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The advantage for action video game players in eye movement behavior during visual search tasks

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Abstract
Research has shown that playing action games is effective in promoting abilities for visual attention tasks. However, it is unclear whether the advantages of playing these games are wider peripheral vision (PV), a greater ability to process information, or a greater PV ability. This study aims to investigate the characteristics and advantages regarding the eye movements of action video game players (AVGPs) during a visual search comprising 154 participants in Experiment 1 and 166 participants in Experiment 2. The results show that compared with non-video game players (NVGPs), AVGPs have a significant time advantage in visual search tasks, with a shorter response time and fixation duration. Further, this advantage is not present unconditionally in central vision (CV) and PV but is only apparent with cues; that is, AVGPs show a greater ability to use cues. Especially in CV with cues, the saccade velocity of AVGPs is significantly faster than that of NVGPs. The results also show that AVGPs have a significant advantage in visual searching, which is mainly reflected in their use of cues and their saccade velocity of eye movement behavior in CV.

Keywords Action video game · Eye movements · Visual search · Central vision · Peripheral vision

Introduction

Visual searching is the ability to find targets among distractors, which is not only a core cognitive ability for many professions such as security screening and radiology (Biggs & Mitroff, 2019) but is also important in daily life activities, such as checking on a map for another location and looking for a book on bookshelves. Some studies have examined the effects of playing specific video games on visual attention (Bediou et al., 2018; Powers et al., 2013; Wang et al., 2016), many of which involved action video games (AVG) that are fast-paced, require vigilant monitoring of the visual periphery, and often require the simultaneous tracking of multiple targets (Green & Bavelier, 2003).

Moreover, most empirical research has suggested that playing AVGs is associated with improvements in various aspects of visual attention (Bejjanki et al., 2014; Feng et al., 2007; Green & Bavelier, 2003). For example, highly experienced AVG players (AVGPs) perform better at visual–spatial attentional tasks than non-video game players (NVGPs). They can follow the targets faster, detect changes in objects stored in visual short-term memory more easily, and perform mental rotation better (Achtman et al., 2008; Green & Bavelier, 2007). Playing AVGs has also been used as a method of cognitive behavior training for visual cognition (Azizi et al., 2017). For example, in healthy young adults, AVG training can improve visual search ability, while it helps dyslexic children and the elderly perform better in visual tasks, such as focused attention and divided attention (Belchior et al., 2013; Franceschini et al., 2013; Wu & Spence, 2013). This improvement in visual search ability is related to the experience of AVGs, that is, the characteristics of an AVG require players to attend to information that is rapidly presented both centrally and peripherally and to make quick and accurate decisions based on this information (Dale & Green, 2017). However, few studies have been conducted on AVGPs' and NVGPs' information processing ability regarding different fields of vision (FOV).

FOV is divided into central vision (CV) and peripheral vision (PV). Researchers have argued that when participants need to pay attention to PV, their CV is considered to be a

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more automatic process (Müller & Rabbit, 1989; Yantis & Jonides, 1990) and that it is more difficult for a cue from CV to influence a cue from PV or change the focus of the participant's gaze (Zhou & Duan, 2010). While gaming, AVGPs can perform a dual function: using both CV and PV when important stimuli are present. This skill-related advantage may not come from CV but from PV (Zhang et al., 2020).

First, Bediou et al. (2018) showed that AVGPs have better physical functions than NVGPs, including those relating to their FOV and visual sensitivity. That is, AVGPs may have a wider FOV or be more sensitive to cues. Second, through AVG training, AVGPs may have formed the ability to judge game information in their mind and can, thus, effectively code, recognize, and compile complex and changeable game environments, which gives them a greater ability to process information (Colzato, 2010). Third, AVGPs have a better ability to process information from PV than NVGPs. That is, PV plays a key role in a game. In a team competition, for example, AVGPs, in addition to accomplishing their own tasks, should also help their teammates appropriately and make choices regarding the overall situation. Cooperation between AVGPs means that a player should not only pay close attention to the positions and movements of the attackers (Bediou et al., 2018) but also accurately grasp relevant information regarding their partners (Qiu et al., 2018). While faced with numerous visual distractions in-game, highly experienced players pay close attention to changes in the information around them and can use early cues more effectively than non-gamers to obtain information about changes in their opponents' movements to make better choices (Chisholm & Kingstone, 2012; Zhang et al., 2020). Furthermore, the information in a game is a clue in visual tasks. For example, in a typical spatial cueing task, there are specific locations where targets could appear; one of these locations is cued prior to the target's appearance, allowing for an exogenous capture (Cain et al., 2014; West et al., 2013). Therefore, it is unclear whether the advantages of playing these games are wider PV, a greater ability to process information, or a greater PV ability.

Some studies on action games typically measured visual attention by recording the reaction time and accuracy of manual responses in various attentional and perceptual tasks (Green & Bavelier, 2006; Hubert-Wallander et al., 2011). However, one of the core functions of visual attention is programming saccadic eye movements to focus on areas that contain the information needed (Hoffman & Subramaniam, 1995). Thus, after long-term training by playing AVGs, AVGPs may be able to search more quickly and efficiently during search tasks. For example, the eyes may move futher (i.e., greater saccade amplitude) and faster (i.e., faster saccade velocity), expanding the search area that can be monitored. Although the spatial position of a target is usually random, its detection may be influenced by experience (Clark et al., 2011). For example, when a visual search task is similar to an AVG, the abilities learned while playing an AVG can be transferred to the experimental task (Zhang et al., 2019). However, it is uncertain whether AVGPs are more sensitive to peripheral stimuli. To address this question, it is necessary to record eye movement behavior during visual search tasks.

The present study aimed to investigate the advantages of AVGPs when performing a visual search task. Experiment 1 aimed to verify the visual search advantage of AVGPs, while Experiment 2 investigated whether visual advantages are reflected in PV or whether there is better visual information processing in PV by matching search tasks. Combined with the method of studying eye movements, the visual information processing ability of AVGPs and NVGPs was also studied from the PV perspective and cue utilization.

Experiment 1: Comparison of the Differences Between AVGPs and NVGPs in Visual Search Tasks

Method

Participants

Participants were selected by using a questionnaire that included three parts. First, the Internet addiction test (IAT) by Young (2009) includes 20 items about problematic Internet use, including psychological dependence, compulsive use, withdrawal symptoms, problems at school or at work, and problems with sleep, family, or time management. The IAT is a valid and reliable test used in classifying Internet addiction (Widyanto & McMurran, 2004; Widyanto et al., 2011). For each item, a graded response is selected from 1 = ''Rarely'' to 5 = ''Always.'' Scores in the range of 50 to 79 indicate occasional or frequent Internet-related problems (Young, 2009), and scores between 80 and 100 indicate serious problems or obvious signs of addiction. Second, the DSM-5 includes nine items that are useful for researching Internet gaming disorder (IGD) (Yuan et al., 2017). All items were self-reported as *Yes* or *No* ($Yes = 1$, $No = 0$). Third, a further question addressed the average number of hours spent playing AVGs in terms of hours a day and hours a week in the last 12 months at least. In this study, NVGPs needed to score less than 40 on Young's IAT, score less than 3 (out of 9) in the proposed DSM-5 criteria for IGD, and less than 2 h a week playing AVGs. Respondents who played AVGs more than 14 h a week without strict requirements on IAT and DSM-5 were classed as AVGPs.

Based on the results, which require 34 participants with effect size of 0.25, a type 1 error rate of 5% and a power of 80% using GPower, and previous studies, we decided to collect data from at least 20 participants in each group. By analyzing the questionnaire, 166 participants were selected from 877 students at Southwest University, Chongqing, China. However, 12 participants were not included in the analysis, three because of the unexpected ending of the experimental procedure causing by a broken computer in our lab and nine due to data corruption. Therefore 75 individuals as AVGPs (males = 37) and 79 as NVGPs (males = 13) completed Experiment 1. And 20 individuals as AVGPs and 20 as NVGPs, with an average of 10 males and 10 females in each group, completed the Eye Movement Study.

There were significant differences in age, IAT scores, DSM-5 scores, and game-playing per week between two groups, but there was no significant difference in education between two groups (see 28). All participants had normal or corrected-to-normal visual acuity, no history of smoking or alcohol abuse, no anxiety or depression, no astigmatism, and were right-handed. The Human Investigations Committee of Southwest University approved this research.

Apparatus

All participants used desktop computers with the same parameters. And eye movements were recorded using an EyeLink 1000 Plus eye tracker (SR Research). Viewing was binocular, but the right eye only was tracked as no disconjugacy was expected in normal subjects. Eye position was sampled at 2000 Hz with a spatial accuracy of 0.5°. The images were displayed on a computer at a viewing distance of 60 cm and resolution of 1024 × 768 px. Image presentation and eye tracking was controlled with SR Research Experiment Builder software.

Stimuli

The visual search task was adapted from Biggs et al. (2017). Search displays presented multiple pseudo- “L”s as distractors with 100% of the displays containing the only target “T.” Individual display items were comprised of two perpendicular black lines (15 × 13 px). The crossbar aligned perfectly with the other line segment to form target “T”s, whereas the crossbar slid off-center for the distractor pseudo- “L”s (see Fig. 1). All items were presented against white backgrounds. Set size varied with four possible options: 8, 16, 24, and 32. Display items were randomly rotated (0°, 90°, 180°, and 270°).

Procedure

Experiment 1 was based on a 2 × 4 design: (group: AVGPs and NVGPs) × (size of “L”: 8, 16, 24, and 32). Participants were asked to locate the target “T” as soon as possible under the interference of different numbers of “L”s. Trials began with a fixation cross for 500 ms. The search array then appeared and remained on-screen until a response or until 30 s had elapsed. Participants responded to the target’s presence by pressing the “1” key. After a 500 ms gray screen, the next trial started. The full experiment included practice (16 trials) followed by experimental trials (192 trials) of which 48 were different for each size.

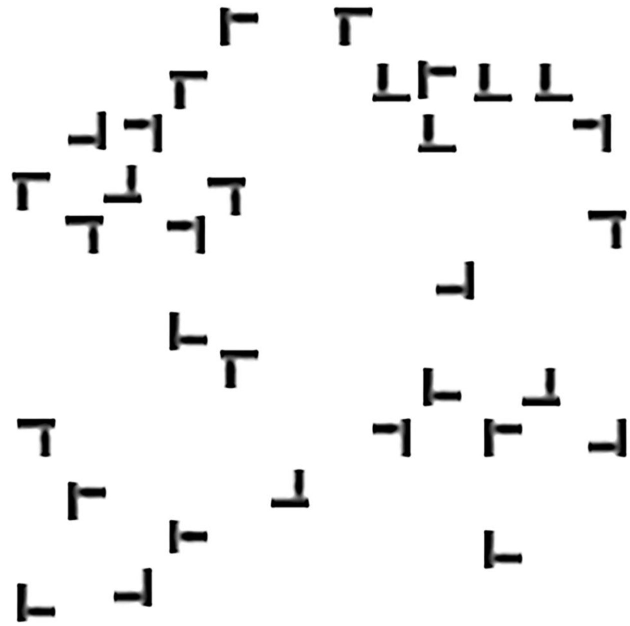

Fig. 1 Sample display from the visual search task (set size 32)

Results

All data were analyzed in SPSS 25.0. Saccades and fixations were detected by SR Research and exported data from Data View. All dependent variables were analyzed with a 2 × 4 ANOVA, with Group (AVGPs or NVGPs) as between-subjects, and Size (8, 16, 24, or 32) as within-subjects factors.

Response Time

To assess participant accuracy in performing the visual search task, we calculated the mean response times (RTs) by set size (Table 1). There was no significant difference between gender in response time (all $p > 0.05$).

A 2 × 4 ANOVA revealed a significant main effect for Group, $F = 7.50$, $p = 0.007 < 0.01$, $\eta_p^2 = 0.05$, Cohen’s $f = 0.22$, and a significant main effect for Size, $F = 400.83$, $p < 0.001$, $\eta_p^2 = 0.73$, Cohen’ s $f = 1.64$. A significant two-way interaction effect was revealed for Size × Group, $F = 7.19$, $p < 0.01$, $\eta_p^2 = 0.05$, Cohen’s $f = 0.23$. Further multiple comparative analysis showed that there were significant differences in size 8, 16, 24 (all $p < 0.05$, see Fig. 2 and 28 for detailed results), AVGPs' response time was significantly less than NVGPs'. And there was no significant difference in size 32.

In order to explore the characteristics of AVGP eye movements in visual search, we analyzed fixation duration, fixation count, saccade amplitude, and velocity of the interest area under different set Sizes (see Table 2). There was no significant difference in gender (all $p > 0.05$). Therefore, a 2×4 ANOVA was used to analyze further the differences between the two groups.

Fixation Duration

A significant main effect was revealed for Group, $F = 14.59$, $p < 0.001$, $\eta_p^2 = 0.28$, Cohen's $f = 0.62$, and for Size, $F = 255.11$, $p < 0.001$, $\eta_p^2 = 0.87$, Cohen's $f = 2.59$. A significant two-way interaction effect was revealed for Size × Group, $F = 9.64$, $p < 0.01$, $\eta_p^2 = 0.20$, Cohen's $f = 0.50$. Further multiple comparative analysis showed that there were significant differences in size 8, 16, 24 and 32 (all $p < 0.05$, see Fig. 2 and 28), AVGPs' fixation duration was significantly less than NVGPs', which was similar to response time.

Fixation Count

A significant main effect was revealed for Group, $F = 5.26$, $p < 0.05$, $\eta_p^2 = 0.12$, Cohen's $f = 0.37$, AVGPs' fixation count was significantly less than NVGPs', and for Size, $F = 272.39$, $p < 0.001$, $\eta_p^2 = 0.88$, Cohen's $f = 2.71$, but no significant interaction effects ($p = 0.051$) were observed for any of the

Table 1 Mean response times by set size (ms, M ± SD)

Set size	8	16	24	32
AVGPs	1956.57 ± 327.84	2866.37 ± 710.27	3754.70 ± 1229.99	4789.57 ± 1549.85
NVGPs	2096.19 ± 427.64	3329.15 ± 939.24	4442.28 ± 1618.36	5332.95 ± 2021.64

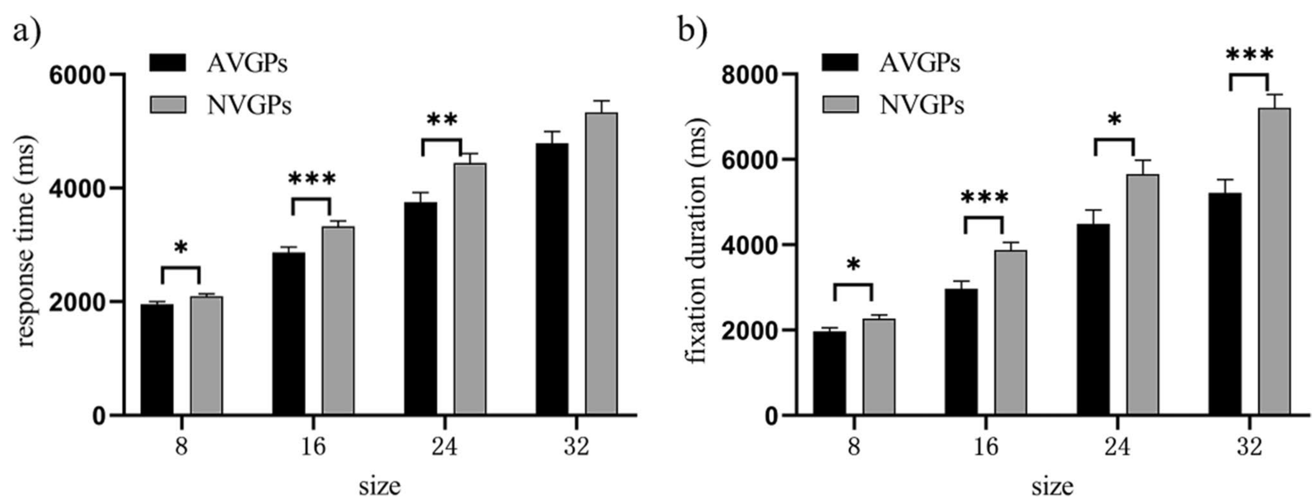

Fig.2 Experiment 1: **a)** Interaction effect for Size × Group of response time. **b)** Interaction effect for Size × Group of fixation duration. *Notes.* Error bars represent standard error. *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$. The same below

Table 2 Eye movement data in Experiment 1 (M ± SD)

		8	16	24	32
Fixation duration (s)	AVGPs	1.97 ± 0.23	2.97 ± 0.51	4.49 ± 0.89	5.22 ± 0.78
	NVGPs	2.27 ± 0.48	3.88 ± 0.97	5.66 ± 1.80	7.21 ± 1.73
Fixation count	AVGPs	6.85 ± 1.43	11.94 ± 2.99	17.74 ± 4.26	21.31 ± 5.12
	NVGPs	7.80 ± 1.49	13.74 ± 3.43	20.39 ± 5.17	25.54 ± 5.42
Saccade amplitude (°)	AVGPs	3.23 ± 0.30	3.00 ± 0.40	2.70 ± 0.40	2.62 ± 0.39
	NVGPs	3.05 ± 0.26	2.86 ± 0.32	2.52 ± 0.28	2.48 ± 0.35
Saccade velocity (°/ms)	AVGPs	117.21 ± 10.05	113.62 ± 10.96	105.15 ± 10.35	102.80 ± 10.80
	NVGPs	114.95 ± 7.54	110.40 ± 7.99	102.16 ± 6.90	99.39 ± 7.28

tasks. In both groups, the size can significantly and positively predict fixation count.

Saccade Amplitude

A significant main effect was revealed for Size, $F = 118.67$, $p < 0.001$, $\eta_p^2 = 0.76$, Cohen's $f = 1.78$, but the main effect for Group ($p = 0.11$) and interaction effects ($p = 0.94$) were not significant for any of the tasks. In both groups, the size can significantly and positively predict the saccade amplitude.

Saccade Velocity

A significant main effect was revealed for Size, $F = 187.83$, $p < 0.001$, $\eta_p^2 = 0.83$, Cohen's $f = 2.21$, but there was no significant main effect for Group ($p = 0.30$) and no interaction effects ($p = 0.87$). In both groups, the size can significantly and negatively predict the saccade velocity.

Discussion of Experiment 1

In Experiment 1, we investigated how AVGs contact was related to eye movement behaviors during visual searching in an abstract letter search task.

First, it was found that the AVGPs' response times were significantly faster than those of the NVGPs for sizes 8, 16, and 24, but not for size 32 because it may have been too difficult to respond to the target. Additionally, there was a significant difference between the groups in fixation duration that was similar to response time: the AVGPs' fixation durations were significantly shorter than those of the NVGPs for each size. The AVGPs' fixation counts were also significantly less than those of the NVGPs. These results indicate that AVGPs might have a time advantage over NVGPs, which is similar to what was found in previous studies (e.g., Green & Bavelier, 2003, 2007). In Experiment 1, participants were required to complete a fast search of multiple distractors, which required efficient rejection of distractors and the completion of the task using more accurate visual selection attention. Moreover, AVGPs had to track multiple targets simultaneously using intense concentration and with distractions due to the characteristics of an AVG (Bediou et al., 2018). That is, a visual search task is similar to an AVG, meaning that the abilities learned while playing an AVG can be transferred to the experimental task (Zhang et al., 2019).

Second, although differences in saccade amplitude and velocity were not significant between the two groups, the AVGPs still showed greater saccade amplitude and velocity than the NVGPs. These results indicate that AVGPs might have more efficient search behaviors with a faster search velocity and a wider search area.

This advantage may be due to a wider PV, or a greater ability to process information. When playing an AVG, AVGPs have to recognize and match the information regarding their peers and opponents with their game experience as quickly as possible to make various gaming decisions. Therefore, AVGPs may form patterns or use existing clues to improve their level of information processing. To effectively control their FOV and match the visual search task to the game scene, Experiment 2 was designed to include a figure recognition and matching search task.

Experiment 2. Investigation into the FOV and Cue on AVGPs in Visual Search

Method

Participants and Apparatus

Experiment 2 used the same participants and apparatus as Experiment 1. Finally, 82 individuals as AVGPs (males = 41) and 84 as NVGPs (males = 13) completed Experiment 2. And the same 20 individuals as AVGPs and 20 as NVGPs completed the Eye Movement Study.

Stimuli

The search image was composed of eight figures from Experiment 1. Each figure had a different shape. The images were divided into two types, large and small, and the positions of the figures were randomly distributed (see Fig. 3). The large image had a 13° visual angle on the screen, whereas the small image had a 1° visual angle. The screen resolution for both the produced and experimental pictures was 1024 × 768 px.

Procedure

Experiment 2 was based on a 2 × 2 × 2 design: group (AVGPs and NVGPs) × FOV (CV and PV) × Cue (with and without). The participants were asked to locate the target in the search image of eight figures as soon as possible (see Fig. 3). After eye movement calibration, trials began with a fixation cross for 500 ms. The search target then appeared for 200 ms and disappeared. There followed a 200 ms cue or white screen (the cue indicated that the target will appear at the prompt position), and the search graph remained on-screen until the participant responded by pressing the corresponding number key on the keyboard. After a 1500 ms gray screen, the next trial started. The full experiment included practice (16 trials) followed by experimental trials (128 trials), of which 64 tested CV vs. PV, and 64 tested with a cue vs. without a cue.

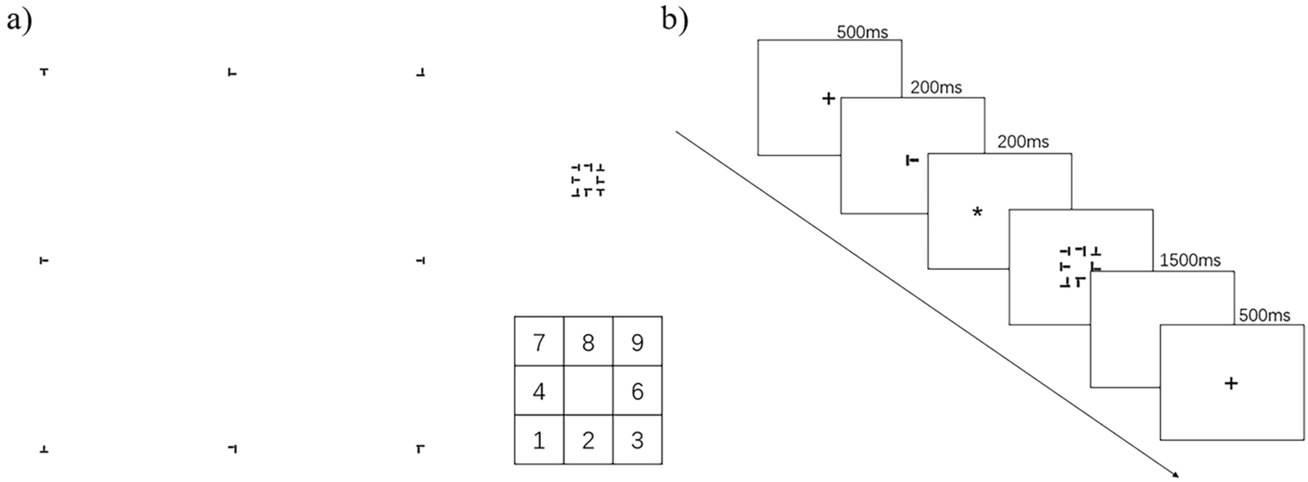

Fig.3 **a**) Stimulus figure and correspondence with numbers on keyboard. **b**) Display sequence

Results

Saccades and fixations were detected by SR Research and exported data from Data View. All data were analyzed in SPSS 25.0. All dependent variables were analyzed with a 2×2×2 ANOVA, with Group (AVGPs or NVGPs) as the between-subjects factor, and FOV (CV or PV) and Cue (with or without) as within-subject factors.

Response Time and Accuracy

To assess the AVGP advantage in visual search in different fields of vision, we calculated mean response times and accuracy (Table 3). There was no significant difference between gender in response time and accuracy (all $p > 0.05$).

The accuracy rate for both groups reached more than 95%. However, previous research has suggested that accuracy should not be considered as the dependent variable in a visual search task (Gao & Huang, 2008). Therefore, response time was treated as the main variable in the behavioral results of Experiment 2.

A 2×2×2 ANOVA revealed a significant main effect for Group, $F = 6.39$, $p < 0.\ 05$, $\eta_p{}^2 = 0.04$, Cohen's $f = 0.20$, a significant main effect for FOV, $F = 5.60$, $p < 0.05$, $\eta_p{}^2 = 0.04$, Cohen's $f = 0.20$, and a significant main effect for Cue, $F = 812.46$, $p = 0.001$, $\eta_p{}^2 = 0.83$, Cohen's $f = 2.21$. A significant two-way interaction effect was revealed for Group × Cue, $F = 12.51$, $p = 0.001$, $\eta_p{}^2 = 0.07$, Cohen's $f = 0.27$ (see Fig. 4). Further multiple comparative analysis showed that the response time for AVGPs was significantly less than that for NVGPs with a cue, there was no significant difference without a cue. And a significant interaction effect was revealed for FOV × Cue, $F = 248.65$, $p < 0.001$, $\eta_p{}^2 = 0.60$, Cohen's $f = 1.22$ (see 28 for detailed results of significant interaction effect). But no significant interaction effects were revealed for Group × FOV ($p = 0.30$) or Group × FOV × Cue ($p = 0.41$). The results show that both AVGPs and NVGPs can effectively shorten the response time by using cues, but AVGPs have a stronger ability to use cues, and their response time is significantly less than NVGP response times whether the stimulus is presented in CV or PV.

No gender difference was found in the interest analysis indexes such as fixation duration, fixation count, saccade amplitude, and velocity (all $p > 0.05$). To investigate and compare the characteristics of eye movements in the matching search task, only the correct trials were analyzed. The results are shown in Table 4, and a 2×2×2 ANOVA was used to analyze further the differences between the two groups.

Fixation Duration

A 2×2×2 ANOVA revealed a significant main effect for FOV, $F = 294.82$, $p < 0.001$, $\eta_p{}^2 = 0.89$, Cohen's $f = 2.84$, and

Table 3 Mean response times and accuracy in Experiment 2 (ms, M ± SD)

Group	Accuracy	Without Cue		With Cue	
		CV	PV	CV	PV
AVGPs	0.95 ± 0.04	2190.79 ± 419.33	2496.88 ± 337.14	1183.06 ± 746.26	932.77 ± 488.02
NVGPs	0.95 ± 0.04	2214.13 ± 464.29	2534.30 ± 416.95	1462.78 ± 679.60	1281.56 ± 604.22

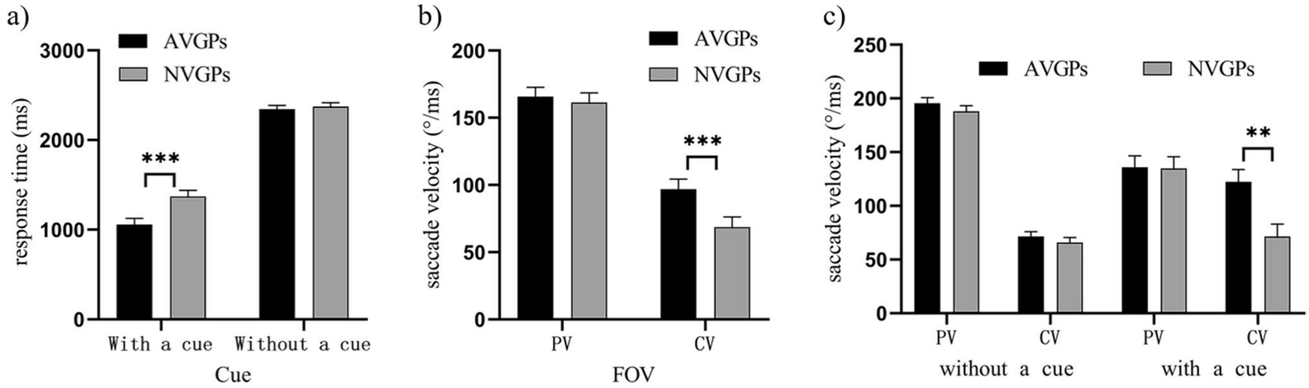

Fig.4 Experiment 2: **a)** Interaction effect for Group × Cue of response time. **b)** Interaction effect for Group × FOV of saccade velocity. **c)** Interaction effect for Group × FOV × Cue of saccade velocity

Table 4 Eye movement data in Experiment 2 (M ± SD)

	Group	Without cue		With cue	
		CV	PV	CV	PV
Fixation duration (ms)	AVGPs	562.52 ± 121.18	245.97 ± 27.06	545.73 ± 132.54	368.86 ± 83.57
	NVGPs	560.87 ± 125.51	245.96 ± 39.87	530.54 ± 150.10	347.78 ± 141.30
Fixation count	AVGPs	4.53 ± 0.82	9.26 ± 1.25	1.82 ± 1.04	2.76 ± 1.48
	NVGPs	4.76 ± 0.89	9.60 ± 1.20	2.55 ± 1.32	3.54 ± 2.24
Saccade amplitude (°)	AVGPs	3.12 ± 3.10	10.66 ± 1.87	6.87 ± 6.62	8.68 ± 3.72
	NVGPs	2.67 ± 2.21	10.63 ± 1.09	4.84 ± 4.68	8.16 ± 3.84
Saccade velocity (°/ms)	AVGPs	71.48 ± 13.54	195.52 ± 20.65	122.34 ± 38.94	135.87 ± 33.87
	NVGPs	65.86 ± 24.63	187.98 ± 24.38	71.47 ± 59.32	134.94 ± 56.95

for Cue, $F = 11.54$, $p < 0.01$, $\eta_p^2 = 0.23$, Cohen's $f = 0.55$. A significant interaction effect was revealed for FOV × Cue, $F = 58.42$, $p < 0.001$, $\eta_p^2 = 0.61$, Cohen's $f = 1.25$ (see 28). There was no other significant main effect and interaction effects (all $p > 0.05$).

Fixation Count

There was a significant main effect for FOV, $F = 406.50$, $p < 0.001$, $\eta_p^2 = 0.92$, Cohen's $f = 3.39$, and for Cue, $F = 367.82$, $p < 0.001$, $\eta_p^2 = 0.91$, Cohen's $f = 3.18$. A significant interaction effect was revealed for FOV × Cue, $F = 331.71$, $p < 0.001$, $\eta_p^2 = 0.90$, Cohen's $f = 3.00$ (see 28). However, there was no significant main effect for Group, and other interaction effects (all $p > 0.05$).

Saccade Amplitude

There was a significant main effect for FOV, $F = 137.36$, $p < 0.001$, $\eta_p^2 = 0.78$, Cohen's $f = 1.90$, and interaction effects for FOV × Cue, $F = 47.32$, $p < 0.001$, $\eta_p^2 = 0.56$, Cohen's $f = 1.12$ (see 28). Other main effects and interaction effects were not significant (all $p > 0.05$).

Saccade Velocity

There was no significant main effect for Group and interaction effect for Group × Cue ($p > 0.05$). Analysis revealed a significant main effect for FOV, $F = 286.23$, $p < 0.001$, $\eta_p^2 = 0.88$, Cohen's $f = 2.75$, and for Cue, $F = 8.69$, $p < 0.01$, $\eta_p^2 = 0.19$, Cohen's $f = 0.48$. A significant interaction effect was revealed for Group × FOV, $F = 8.69$, $p < 0.05$, $\eta_p^2 = 0.19$, Cohen's $f = 0.48$ (see Fig. 4 and 28 for detailed results of significant interaction effect), with the AVGPs having a faster saccade velocity in CV compared to NVGPs not in PV. A significant two-way interaction effect was also revealed for FOV × Cue, $F = 100.91$, $p < 0.001$, $\eta_p^2 = 0.73$, Cohen's $f = 1.63$. There was a significant three-way interaction effect for Group × FOV × Cue, $F = 9.48$, $p < 0.01$, $\eta_p^2 = 0.20$, Cohen's $f = 0.50$ (see Fig. 4). Further analysis that, only with a cue, the saccade velocity for AVGPs in CV was significantly faster compared to NVGPs.

Discussion of Experiment 2

When performing the recognition and matching search task, AVGPs have an obvious advantage in terms of response time compared with NVGPs due to the former's higher accuracy. Experiment 2 was conducted to investigate the question of whether this advantage is due to a wider PV, a greater ability to process information, or a greater ability regarding PV. The results showed that the advantage was conditional in CV or PV but was apparent only with cues. The AVGPs outperformed the NVGPs in both CV and PV, which partially verifies the findings of previous studies (Azizi et al., 2017; Green & Seitz, 2015). FOV also affected the visual search velocity of the AVGPs, but the trend for the two groups was consistent; that is, search velocity without a cue in CV was faster than that in PV, while the result with a cue was the contrary. This indicates that cues have a more obvious influence on visual searching.

AVGPs and Cues in Visual Search

The question remains regarding why AVGPs' advantage is significantly pronounced when a cue appears. In this study, the cues appeared 200 ms before the search graph, which effectively reduced the response time of the participants' searching for the target, but the cues had a more significant impact on the AVGPs; that is, the AVGPs could make better use of the cues to improve their reaction velocity. Therefore, we could infer that AVGPs are better at using cues than NVGPs.

First, this may be because playing an AVG makes AVGPs more sensitive to effective clues and information (Hubert-Wallander et al., 2011), so they can quickly establish a response mode to use clues to capture targets (Heimler et al., 2014), thus greatly improving their response time. Second, AVGPs could be better utilizing specific behavioral information rather than any specific search pattern to focus on cues during the search (Biggs et al., 2017; Biggs & Mitroff, 2019). AVGPs using this better visual search strategy could be able to focus on more important information to capture cues and complete tasks (Cain et al., 2014). In this study, however, the forms of presentation and clues were abstract, which made experimental control more delicate (Zhang et al., 2020), but the group differences in the results indicated that AVGPs had the ability to generalize cue information. The ability to use cues across different contexts may reflect a relationship between playing AVGs and improvements in cognition. More importantly, this generalization ability is conducive to the rapid and rational behavior of AVGPs when facing different game or daily life scenarios (Clark et al., 2011; Zhang et al., 2019), for example, while capturing cues regarding the ball while playing football and basketball, while capturing dangerous cues while walking or driving, and even while observing specific cues while a pilot is flying.

AVGPs and Eye Movement Behavior

The results showed that AVGPs can take advantage of clues to improve their response time in both CV and PV, but how they make better use of clues remains to be answered.

The difference between Experiment 1 and Experiment 2 relates to fixation duration, which may be because of the different types of tasks. In Experiment 1, the AVGPs had significantly shorter fixation durations compared to the NVGPs. Further, due to the random spacing between stimuli, the actual number of distractors within the range of the same fixation count was uncertain (Biggs et al., 2017). A shorter fixation duration suggested that the AVGPs had a shorter response time compared to the NVGPs. In Experiment 2, the spacing between stimuli was fixed, and the AVGPs exhibited longer fixation durations, suggesting that their visual searching was more efficient. The results are, therefore, not contradictory.

The similarities between Experiment 1 and Experiment 2 relate to fixation count, saccade amplitude, and saccade velocity. In Experiment 2, the saccade velocity of the AVGPs in CV was significantly faster compared to the NVGPs, but only with a cue, which is similar to hypotheses regarding PV in previous studies (e.g., Chisholm & Kingstone, 2012). The search graphs were presented at 1° or 13° visual angles, making it possible to obtain more information at one time if the participant concentrated on their PV. While the AVGPs paid more attention to their PV, when the stimulus was present in CV, they needed to choose to focus on the most pertinent central cues, resulting in greater saccade amplitude and faster saccade velocity. This indicates that searching for a target in a larger FOV requires a more active attention transfer and, potentially, the adoption of an attentional strategy. In a similar study between experts and novices (Bard et al., 1994), the results showed that this strategy regarding PV may not work to the advantage of experts, but this mechanism may help to direct focus to pertinent cues in CV. Under all conditions, experts (i.e., AVGPs) make decisions more accurately and quickly (Dobrowolski et al., 2015; West et al., 2013). Moreover, although other differences were not significant between the two groups, the AVGPs still showed a lower fixation count and greater saccade amplitude than the NVGPs. Overall, experienced AVGPs value the use of clues and can obtain correct information quickly through efficient eye movement patterns.

General Discussion and Conclusion

In general, the results showed that AVGPs had a significant time advantage in visual search tasks and showed a greater ability to use cues. Especially in CV with cues, the saccade velocity of AVGPs was significantly faster than that of NVGPs. In terms of theoretical and practical implications for interventions, first, the visual search process of AVGPs is faster and more efficient, and AVGPs have a great advantage over NVGPs in terms of cues. This generalization ability is conducive to AVGPs' rapid behavior changes in games or life, such as while driving and walking. Second, we found that especially in terms of CV, AVGPs exhibit a faster saccade velocity than NVGPs, which means that AVGPs have more active search habits in their focused FOV. Third, certain people who need better visual search abilities, such as security inspectors, can improve their ability by playing AVGs to better transfer the advantages of AVG attention abilities to daily life.

Despite these implications, this study had several limitations. First, this study examined the differences between AVGPs and NVGPs, but the AVGPs may have needed to be subdivided, for example, players of first-person shooter video games and other genres of AVGs (e.g., fighting games), game users with Internet gaming disorder and recreational Internet game users. Second, we used a recognition and matching search task to examine the influence of FOV and effective cues. Future studies could use other tasks to define FOV or other cues to explore the characteristics of eye movements. Third, a cross-sectional study cannot determine a causal relationship between AVG exposure and visual searching, so future research could focus on establishing this causal relationship through AVG training.

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Data Availability The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Conflict of Interest The authors declare that they have no conflict of interest.

Consent to Publish Patients signed informed consent regarding publishing their data.

Ethical Approval and Consent to Participate The Human Investigations Committee of Southwest University approved this research. All participants were recruited through an online advertisement and volunteered to participate in the experiment. Prior to the formal experiment, the participants had a detailed understanding of the procedure and the payment. And the tasks were prior to the consent of participants, they had the right to terminate the experiment if, for example, they felt unwell.

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