 8 were classified as VGPs (mean age = 19.5, all right-handed), and the remaining 8 fell into the NVGP category (mean age = 20.1, 7 right-handed).

Apparatus

The apparatus consisted of a Macintosh G3 computer running a program to present stimuli and collect the data using the MATLAB computer language (The MathWorks Inc., Natick, MA) and the Psychophysical Toolbox routines (Brainard, 1997; Pelli, 1997) (http://psychtoolbox.org). The stimuli were displayed on a 24-in. Sony GDM-FW900 driven at 160 Hz, with 800 × 600 resolution, by an MP 850 video card (Village Tronic Computer, Sarstedt, Germany).

Stimuli and Procedure

Each observer viewed the display binocularly with his head positioned in a chin rest at a test distance of 22 cm. Each trial consisted of four successive displays presented on a large monitor. The displays were similar to those used by Ball et al. (1988), but stimulus size and presentation time were both decreased to account for the increased ability of comparatively younger participants.

The initial display consisted of a square outline (4° × 4°) that directed fixation to the center of the screen. After 1 s, the target stimulus, a filled triangle within a circle outline (subtending 3° × 3°), appeared along with the central fixation box. The target stimulus could appear randomly at one of 24 locations on the screen. Each location was positioned on one of eight radial spokes and at one of three possible eccentricities: 10°, 20°, or 30°. Rapid presentation of the stimulus ensured that no purposeful change in fixation could be completed during the presentation. Localization difficulty was roughly equated at all eccentricities by manipulating the exact stimulus presentation duration to allow a fair comparison of the effects of gaming across eccentricities. On the basis of the results from a few pilot VGPs (none of whom took part in the subsequent experiments), the duration of the stimulus presentation was chosen to lead to about 80% correct performance in VGPs at all three eccentricities tested. To achieve this goal, we used a shorter display presentation at 10° (6.7 ms) than at 20° and 30° (13.4 ms). By preventing ceiling effects in the VGP group, this manipulation enabled us to assess the true size of the group effects at each eccentricity.

After the test stimulus, a mask screen appeared for 750 ms. The mask screen, designed to eliminate afterimages as a possible source of information, consisted of randomly spaced vertical and horizontal lines of variable thickness and luminance, circles and squares of random sizes, and thick lines (luminance equal to that of the stimulus) that completely covered each possible stimulus location. The location, size, and contrast of the mask items were randomized for every trial to prevent the creation of potentially confounding consistent local elements. Finally, a response screen consisting of a radial pattern (eight evenly spaced spokes: four cardinal directions as well as four diagonals) appeared to direct the response. Each spoke was labeled in a one-to-one stimulus–response mapping with the keyboard number pad (i.e., the Number 8 spoke was straight up from center, the Number 4 spoke was straight left) to best facilitate participant response.

Participants were allowed to respond at any time after the presentation of the stimulus by pressing the number on the keyboard number pad corresponding to the radial spoke they believed the stimulus had appeared on. Pilot data from Ball et al. (1988) indicated that when participants could accurately determine the radial location of the stimulus, they also knew the target's eccentricity more than 90% of the time. Therefore, participants were not required to indicate the eccentricity of the target. Although most participants responded during the mask presentation time, if a participant had not yet responded, the spoke pattern remained visible until he made a selection. Participants were made aware that accuracy rather than speed of response was critical and that no penalty was assessed for slow responses. After participant response, feedback was given, and the participant pressed the middle key on the number pad (the number 5, which was not associated with a spoke) to initiate a new trial.

Two main levels of distraction were tested. Under the no-distractors condition (0-distractor block), the stimulus appeared alone on the screen. In the distractors-present condition, two sublevels of distraction were tested. In one (23-distractor block), distractors were present in the 23 potential target positions not occupied by the target (on the eight spokes and at all three possible eccentricities). The distractors consisted of open squares of the same luminance as the stimulus and subtending 4° × 4°. In the other (47-distractor block), the distractors occupied all of the same locations as in the half-distraction condition as well as the areas between, thus filling a 60° diameter circle with distractors. Each participant underwent 120 trials (eight spokes × three eccentricities × five repetitions of each) for each of the three distraction blocks (0, 23, and 47). The blocks were always tested in a fixed order: 0 distractors, followed by 23 distractors, and then 47 distractors. It should be noted again that for the purposes of statistics and discussion, because performance differences have not been observed between the 23- and 47-distractor block either by our own lab or others (Ball et al., 1988), the data from the 23- and 47-distractor blocks were collapsed into the distractors-present group. This resulted in twice as many trials in the distractors-present group than in the no-distractors group. Considering also that distractor order was not counterbalanced, we chose to perform separate analyses for no-distractors and distractors-present conditions.

In a different set of blocks, one for each block of distractors (0, 23, and 47), participants performed the same peripheral localization task but also performed a center-shape discrimination task as well. The central stimulus was either an isosceles triangle or a diamond. In these blocks, participants were asked to determine which of the two shapes (triangle or diamond) was presented centrally (within the center fixation box) by pressing the correspondingly labeled key on the keyboard. Participants then indicated the spoke upon which the peripheral target fell on the keypad (in the same manner as previously described).

The experiment therefore consisted of six blocks: 0-, 23-, and 47-distractor blocks each with and without a simultaneous central task. The level of center task was counterbalanced as to which was given first, but again, the distractor conditions were always run in the order 0, 23, and 47.

To summarize, four main factors were manipulated: the amount of video-game experience of each participant (two levels: VGP vs. NVGP), the eccentricity of the target (three levels: 10°, 20°, or 30°), the amount of distraction (two levels: no distractors vs. distractors present), and the center task (two levels: no center task vs. center task present).

Results

Because the design of the experiment did not counterbalance between distractor blocks (and thus distractor condition is confounded with task experience), peripheral localization accuracy was analyzed in two separate 2 × 3 × 2 ANOVAs, one for the no-distractors condition and one for the distractors-present condition, with video-game experience (VGP vs. NVGP), eccentricity (10°, 20°, or 30°) and center task (no center task vs. center task present) as factors. The peripheral localization data for the center task present conditions were filtered prior to analysis by removing any trials in which the center shape was incorrectly identified.

It should be noted that because several of the cell means for the NVGPs approached floor (and thus may have deviated from normality), we also performed the same ANOVAs on arcsin-transformed data. In no cases did a significant p value in the untransformed analyses become nonsignificant using the arcsin transform or vice versa, and thus for ease of interpretation, only the analyses on untransformed accuracy are presented.

Peripheral Localization Accuracy

No-distractors condition. First, although we tried to match performance across eccentricities, a main effect of eccentricity, $F(2, 28) = 4.7$, $p < .05$, was still observed. Unlike previous UFOV studies, however, where the main effect of eccentricity represented decreasing accuracy with increasing eccentricity, the main effect of eccentricity here represents a failure to equalize the difficulty of each eccentricity by altering the presentation times. By using different presentation times (7 ms for 10° and 13 ms for 20° and 30°) we had hoped to achieve relatively stable performance across eccentricities. However, whereas 10° and 30° did have similar performance with these timings, performance at 20° was slightly better than both. Second, a main effect of center task, $F(1, 14) = 5.2$, $p < .05$, was observed, with participants making more peripheral localization errors when the center task was present. Finally, as predicted by our hypothesis, a main effect of video-game experience was observed (VGP: 84.3% ± 2.5; NVGP: 31.8% ± 3.6), $F(1, 14) = 44.4$, $p < .001$ (Figure 3A), as the VGP group outperformed the NVGP group by a large margin. No other effects reached significance.

Distractors-present condition. As in the no-distractors condition, a main effect of eccentricity, $F(2, 28) = 6.5$, $p < .01$, was observed. The main effect of center task did not reach significance, $F(1, 14) = 3.8$, $p = .07$, but was in the same general direction as in the previous analysis. Again, as predicted, a large main effect of video-game experience was observed (VGP: 73.6% ± 3.0; NVGP: 30.0% ± 3.1), $F(1, 14) = 37.5$, $p < .001$ (Figure 3B), indicating superior localization performance by the VGPs. Finally, a Video-Game Experience × Eccentricity × Center Task interaction, $F(2, 28) = 4.5$, $p = .02$, was observed and appears to be rooted in the fact that the VGPs performed disproportionately well in the center task condition at 10° of eccentricity (fastest presentation time).

Center Identification Task Performance

The previous analyses included only trials in which the center shape identification was correct. However, to conclusively demonstrate that any differences observed in peripheral localization accuracy were not related to allocation of attention to the periphery at the expense of the center task, center shape identification was analyzed in a 2 (video-game experience: VGP vs. NVGP) × 3 (eccentricity: 10°, 20°, or 30°) ANOVA collapsed across all distractor conditions.

VGPs exhibited greater accuracy than NVGPs at the center discrimination task itself (VGP: 97.2% ± 0.8; NVGP: 90.1% ± 1.1), $F(1, 14) = 25.4$, $p < .001$. A main effect of eccentricity, $F(2, 28) = 15.0$, $p < .001$, highlights the differences in presentation time. When the peripheral stimulus was presented at 10° of eccentricity, the presentation time was one screen refresh fewer than

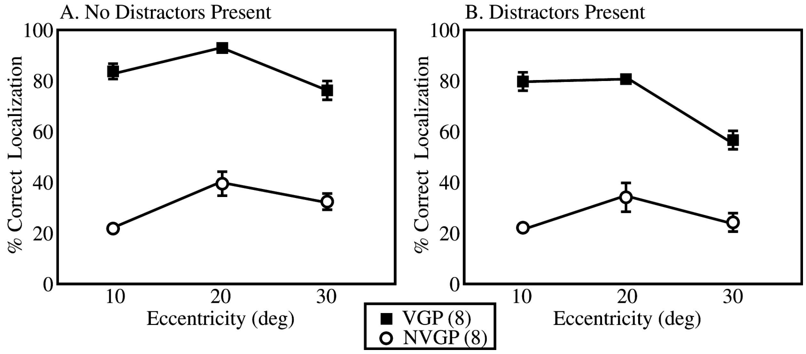

Figure 3. Experiment 2: Accuracy of target localization as a function of eccentricity for gamers (VGPs) and nongamers (NVGPs). VGPs localize a peripheral target far more accurately than NVGPs at each eccentricity (x-axis), both without (A) and with (B) distractors present.

when the peripheral stimulus was at 20° or 30°. Thus, the presentation time of the center stimulus was also decreased by this amount at 10°. VGPs were able to achieve the same level of center identification performance for each eccentricity/presentation time (10°: 98.6% ± 0.41; 20°: 97.9% ± 0.6; 30°: 95.2% ± 1.5), whereas NVGPs suffered a cost at the quicker presentation time (10°: 81.1% ± 2.5; 20°: 95.2% ± 1.0; 30°: 96.0% ± 0.8), resulting in a Video-Game Experience × Eccentricity interaction, $F(2, 28) = 6.3$, $p = .006$.

Overall Effect of Center Task on Peripheral Localization

Because the results of Experiment 1 made the specific prediction that NVGPs would be more strongly affected by the addition of a concurrent center task than VGPs, the two groups were separated and the effect of center task on peripheral localization accuracy was analyzed collapsed across eccentricities and distractor levels. As predicted, only the NVGP group showed a significant decrease in performance when the center task was added (no center task: 33.8% ± 7.1; center task present: 25.3% ± 5.8), $F(1, 7) = 7.0$, $p = .03$; the VGPs showed no such decrement (no center task: 77.9% ± 5.0; center task present: 76.3% ± 3.6), $F(1, 7) = 0.2$, $p = .65$. This pattern of results supports the conclusion that VGPs have more attentional resources available than NVGPs.

Discussion

VGPs display enhanced target localization abilities under all conditions tested. VGP performance is superior to that of NVGPs at all eccentricities, with and without the addition of distractors and with or without a concurrent center task. Together, these findings support the results of Experiment 1 and demonstrate an enhancement in spatial attention in VGPs not only at peripheral but also at central locations.

VGPs more accurately localize the target at all three eccentricities (10°, 20°, and 30°), demonstrating that video-game experience enhances visual processing across a large portion of the visual field. In particular, the superior performance of VGPs at 30° suggests that the effects of video-game play generalize to untrained locations, as this eccentricity is beyond the eccentricity at which most gamers play.

VGPs also show a clear advantage in localization with or without the presence of distracting objects. The superior performance in the no-distractors condition indicates an enhancement at localizing abrupt onsets in the visual periphery. The very brief amount of time the stimulus is displayed (< 15 ms) appears sufficient to create a detectable change in the visual field that is more easily localized by the VGP population than by the NVGP population. While this condition requires the participant to locate abrupt onsets and so may draw on exogenous attention, it is also possible that improvement on this condition could be due to more perceptual factors. The advantage in the distractors-present blocks indicates that video-game experience increases the ability to select targets among distractors. Therefore, although the results of Experiment 1 could have been attributed to an increase in distractibility in VGPs, the findings of Experiment 2 conclusively demonstrate not only that more resources are available to VGPs but also that this enhanced attention can act to increase target selection. This is consistent with previous reports that have found a positive relationship between increased attention and enhanced visual selection (Carrasco & Yeshurun, 1998; Eckstein, Shimozaki, & Abbey, 2002; Palmer, 1994).

Finally, when the center task is added, VGPs continue to substantially outperform the NVGPs. VGPs perform both tasks easily, and in fact, their localization performance shows no effect of the added center task. Conversely, NVGPs show a small decrease in task performance with the addition of a center task. The size of the falloff is consistent with previous work on the UFOV paradigm, namely, relatively modest decreases in peripheral localization performance with the addition of a center discrimination task in younger observers, with substantially larger effects being seen in the elderly (Ball et al., 1988).

Of importance, VGPs outperform NVGPs on the center task itself, suggesting that no trade-off of attentional distribution is involved (although we note that it could be the case that the central task was simply easier for the VGPs). Essentially, VGPs can perform both tasks with near perfect accuracy; this suggests that the load of these two tasks combined is below their capacity limit for dual-task performance, whereas NVGPs show lessened performance at both tasks, suggesting that their capacity limit is substantially lower. This mirrors the predictions given by the results of Experiment 1 in which NVGPs were seen to have fewer attentional resources than VGPs, both peripherally and centrally.

Whereas our hypothesis predicts that extensive video-game playing leads to these enhanced skills, it could also be the case that VGPs have inherently better visual skills and/or were somehow genetically endowed with greater attentional abilities. To demonstrate a causative role of action video-game play in these effects, we trained a group of NVGPs on an action video game in Experiment 3. If the effects are due to action video-game experience, similar enhancements in localization performance should be observed following training.

Experiment 3: Training Study

NVGPs were divided into two training groups. Half underwent video-game training using an action video game, whereas the others played a game that made heavy demands on visuomotor coordination but, unlike action video games, did not require the participant to process multiple objects at once at a fast pace. This control group was added to check for another possible explanation for the difference between VGPs and NVGPs whereby what is learned during video-game play is not necessarily visual in nature but is instead visuomotor. Although the use of percentage correct, and not RT, should minimize the effect of visuomotor coordination in our measures, it is possible that by alleviating the demands of the motor response, video-game playing allows VGPs to have more "leftover" resources available to process the stimulus. If the differences observed in Experiment 2 are due to an attentional enhancement and not due to lightened visuomotor control or genetically endowed traits, a notable improvement in UFOV performance should be observed following training in the action game trainees but not in the control game trainees. Unlike Experiments 1 and 2, which only included men, Experiment 3 included half men and half women, allowing us to test the generality of our findings to both sexes.

On the basis of the results of Experiment 2 as well as pilot training data, several modifications were made to the design of the paradigm. Among these were to remove feedback in order to minimize the amount of task-related learning that occurred during testing. Also, a more difficult center discrimination task was used to avoid potential ceiling effects, as performance on the center identification task of Experiment 2 was quite high.

Method

Participants

The study enrolled 32 NVGPs, none of whom had taken part in Experiments 1 or 2, who were equally and randomly divided between the experimental and control groups. The criteria for NVGP remained the same as in all previous experiments. All participants underwent training as described below. In all, 8 women and 8 men (mean age = 21.3, all right-handed) made up the final experimental group, and the final control group consisted of 9 women and 7 men (mean age = 21.0, 15 right-handed).

Pretest

Participants underwent a slightly modified version of the previous tasks. First, only four blocks were run: two no center task blocks and two center task present blocks, each with a no-distractors and a distractors-present condition. Second, a fine orientation discrimination task was selected for the center task. The difficulty of the center task was manipulated on the basis of pilot data to lead to around 70% correct performance, making it a far more difficult center task than that used in Experiment 2. Third, because the by-eccentricity timing manipulations had failed to yield equal performance across eccentricities in Experiment 2, each eccentricity was tested with a 13-ms stimulus presentation duration. Fourth, a white noise mask was chosen, as participants found the pattern mask used in the previous experiments especially disrupting, and there were concerns that this difficult pattern mask may have been disproportionately disruptive to NVGPs as compared with VGPs. Finally, to minimize the effect of test–retest improvements, no feedback was given. Because no effect of center task order was found in Experiment 2, and because of the presence of several other tasks unrelated to the task at hand, participants were always tested on the no center task condition first, then the center task condition (making the run order as follows: no center task/no distractor, no center task/distractors present, center task present/no distractor, center task present/distractors present). Finally, to minimize any test–retest effects, each participant underwent only 72 trials (8 spokes × 3 eccentricities × 3 repetitions of each) for each condition.

Apparatus

Testing. The apparatus was identical to that described in Experiment 2 except the monitor was a ViewSonic P817 21-in. monitor (ViewSonic, Walnut, CA).

Training. Both groups played on 20-in. monitors.

Training Stimuli and Procedure

For both groups, training consisted of playing the predetermined video game for 30 total hours (maximum of 2 hr per day, minimum of 5 hr per week, maximum of 8 hr per week). The 16 members of the experimental group played the game Unreal Tournament 2004 (henceforth referred to as the action video game). This game was chosen to be similar to those played by our VGPs. It has a relatively simple interface, uses first-person point of view, and requires effective monitoring of the entire visual field (extent from fixation about 13° height × 16° width). Each hour-long session was divided into three 20-min blocks. The difficulty of each block was adjusted according to the kill–death ratio. If in a block the player scored twice as many kills as he or she had deaths, the difficulty level was increased one level. Players were retested on lower difficulty levels on the final 2 days of training to quantitatively assess improvement.

The 16 members of the control group played the game Tetris, which was displayed to cover the entire screen. The field of view of the Tetris game was actually slightly larger than that of the action game—the effective game area extended 18° height × 13° width from fixation. This game was selected to control for the effect of improved visuomotor coordination, while putting little demand on the processing of multiple objects at once. Accordingly, the version of Tetris on which participants were trained had the preview block option turned off. In a manner analogous to the action-trained group, improvement was quantitatively measured by comparing performance on Day 1 with that on Day 30.

Posttest

After video-game training, participants were retested on the same experiment as in the pretest, as well as the other aforementioned unrelated tasks.

Results

Game Play

To assess game improvement, several measures were used, with a percentage change score calculated for each. For the action game, the two measures used were kills and death. For each of five levels of game difficulty (Level 5 being the highest level that all players attained), the measure taken on a participant's first playing of the level (which, because of the way in which difficulty was progressed, was not necessarily on the first day of training) was compared with his or her final playing of that level on Days 29–30. A substantial increase in number of kills, decrease in number of deaths, and increase in the ratio of kills to deaths was seen at each difficulty level (Level 1: 226% increase in kills, 64% decrease in deaths; Level 2: 147% increase in kills, 38% decrease in deaths; Level 3: 160% increase in kills, 27% decrease in deaths; Level 4: 80% increase in kills, 33% decrease in deaths; Level 5: 52% increase in kills, 32% decrease in deaths).

For the control game, the mean and median scores from Day 1 were compared with the same values on Day 30. As in the action game, the control players showed substantial improvements after training, the mean score improving by 323% and the median score by 359%. These results demonstrate that both groups were engaged in their training and showed improvement on the training task.

UFOV Task

Accuracy was analyzed in four 2 × 2 × 3 ANOVAs, blocked by distractor level and center task condition, with game trained (action vs. control), test (pretest vs. posttest), and eccentricity (10°, 20°, or 30°) as factors. As in Experiment 2, center task present trials were first filtered to include only those trials wherein the center task was correct.

As in Experiment 2, the observation of near-ceiling performance in some cells led to an analysis with arcsin-transformed data. In only one case did a nonsignificant p value in the untransformed analyses become significant in the arcsin-transformed analyses (noted in the next section), and in no cases did a significant *p* value in the untransformed analyses become nonsignificant in the arcsin-transformed analyses. As in Experiment 2, only the untransformed analyses are presented.

Peripheral localization accuracy: No distractors, no center task. A main effect of eccentricity was observed, $F(2, 60) = 3.9$, $p < .05$, with accuracy decreasing with increasing eccentricity. A main effect of test was observed, $F(1, 30) = 4.5$, $p < .05$, with accuracy improving from pre- to posttest. However, although the interaction between game trained and test did not reach significance, $F(1, 30) = 3.8$, $p = .06$ (Figure 4A), it was in the direction predicted by our hypothesis, with the action group improving more than the control group. The ability to see a clear difference between groups was likely hindered by the near-ceiling performance in this condition. It is also worth noting that this effect would be statistically significant assuming a one-tailed test, which would be justified given our specific prediction of greater improvements in the action-trained group, and also that this effect was significant, $F(1, 30) = 4.6$, $p < .05$, in the arcsin-transformed analysis.

Peripheral localization accuracy: No distractors, center task present. Main effects of eccentricity, $F(2, 60) = 37.2$, $p < .001$, with accuracy decreasing with increasing eccentricity, and of test, $F(1, 30) = 10.5$, $p < .01$, with accuracy increasing on the posttest relative to the pretest, were observed. Also observed was an interaction between game trained and test, $F(1, 30) = 6.8$, $p < .05$, reflecting greater improvement in the action game than in the control game (Figure 4B).

Peripheral localization accuracy: Distractors present, no center task. A main effect of eccentricity, $F(2, 60) = 72.4$, $p < .001$, was observed. Main effects of game trained, $F(1, 30) = 4.9$, $p < .05$, and of test, $F(1, 30) = 25.4$, $p < .001$, were observed, with the action group being more accurate than the control group and participants performing better on the posttest than on the pretest. A significant interaction between game trained and test, $F(1, 30) = 12.8$, $p = .001$, indicates that the action group improved significantly more than the control group, which is likely the root of the main effect of game trained. Finally, a significant interaction between game trained, test, and eccentricity, $F(2, 60) = 4.8$, $p < .05$, reflected the action group's performance falling off less steeply with eccentricity following training (Figure 4C).

Peripheral localization accuracy: Distractors present, center task present. Only a main effect of eccentricity, $F(2, 60) = 70.3$, $p < .001$, and an interaction between game trained and test, $F(1, 30) = 5.1$, $p < .05$, were observed, with, again, accuracy decreasing with increasing eccentricity and the action group improving by a larger margin than the control group (Figure 4D).

Center Identification Task Performance

First, although the center task performance was knocked far from ceiling, there was no general increase in center discrimination

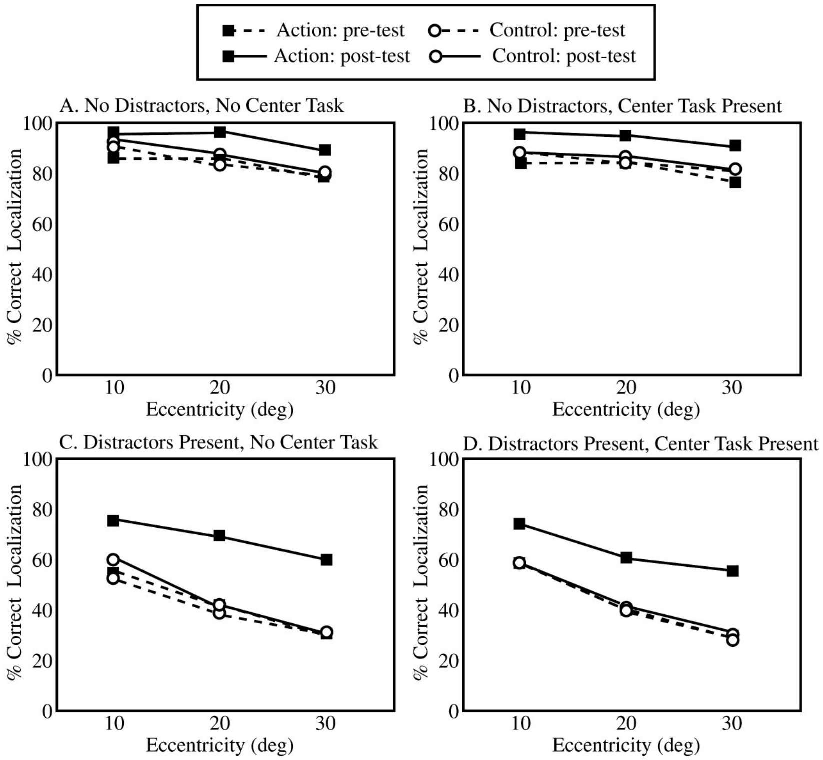

Figure 4. Experiment 3: Accuracy of target localization as a function of eccentricity, training group, and test. The action-trained group showed a significantly greater improvement in localization accuracy than the control group following training at each eccentricity for all of the conditions other than the no-distractors/no-center-task condition, for which the result was nearly significant ($p = .06$).

task accuracy following training, and this held true for both groups (action trained: pretest: 61.3% ± 3.0, posttest: 66.6% ± 4.3; control trained: pretest: 66.6% ± 3.1, posttest: 67.5% ± 3.7; main effect of test, $p > .05$; interaction between test and game trained, $p > .50$). A main effect of distractor level, $F(1, 30) = 7.6$, $p = .01$, indicates that central task performance was affected by the demands of the localization task, with worse central task performance for the distractors-present than for the no-distractors condition.

Discussion

The results from Experiment 3 establish that the act of playing an action video game improves performance on the UFOV task. Of note, action-trained participants showed greater training-induced improvements than participants trained on a control game that relies heavily on eye–hand coordination. Thus, improvement after action game training cannot be attributed to a general test–retest advantage or to the fact that video-game training facilitates visuomotor coordination. Instead, action video-game play appears to truly modify visuospatial attention.

As in Experiment 2, the action video-game trained group improved their localization ability at all eccentricities—even at 30°, which is beyond the maximum eccentricity of game training. This result confirms that the effects of action video-game play do generalize to untrained locations in the visual field. The action-trained group also improved their localization performance both with and without the presence of distractors, confirming that action video-game play does enhance the ability to monitor the peripheral visual field and also to select targets from within a field of distractors.

Finally, a strong effect of training was seen on peripheral localization both without and with the presence of a center task in the action-trained group. The finding that the action-trained group outperforms the control-trained group even when a center task is added demonstrates that the enhanced peripheral localization performance of action gamers is not at the cost of central performance. Unlike in Experiment 2, the central task was equally difficult for both groups. As the participants in Experiment 2 have many more hours of training than those of Experiment 3, this pattern of results is consistent with the view that visual performance may be harder to modify in central than in peripheral vision. Finally, the equivalent performance on the center task in the two training groups in Experiment 3 demonstrates that the center task was perceptually as demanding in action-trained and control-trained group. It is therefore unlikely that the enhanced performance induced by action game training could be due to perceptual factors. Rather, the proposal that action video-game training enhances attentional resources over the whole field offers a more parsimonious explanation of the data presented.

Relationship Between Action Game Improvement and UFOV Improvement

The goal of Experiment 3 was to establish a causal link between action video-game play and enhanced performance on the UFOV task. By showing that participants required to play action video games display greater improvements on a visuospatial attention task than participants required to play a control game, this study establishes a causal link between action game play and attentional capacities. What remains unclear, however, is whether performance on an action video game can be used to predict how good visual selective attention is. On the one hand, it is clear that individuals who play action video games are better at these games than those who do not play. Combined with our finding that action game players outperform nonplayers on a visual selection task, it would seem natural to hypothesize that performance on action game play does predict attentional resources, at least as tested by the UFOV. On the other hand, action video games are extremely rich, not only visually but also strategically. There are therefore many ways to excel at action video-game playing. Although visual selective attention skills likely contribute strongly to action game success, other aspects of cognition—such as planning, memorizing landmarks and the lay of the land, and understanding the strengths and weaknesses of the various characters, weapons, and positions—also play a large role in performance. In addition, the behavioral measures provided by commercially available games are rather coarse. For instance, shooting accuracy is greatly influenced by the type of gun the player uses (a fully automatic weapon requires less accuracy than a semiautomatic weapon to achieve the same ends). Other measures such as kills and deaths are likely much better correlated with high-level strategies (which weapon to use, when to hide and when to attack, remembering to replenish health and armor, etc.) than low-level perceptual skills. Nevertheless for Experiment 3 we tested whether there was a correlation between improvement in action game performance and improvement on the UFOV task.

Correlation Analysis

Percentage improvement for each of the individual UFOV conditions in Experiment 3 (no distractors/no center task, no distractors/center task present, distractors present/no center task, distractors present/center task present) was correlated with percentage change in number of kills and in number of deaths for each of the five levels of game difficulty. If those participants who improved their scores by the greatest margin on a particular condition of the UFOV task also demonstrated the greatest increase in either of these measures, a significant relationship should be observed. Out of the 40 correlations (four UFOV conditions by five kill improvement scores and five death improvement scores), there were no significant correlations (using a Bonferroni-corrected p value of .00125).

Discussion

This analysis indicates a lack of correlation between available measures of game improvements and UFOV improvement. Although the finding of such a positive correlation would have nicely complemented the finding of a causal relationship between number of hours of action game play and UFOV performance, it still remains that the very act of playing action games at a challenging level enhances performance on a visual selection task to a greater extent than playing other, similarly challenging control games. It will be useful for future research to further assess the link between the exact level of game expertise of a player and the quality of his or her visual selective attention. This may require the development of finer outcome measures for action video game improvement that do not mix perceptual aspects of gaming with various strategic decisions.

General Discussion

The results of these three experiments demonstrate the positive effect of action video-game play on visuospatial attention. First, by measuring the compatibility effect as a function of perceptual load, we were able to gain a measure of the attentional resources available to VGPs and NVGPs (Lavie et al., 2004). VGPs continued to show compatibility effects at greater perceptual loads than NVGPs, confirming the proposal that VGPs have enhanced attentional resources. This effect held for both central and peripheral distractors, suggesting an overall enhancement in attentional resources in VGPs rather than some manner of trade-off.

As seen in several recent studies (Beck & Lavie, 2005; Proksch & Bavelier, 2002), there was less of a decrease in the compatibility effect with increasing load for central distractors than for peripheral distractors. It has been suggested that this is due to preferential access to attentional resources around fixation, at least in the hearing population (Beck & Lavie, 2005). Interestingly, the differences seen in VGPs between low and high perceptual load conditions suggest that they may allocate attention in a more dynamic manner across space. During conditions of low perceptual load, VGPs distributed attention proportionally more to the visual periphery, but as the perceptual load of the primary task was increased, attention was shifted to central vision. One can easily imagine how such a configuration would be useful during action video-game play. During “low-load” conditions, such as when the player walks down an empty path, it would be beneficial for attention to be shifted toward the periphery in order to best detect any incoming enemies. However, during “high-load” conditions, such as when the player is being attacked by charging enemies, it would be beneficial for those resources to be shifted to the area around the player (near fixation). In all, these results suggest that although the sizing of the attentional window may be largely automatic, it need not occur with the same spatial distribution in every population or in a static manner across levels of perceptual load.

A more direct measure of the effect of gaming on visuospatial attention was obtained by using the UFOV paradigm (Ball et al., 1988), in which participants were asked to localize a very briefly presented target stimulus at multiple eccentricities, with and without the presence of distracting items and with and without the presence of a concurrent center task. VGPs showed increased localization abilities both within and outside of their typical game playing field of view, indicating that the effect of action video-game play generalizes to untrained locations. VGPs also showed a decided advantage in localization accuracy over NVGPs, both when distractors were absent and when they were present. The former demonstrates that VGPs display a general enhancement in the ability to detect an abrupt onset target in the visual periphery. Although it is known that this type of task draws on exogenous attention (Yantis & Jonides, 1990), it is also possible that improvement on this condition could be accounted for by perceptual rather than purely attentional factors. The VGP advantage in the distractors-present condition indicates that VGPs are better able to select targets among distractors than NVGPs. The fact that the distractors-present condition requires the successful selection of the target from among competing alternatives suggests that VGPs do indeed display an enhancement in visual selective attention, which has been shown to increase the spatial resolution of visual processing (Carrasco, Williams, & Yeshurun, 2002; Talgar & Carrasco, 2002; Yeshurun & Carrasco, 1998).

Alternative hypotheses that have purely perceptual factors at the root of the differences observed in the distractors-present condition are unlikely for several reasons. First, as mentioned briefly in the introduction, performance on the UFOV is quite poorly correlated with basic perceptual skills (acuity, contrast sensitivity, perimetry) (Ball et al., 1990; Owsley et al., 1995). In fact, the UFOV was initially designed by Ball and colleagues specifically because driving accidents in the elderly were found to be poorly predicted by basic perceptual abilities, and a test was required that better tapped the visual attentional requirements present while driving (peripheral monitoring, target selection, distractor rejection). Of special note is the fact that the relationship between low-level perceptual skills and UFOV performance is particularly weak for the distractors-present condition (Owsley et al., 1995). Second, the type of low-level sensory enhancements that could potentially underlie increased performance in the no-distractors condition, such as signal enhancement, would be of much less use in the distractors-present condition, in which target selection is of the essence.

Unfortunately, our design does not allow us to address the issue of search efficiency in which the rate of visual selection is measured by systematically varying set size. Although the UFOV task manipulates the number of distractors, our design used steps in distractor number that are too large (0, 23, or 47 distractors), as well as blocked order of distractor presentation, preventing any estimation of the rate of visual search proper. However, a recent study comparing visual search skills in action video-game players and nonplayers by Castel et al. (2005) speaks to this issue. In the Castel et al. article, video-game players were found to have faster response times for both easy (feature/parallel) and difficult (conjunction/serial) visual search displays—an advantage that held for displays ranging from 4 to 26 items. The difference was quite large, with VGPs performing the difficult search task with a set size of 26 in less time than the NVGPs performed the task with a set size of 18. Of note, as would be predicted by an increase in search efficiency in VGPs, Castel et al. observed a significant interaction between group (VGP vs. NVGP) and set size. The authors stated that this “interaction indicates that videogame players are more efficient in searching through displays than the non-videogame players” (Castel et al., 2005, p. 226). However, because the Set Size × Group interaction disappeared when only the largest set sizes were included in the analysis (set sizes of 10+), the authors concluded that the VGP RT advantage might be better understood as a change in stimulus–response mappings rather than a change in visual selective attention. On the basis of the results of the current study, it appears as though the initial interpretation of increased search efficiency in VGPs may have some validity. This proposal does not discount the possibility that some proportion of the difference between VGP and NVGP RT in their experiment could be accounted for by stimulus–response mappings or other mechanisms. One might hypothesize that the mechanism(s) leading to enhanced search in VGPs is capacity limited, the effect of which on total RT would necessarily be diminished with increasing set size. Future research will be needed to tease out the roles of sensitivity, criteria, and residual RT as they pertain to VGPs in visual search.

Finally, the use of the UFOV paradigm also allowed us to study the effect of action game play on dual-task performance. When a concurrent center task was added to the peripheral localization task, NVGPs showed a clear cost of the added center load in the form of decreases in peripheral localization ability, whereas VGPs showed no such effect, suggesting an improvement in the ability to perform dual tasks in VGPs. These results are well predicted by the increased capacity of visual attention in VGPs seen in Experiment 1. In addition, they unambiguously rule out the possibility that VGPs may show increased peripheral performance at the cost of central vision. The attentional resources of VGPs are sufficient to perform both central and peripheral tasks at high accuracy. In contrast, the center task depletes the resources of NVGPs and therefore decreases peripheral localization. Experiment 3 demonstrated that the effects noted in Experiment 2 can be induced by training, establishing a causative relationship between action video-game experience and performance enhancement on the UFOV. Along with the results of Experiment 1, these findings establish that action video-game experience improves both central and peripheral visuospatial attention by increasing attentional resources and facilitating visual selective attention.

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