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Searching in clutter: Visual behavior and performance of expert action video game players

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Abstract:

Searching for targets among distractors in visual scenes can be more difficult due to the presence of clutter. However, studies in various domains have shown differentiated effects according to the expertise of the searcher. The present study extended these findings to the domain of action video games expertise. 58 participants, split in 2 groups (action video game players and non-action video game players) searched for targets in visual scenes under two clutter conditions (uncluttered and high clutter). Reaction times and accuracy served as measures of performance, and the visual behavior was assessed using the number and duration of eye fixations. Our findings suggest that visual clutter has a negative influence on performance and alters the visual behavior during visual search in action video game scenes. Our results also suggest that expert action video game players might use different visual strategies to cope with clutter, leading however to no performance benefits.

Keywords: Display clutter, Background complexity, MOBA, Eye-tracking, Visual search

1. Introduction

Many tasks action video game players (AVGPs) accomplish during their play time require finding targets of interest within a visual scene among distracting elements, such as searching for opponent virtual characters in building interiors. One of the factors that can make this search more difficult is the amount of clutter in the visual scene, that is the presence of an excessive amount of visual information and the variability of this information (Rosenholtz, Li, and Nakano, 2007). From a performance standpoint, increasing clutter usually results in slower, less accurate visual search (Beck and Lohrenz, 2010; Beck, Trenchard, van Lamsweerde, Goldstein and Lohrenz, 2012).

According to Beck et al. (2010), the negative influence of clutter can be caused by different factors, such as: (1) set size (Treisman and Gelade, 1980), e.g., the number of virtual characters in the crowd; (2) target and distractor similarity (Duncan and Humphreys, 1989; Treisman and Gelade, 1980); e.g., virtual characters resembling the target; (3) spatial layout (Beck and Trafton, 2007), e.g., the shape of the virtual crowd; (4) object occlusion (Bravo and Farid, 2004), e.g., virtual characters superimposed on others; (5) background complexity (Wolfe, Oliva, Horowitz, Butcher and Bompas, 2002), e.g., virtual characters standing in complex interiors. In line with previous studies of clutter in video game-like displays (e.g., Caroux, Le Bigot and Vibert, 2013), the present study considers visual clutter in the form of background complexity. According to Wolfe et al. (2002), complex backgrounds lead to an imperfect segmentation of the candidate targets from the background. This altered segmentation process delivers objects that take longer to identify (Wolfe et al., 2002), and thus alters the visual search performance.

The influence of visual clutter, however, is not only a matter of display properties. In fact, it also depends on various factors, such as the expertise of the searcher (Ognjanovic, Thüring, Murphy and Hölscher, 2019). Hence, the present paper investigated the interrelation of background complexity and action video game expertise during visual search. In other words, the main objectives of this study were (a) to examine the influence of background complexity on the visual search performance, (b) to examine its influence on the visual behavior, and (c) to investigate if action video game expertise can modulate these influences.

1.1. Task-related expertise and visual search in clutter displays

The study of visual search in cluttered scenes has raised a question in the literature: can task-related expertise help counteract the negative effects of clutter? This question takes roots in the fact that experts, because they allocate more efficiently their visual attention, perform better on tasks within their area of expertise; therefore, their visual search performance may be less affected by clutter, and they may show more efficient visual search strategies (Beck et al., 2012). To our best knowledge, only 4 studies have so far investigated this question.

First, in a study on website clutter (Grahame, Laberge and Scialfa, 2004), younger and older adults were asked to search for hyperlinks inside web pages. The younger adults spent significantly more time per week on the internet than their older counterparts. Web pages varied in clutter level, manipulated by the authors by (1) varying the available page spawn that was occupied by text or graphics (i.e., spatial layout) and (2) varying the number of blue underlined links (i.e., set-size). The results have shown that clutter impaired search speed and accuracy for both groups. However, older participants, who were expected to have less experience with websites, performed slower than students in the high clutter condition. Additionally, older adults showed a greater increase in eye fixation number with high visual clutter relative to younger participants. The conclusions of this study should however be taken with caution, as (1) expertise levels were not directly evaluated, and (2) age-related cognitive deficits may partly explain these results.

Second, in another study (Beck et al., 2012), expert pilots and undergraduates searched for targets in aeronautical charts. The latter varied in global (i.e., low, medium, high) and local clutter (i.e., low, high). Clutter was manipulated by the authors by varying for each level set size, distractor similarity, and background complexity. Their results have shown that clutter slowed search performance and increased the number and duration of eye fixations on the visual scene for both groups of expertise. However, expert pilots' visual search was more accurate but slower than undergraduates. Additionally, they spent more time processing information within each eye fixation. Both pilots and undergraduates used a "coarse-to-fine" strategy: as the trial progressed, duration of eye fixations increased and saccade distance decreased (Beck et al., 2012). These results are in line with previous studies showing that experts perform better at tasks within their area of expertise because they use a more efficient allocation of visual attention (Beck et al., 2012).

Third, in a study by Ognjanovic et al. (2019) in the field of financial judgement, participants had to judge the riskiness of pairs of stocks. The participants were split in two groups: students with a background in economics without trading experience (i.e., novices), and students with investment banking internship or stock trading experience (i.e., experts). The stock visualization tools had 2 levels of clutter, the highest level containing more information than the lowest (i.e., set-size). Their results have shown that experts provided more consistent judgements compared to novices, but there was no overall difference between levels of clutter. Interaction analyses however revealed a negative effect of the high clutter condition for the judgment consistency of the novice group. In the high clutter condition additionally, participants of both groups agreed significantly less with each other, and they judged the stimuli more or less consistently on an intra-individual level. The results have also shown effects of both expertise and clutter of the visual attention distribution. Experts had fewer eye fixations per second and longer ones in the high clutter condition, suggesting that they focused their attention on fewer and potentially more relevant items. Finally, high clutter led to more visual transitions and thus to more random scanpaths for both groups of expertise. In line with Beck et al. (2012), this study shows that measuring the visual behavior is essential in order to complete performance measures during visual search.

Finally, in a study by Maturi and Sheridan (2020), expert musicians and non-musicians had to search for a target section in a music score. Due to the complexity of the targets, both the search template (i.e., the target section) and the search array (i.e., the music score) were presented simultaneously in each trial, allowing for visual comparisons between them in order to find the matching section. Visual complexity of the music scores was manipulated (simple, complex), and defined by the authors as the amount of ink on the page (i.e., set size, target and distractor similarity, spatial layout). Their results have shown that both groups engaged in a speed-accuracy tradeoff and had more but shorter eye fixations in the presence of visual complexity. Interestingly, their results have also shown that expert musicians had more dwells (i.e., one or more consecutive fixations on the region, prior to the eyes moving to a different region of the display) on the search template in the complex condition than in the simple one, while non-musicians had more dwells on the search template in the simple conditions than in the complex one. Additionally, there was an increase in the first-dwell duration and the total dwell duration for the expert musicians in the presence of visual complexity, while there was

no effect for the non-musicians. According to the authors, these results suggest that expert musicians engaged in an in-depth processing of the search templates, whereas the non-musician engaged in a more superficial processing.

Overall, these few studies highlight the existence of an interrelation between expertise and visual clutter. In the present study, we sought to extend these findings by considering the influence of action video games-related expertise.

1.2. Action video games and visual search

Many types of video games exist and differ greatly in their characteristics. According to Bediou et al. (2018), action video games differ from other subtype as they all share a set of features: (1) a fast pace; (2) a high degree of perceptual and motor load, and a high degree of working memory, planning and goal settings demand; (3) a constant switch between a narrow-focused state and a more distributed state of attention; and finally (4) a high degree of clutter and distraction.

Hence, most action video game tasks require players to search for targets within visual scenes of varying levels of clutter. Video games displays are usually composed of three critical spaces: (a) a background (e.g., building interiors, landscapes, etc.), (b) a main action scene, where the player sees objects with which to interact (e.g., enemies, objects, etc.), and (c) contextual information superimposed on the background and the main action scene (e.g., map, score, etc.) (Marre, Caroux and Sakdavong, 2021). The visual clutter in video game scenes can therefore be manipulated in each of these three components, for instance with visual complex landscape backgrounds, with the presence of numerous enemies in the main action scene or with superimposed contextual information occluding a part of the display.

Previous studies have already shown that visual clutter in video game scenes has a negative impact on the visual search performance. Caroux et al. (2013), for instance, have asked participants to either search for targets among distractors (geometric shapes), or search and shoot on single targets (virtual avatars), with different levels of background complexity. Their results have shown that in both tasks, the presence of complex backgrounds impaired performance (i.e., higher reaction times and shooting times), and led to longer eye fixations.

The interrelation between visual clutter and expertise in video games yet remains to be investigated. Just like in other areas of expertise (e.g., Beck et al., 2012), video game experts might allocate more efficiently their visual attention, and thus be less affected by clutter when performing tasks within their area of expertise.

On top of that, action video game experts are expected to perform even better than experts from other domains, as researches have shown that they may possess enhanced cognitive abilities compared to non-video game players (NVGPs), leading to better visual search performances. For instance, Castel, Pratt and Drummond (2005) have shown that they possess faster stimulus-response mappings that lead to rapid execution of responses to the presence of targets during visual search, compared to NVGPs. According to the authors, these results might be due to a better control over the allocation of attention in situations that require the rapid processing of many items. Kowal, Toth, Exton and Campbell (2018) have shown that AVGPs had higher performance in cognitive tests evaluating visual search speed (e.g., Trail-Making Test), reflecting higher working memory, attention, and psychomotor speed. When searching for targets among distractors, studies have also shown that AVGPs are less susceptible to visual distraction (Chisholm et al., 2010; Chisholm and Kingstone, 2012, 2015a, 2015b) and have a stronger inhibitory control in oculomotor behavior (West, Al-Aidroos and Pratt, 2013).

Training studies have also shown that NVGPs could develop similar cognitive advantages by practicing action video games for some hours. Wu and Spence (2013) have for instance shown that after playing 10 hours to action video games (first-person shooter or driving game), NVGPs performed better in both feature and conjunction visual search, suggesting a better top-down guidance for target localization. In another study (Azizi, Abel and Stainer, 2017), NVGPs were also trained for 10 hours to action video games (first-person shooter). In a subsequent game-related search task, their eye movements revealed a smaller vertical spread in fixations, suggesting that participants were developing an effective search strategy.

Overall, as noted by Bediou et al. (2018) in their meta-analysis: “we can safely conclude that being a habitual AVGP benefits cognition at large, with the most robust positive effects on perception, spatial cognition and top-down attention”.

1.3. The present study

Hence, the present study investigated the transferability of findings from other domains (e.g., financial risk judgement), regarding the effects of visual clutter and expertise, to the domain of action video games expertise. On top of providing insights about the influence of task-related expertise, the present study also shed light on the cognitive benefits of AVGPs during visual search.

Visual search performance was related to two measures: reaction times and accuracy of answers (Beck et al., 2012; Caroux et al., 2013). In line with previous studies (e.g., Beck et al., 2012), eye-tracking methodology was also used to assess the visual behavior, and was related to two measures: number and mean duration of eye fixations. Previous studies have shown that a high number of eye fixations have been linked to decreased search efficiency in cluttered displays (Beck et al., 2012; Grahame et al., 2004), and mean duration of eye fixations has been extensively used to measure the time it takes users to extract information (Moadieh and Sarter, 2017).

Hence, our hypotheses for performance and visual behavior measures were as follows:

H1. The reaction times are longer in the high clutter condition than in the low clutter condition.

H2. The accuracy is lower in the high clutter condition than in the low clutter condition.

H3. The duration of eye fixations is higher in the high clutter condition than in the low clutter condition.

H4. The number of eye fixations is higher in the high clutter condition than in the low clutter condition.

H5. These four measures (i.e., reaction time, accuracy, duration and number of eye fixations) are more altered by clutter for novices than for experts.

2. Method

2.1. Participants

A total of 58 participants (34 men and 24 women) with an average age of $M = 22.3$ years ($SD = 2.9$) agreed to participate in the experiment. They had normal or corrected vision, and did

not suffer from color blindness. They were recruited via Facebook groups or by email (professional and personal networks).

Participants were divided into 2 groups of expertise. The expert AVGP group (N = 28, 15 men and 13 women) was composed of individuals who were all Multiplayer Online Battle Arena (MOBA) players. MOBA games share all features described by Bediou et al. (2018), and thus deserve strong consideration as a subtype of action video games (Kowal et al., 2018). More specifically, expert participants were all players of one of the most popular MOBA games in the world: League of Legends (Riot Games, 2009). Although the number of hours played per week in video games is usually collected to assess player expertise in video game research studies, a different, more objective and accurate approach (as it is not based on declarative data) was used in the present study. It was based on the last ranking obtained by the participants in the official “League of Legends” rankings. In fact, once players have completed 10 “placement matches”, they are given a rank for the season (i.e., around a year), which represents their level of expertise. Participants in this group all had spent at least 100 hours playing the game (i.e., the average time required to be ranked in the game), and all had to have a rank at the given season or the past one. We decided to include participants not yet ranked this season, but with a rank the last season, as the experiment took place after the beginning of the season and not all players had completed their placement matches. These ranks are split from the lowest to the highest as follows: Iron, Bronze, Silver, Gold, Platinum, Diamond, Master, Grandmaster, Challenger. The three highest ranks (i.e., Master, Grandmaster and Challenger) combined contain only 0.14% of the total players base, which makes them almost impossible to recruit. In the present study, 3% of the players were Iron; 20% were Silver; 23% were Gold; 20% were Platinum, and 7% were Diamond. Twenty-seven percent had not played their placement matches to get a ranking this season, but had already done so for past seasons. The novice group (N = 30, 19 men and 11 women) was composed of individuals who had never played League of Legends, or any other video games in the same subtype.

2.2. Apparatus

A SMI RED250 mobile non-invasive head-free tracking device, coupled to a 22” monitor (1920 x 1080 pixels resolution, 60hz refresh rate) was used to reproduce the interaction with a

virtual environment as ecologically as possible. The eye tracking equipment was controlled by the computer, which collected the data while executing the program of the experimental task. The position of the gaze was obtained at 250hz, with an average accuracy of 0.4°. Eye movements were analyzed using BeGaze software version 3.7 (SensoMotoric Instruments, 2014). Eye fixations were defined using the standard "high speed event detection" provided by the BeGaze 3.7 software.

2.3. Material

The visual search scenes were created using PowerPoint software (Microsoft, 2019). Two backgrounds of variable clutter have been designed. The first, entirely white, was considered as non-cluttered (Figure 1). The second, considered cluttered (Figure 1 and 2), was designed following the concept of entropy. The latter is a measure of the amount of information contained in an image (Asher, Tolhurst, Troscianko and Gilchrist, 2013; Jie and Clark 2008; Raj, Geisler, Frazor and Bovik, 2005), and can help to evaluate the complexity of a visual scene (Caroux et al., 2013). Hence, a visual scene has high entropy when it includes many salient colors, contrasts or luminance per unit area (Caroux et al., 2013). In the present study, the complex background was therefore designed by varying the number of objects (5094 circles), their color (10 different colors: light purple (RGB: 112, 48, 160), dark purple (RGB: 0, 32, 96), dark blue (RGB: 0, 112, 192), light blue (RGB: 0, 176, 240), dark green (RGB: 0, 176, 80), light green (RGB: 146, 208, 80), yellow (RGB: 255, 255, 0), orange (RGB: 255, 192, 0), light red (RGB: 255, 0, 0), dark red (RGB: 192, 0, 0)), their luminance (a column of circles out of two was covered with a black mask of 75% transparency), as well as their size (small circles: 0.38 cm x 0.38 cm; large circles: 3.51 cm x 3.51 cm) For this last point, the large yellow circles were placed pseudo-randomly in 20 modalities to avoid a training effect. They were designed to interfere with the task, with support of analyzes performed using the Saliency Toolbox 2.3 (Walther and Koch, 2006), which implements the salience model originally proposed by Itti and Koch (2000). This model predicts the gaze orientation of an observer on the different areas of a visual scene by calculating regions of salience. The results of these analyzes show a high salience on areas of presence of large yellow circles (Figure 2), suggesting that the visual and attentional behavior of the participants will be more influenced in the cluttered background condition, compared to the uncluttered one, containing no salient elements.

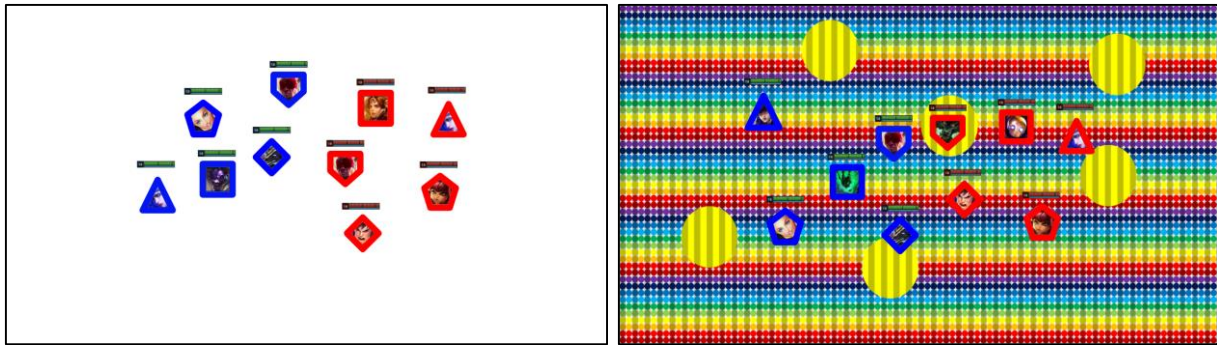


Figure 1. Example of visual scenes with uncluttered background (left) and cluttered background (right)
[Note to the editor: colors should be used for this figure]

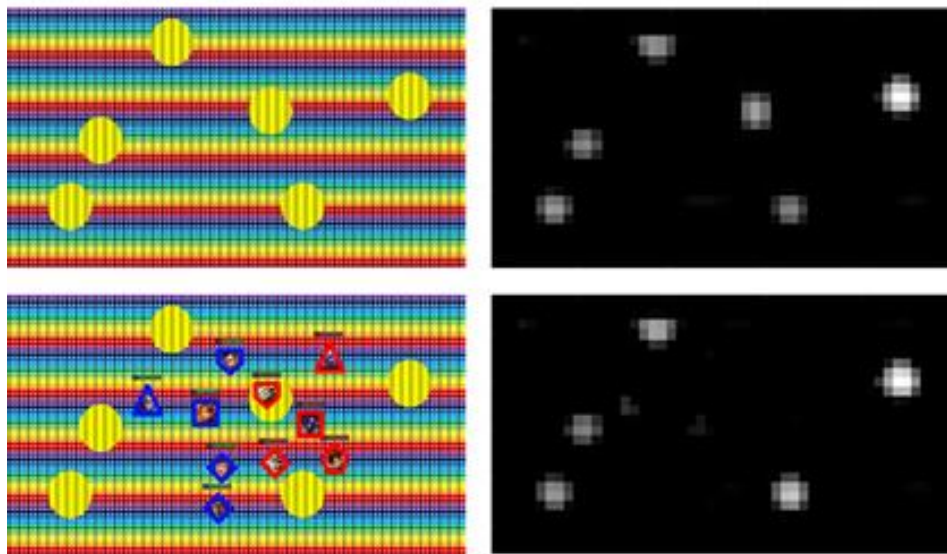


Figure 2. Example of cluttered backgrounds (left) with corresponding saliency maps (right). The upper image pair corresponds to the empty background, and the lower image pair overlaps the target/distractors on the background. The brightest regions in the saliency maps indicate a higher value of salience.
[Note to the editor: colors should be used for this figure]

The present study was primarily focused on the influence of task-related expertise, rather than the cognitive benefits of AVGPs. Therefore, participants had to search for targets located in familiar video game scenes, rather than neutral ones. These scenes represented team fight situations in League of Legends, that is situations where the 10 players of the two opposite teams regroup together at the same location in the virtual environment to engage in a fight. These situations are the most complex for the players because they involve a lot of information to be managed simultaneously (i.e., actions from up to 10 players at the same time).

The target and the distractors of the task, representing the 10 players' avatars, were characterized by three factors: the color (blue: RGB: 4, 23, 240; and red: RGB: 255, 0, 0), the

shape (triangle, pentagon, square, rhombus and "banner"), and the illustration at the center of the form (four different illustrations by shape). The colors corresponded to the colors of the two teams in League of Legends (blue: ally team; red: opponent team). The forms, associated with the illustrations in their center, represented the various roles in League of Legends, as well as the avatars controlled by the players associated with them (e.g., the triangle corresponds to the role of "marksman", and the illustrations in the center of the triangles are marksmen playable in the game). Four of the most used avatars for each role in the game were chosen to ensure that the experts would recognize them. Above each target/distractor was a colored bar, representing the health and energy reserves of the avatar. The position of the target/distractors in each scene was randomized in order to nullify the influence of the salience resulting from the position of the objects on the background.

For the experimental phase, a total of 400 scenes were presented to each participant, with 200 scenes per background condition. These 400 scenes were split into 10 blocks (i.e., one for each target) of 40 scenes. The order of presentation of the different blocks as well as the order of presentation of the scenes within each block were randomized.

All these concepts (e.g., why there were different shapes) were tested in a post-task questionnaire in order to validate their understanding by the expert participants.

2.4. Design and procedure

Before starting the experimental task, participants were familiarized with the various concepts (e.g., presence/absence of the target, importance of the contour of the geometric forms, etc.) during a training block of 10 scenes. The targets and distractors in the training scenes used colors, shapes and illustrations that were not related to the experimental task.

When participants were ready to start the experimental task, a screen containing all the targets was presented. It allowed participants to familiarize with them, and expert players to integrate the concepts of roles, characters and teams (Figure 3).



Figure 3. Introduction screen of the different targets, with all combinations of colors, shapes and illustrations.
[Note to the editor: colors should be used for this figure]

Before each block of scenes, an instruction screen was presented to indicate to the participants the target to be found, as well as to remind them of the commands (Figure 4). Between each scene, a screen was presented for 300 ms, containing the target to be searched in the center, allowing both to refocus the participant's gaze on the center, and to refresh the identity of the target to search for (Figure 5).



Figure 4. Example of instruction screen. The background used in the instruction screen was a screenshot of a central area of the "Summoner's Rift" map in League of Legends. Translation of the text from top to bottom: "The target is: [target]"; "As quickly as possible, press: [green] if the target is present, [grey] if the target is absent"; "Press the spacebar to continue".

[Note to the editor: colors should be used for this figure]

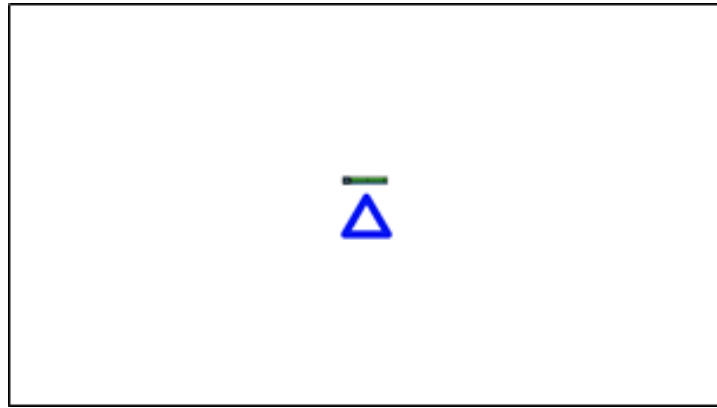


Figure 5. Example of fixation screen

[Note to the editor: colors should be used for this figure]

In line with previous research on the influence of visual clutter during visual search in video game-like displays (e.g., Caroux et al., 2013, 2015), each scene was presented until the participant answered, or for a maximum of 3 seconds. This interval allows participants to respond while having a form of time pressure that can be found in action video games. Given that for basic visual search (i.e. in lab studies with no specific difficulty), the rate of response times is about 20 to 60 ms/item (e.g., Wolfe, 1998), we estimated that the present research task might be regularly performed within this time limit. Participants answered using a keyboard. They had to press a green dot pasted on the "D" key of the keyboard if the target was present, and on the white dot pasted on the "L" key if the target was absent. In 50% of the trials, the target was present. For the remaining 50%, the target was absent and randomly replaced by one of the other geometric shapes of the same color.

Participants were instructed to respond as quickly as possible, with as few errors as possible throughout the task. At the end of each block, participants had to press the spacebar to access the next instruction screen. Once the 400 scenes were completed, a "thank you" screen was displayed and the task was complete. Participants were then invited to answer a validation questionnaire of the concepts presented during the task.

3. Results

The analysis only focused on the trials where the target was present. In addition, trials where no response was given within the 3 seconds time limit were excluded from the analysis (1.2% of the trials).

The main goal of this study was to investigate the interaction between expertise and visual clutter. In order to achieve a high statistical power, we therefore adjusted the size of our sample according to this effect. Since the present study was not a replication, we had no hint of the expected effect sizes, and thus we used the mean effect size reported in psychology studies, $d = .4$, as advised in Brysbaert (2019). All statistical power calculations were done using the G*Power software (Faul, Erdfelder, Lang and Buchner, 2007). With a sample size of 58 participants (28 participants in group 1 and 30 participants in group 2), we were able to reach a statistical power of 99.99% for the main effect of clutter and for the expertise \times clutter interaction, but only 32.17% and 44.39% respectively for two and one tails tests of the main effect of expertise. Given the risks of interpreting under-powered statistical analysis (see Brysbaert, 2019), we therefore decided not to run nor include them.

3.1. Reaction times

There was a main effect of clutter on reaction times ($F(1,56) = 111, p < .001, \eta_p^2 = .66$). Participants responded faster in the uncluttered condition ($M = 1117.93$ ms; $SD = 173.85$) than in high clutter condition ($M = 1179.57$ ms; $SD = 174.55$).

There was no significant interaction effect between clutter and expertise on reaction times ($p = .40$).

3.2. Accuracy

Accuracy was calculated by dividing the number of accurate trials by the number of trials for which a response was given within the 3 seconds time limit.

There was a main effect of clutter on accuracy ($F(1,56) = 9.21, p < .01, \eta_p^2 = .14$). Accuracy was higher in the uncluttered condition ($M = .90$; $SD = .05$) than in the high clutter condition ($M = .88$; $SD = .05$).

There was no significant interaction effect between clutter and expertise on accuracy ($p = .11$).

3.3. Mean duration of eye fixations

There was a main effect of clutter on the mean duration of eye fixations ($F(1,56) = 14.95$, $p < .001$, $\eta_p^2 = .21$). Participants' mean duration of eye fixations was shorter in the uncluttered condition ($M = 203.22$ ms; $SD = 28.43$) than in the high clutter condition ($M = 209$ ms; $SD = 29.13$).

There was no significant interaction effect between clutter and expertise on the duration of eye fixations ($p = .14$).

3.4. Number of eye fixations

There was a main effect of clutter on the number of eye fixations ($F(1,56) = 7.24$, $p < .01$., $\eta_p^2 = .12$).

However, a significant interaction analysis ($F(1,56) = 7.40$, $p < .01$., $\eta_p^2 = .12$) revealed that clutter only has an effect on the number of eye fixations of the expert group ($F(1,29) = 15.85$, $p < .001$., $\eta_p^2 = .35$) (Figure 6). Their number of eye fixations was higher in the high clutter condition ($M = 6.27$; $SD = 1.25$) than in the uncluttered condition ($M = 6.04$; $SD = 1.20$). There was no difference between clutter conditions for the novice group ($M = 5.43$; $SD = .72$ in the high clutter condition, and $M = 5.43$; $SD = .83$ in the uncluttered condition), $p = .99$.

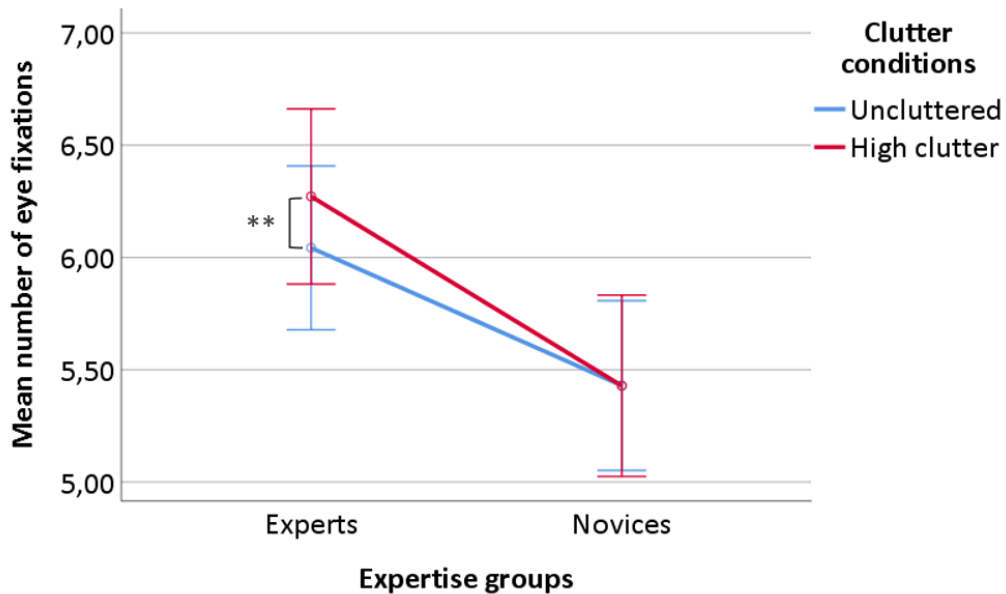


Figure 6. Mean number of eye fixations according to clutter conditions and expertise groups.

** = $p < .001$

Error bars: 95% confidence interval

[Note to the editor: colors should be used for this figure]

4. Discussion

The objectives of this study were to examine how visual clutter affects performance and visual behavior during visual search in the context of action video games, and to investigate if action video game expertise modulates this influence.

In line with our hypotheses H1, H2, H3 and some previous research, our study has shown that visual clutter had a negative influence on reaction times, mean duration of eye fixations (Beck et al., 2012; Caroux et al., 2013) and accuracy (Beck et al., 2012) with large effect sizes. The alteration of the mean duration of eye fixations due to visual clutter are not in line with Ognjanovic et al. (2019), who's results have shown no main effect of visual clutter on this variable. This difference might be explained by the nature of visual clutter used in the different studies: solely set-size in Ognjanovic et al. (2019); set-size, distractor similarity, and background complexity in Beck et al. (2012); and solely background complexity in Caroux et al. (2013) and the present study. This is in line with Wolfe et al. (2002), and corroborates the fact that background complexity alters the segmentation process of the targets from the background, and thus delivers objects that take longer to identify within eye fixations. It's worth noting that, due to the abstract and multidimensional nature of the visual clutter used

in this study (i.e., chromatic, contrast and luminance variation; presence of salient objects), the results are more directly relevant to real-world environments compared to other studies (e.g., Beck et al., 2012).

Contrary to our hypothesis H4 and some previous research (i.e., Beck et al., 2012), our results have shown that the mean number of eye fixations was not influenced by visual clutter. However, contrary to our hypothesis H5 and some previous research (i.e., Beck et al., 2012; Grahame et al., 2004), interaction analyses revealed that there was in fact an increase in the number of eye fixations from experts in the presence of clutter, with a large effect size. This result is surprising, as some previous studies have shown a link between a higher number of eye fixations and a decreased search efficiency in cluttered displays (Beck et al., 2012; Grahame et al., 2004; Ognjanovic et al., 2019). In the present study, this difference might be explained by the difference in duration of eye fixations. In fact, descriptive statistics showed that experts actually spend less time than novices within each eye fixation in both clutter conditions, but this difference was even higher when searching in clutter ($M = 200.23$ ms, $SD = 23.01$ for the expert group; $M = 218.39$ ms, $SD = 32.33$ for the novice group). Future studies should investigate the statistical significance of this difference with an adequate sample size. Overall, this result suggests that experts use different visual strategies in order to cope with clutter, characterized by more and shorter eye fixations. However, this different strategy did not lead to benefits or costs on performance, in terms of reaction times or accuracy, compared to novices in the context of this study. This is also surprising, as AVGPs were expected to be less affected by visual clutter than NVGPs, for instance due to their better resistance to visual distraction (e.g., Chisholm et al., 2010). However, this may well be the case, and the explanation may lie in the fact that AVGPs tried to gather more information than necessary to complete the task, as team fight situations in League of Legends are dynamic and can for instance require the player to locate different targets.

Finally, contrary to our hypotheses H5 and some previous research (i.e., Beck et al., 2012; Grahame et al., 2004; Ognjanovic et al., 2019), expertise did not modulate the influence of visual clutter on the mean duration of eye fixations. This is however in line with Maturi and Sheridan (2020), who also did not observe this effects.

Different elements could explain the difference of results highlighted in this study, from what was expected *a priori*. One of these elements is the time limit for each trial used in the present experiment. In fact, the very limited 3 seconds time window may not have made possible the expression of a modulating effect of expertise on some variables (e.g., accuracy). In Beck et al. (2012), participants had up to 1 minute to respond, and in Grahame et al. (2004), Ognjanovic et al. (2019) and Maturi and Sheridan (2020), participants had no time limit. Previous research has for instance shown that visual search accuracy could increase with display times of each trial: approximately 61% accuracy for 2 seconds, 82% accuracy for 3 seconds, and around 93% accuracy for 4, 5 and 6 seconds (Fan, Zhou, Xie and Liu, 2017). These differences in time limit might also explain the differences in visual strategies observed in this study. In fact, the time pressure induced by the 3 seconds time limit could explain the faster and more extensive screening visual strategy used by the experts. In order to go further in understanding the interrelation between action video game expertise and visual clutter in video game scenes, future studies should replicate the present study with either a manipulation of the display time (e.g., 1 second vs. 3 seconds vs. 6 seconds) or no time limit.

Another element that could explain the difference of results highlighted in this study is the ecological level of the experimental task. In order to use a very controlled experimental task, participants were asked to search for randomly arranged static targets and distractors. However, in League of Legends, players actively participate in team fights, by engaging in various dynamic actions (e.g., moving around and looking for targets to eliminate) located in complex, 3-dimensionnal terrains. Additionally, the arrangement of the different players in team fights usually follows a certain logic, possibly giving cues for the players when they are looking for specific targets (e.g., marksmen generally try to stay at range from the enemy team). Some studies have already shown that disrupting the usual visual structure of a given task could remove the cues surrounding target features, and thus partially neutralize the visual search strategies of the experts (Robson, Tangen and Searston, 2021). Future studies should replicate the present study by taking another step towards a more ecological experimental task.

Finally, it has been shown that the usefulness of the target is a key determinant in the expert's performance. Robson et al. (2021) have for instance shown that fingerprint examiners outperformed novices when searching for fingerprint fragments considered as very useful for

the domain, but performed like novices when searching for fingerprint fragments considered as less useful. In League of Legends, while all targets are useful to some degree, some are more useful than others depending on the situation, for instance according to the role of the player. Future studies should control this variable, by specifying the role of the player, and by doing separate analyzes for each type of target (i.e., each role).

5. Conclusion

Our findings suggest that visual clutter, in the form of background complexity, has a negative influence on performance during visual search in action video game scenes. Additionally, this decrease in search efficiency may be echoed by longer eye fixations, reflecting more difficulty in extracting information in the presence of high visual clutter. Finally, our results suggest that expert AVGPs might use different visual strategies to cope with visual clutter, characterized by more and shorter eye fixations, leading however to no performance costs or benefits.

The present study aimed at extending previous findings regarding the interrelation between expertise and visual clutter to the domain of action video games-related expertise. It is a first milestone, and more research should be dedicated to replicate these findings and extend them. It could be relevant to mix and vary the nature of clutter, for instance by implementing set-size variations along with background complexity. The present study should also be replicated with a manipulation of the trials display time or no time limit, with a more ecological experimental task, and with a control of the usefulness of the target. Finally, it could be relevant to consider the expertise of other subtypes of action video games, such as first-person shooters.

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REFERENCES

- Asher, M. F., Tolhurst, D. J., Troscianko, T., & Gilchrist, I. D. (2013). Regional effects of clutter on human target detection performance. *Journal of vision, 13*(5), 25-25.
- Azizi, E., Abel, L. A., & Stainer, M. J. (2017). The influence of action video game playing on eye movement behaviour during visual search in abstract, in-game and natural scenes. *Attention, Perception, & Psychophysics, 79*(2), 484-497.
- Beck, M. R., Lohrenz, M. C., & Trafton, J. G. (2010). Measuring search efficiency in complex visual search tasks: Global and local clutter. *Journal of experimental psychology: applied, 16*(3), 238.
- Beck, M. R., Trenchard, M., van Lamsweerde, A., Goldstein, R. R., & Lohrenz, M. (2012, September). Searching in clutter: Visual attention strategies of expert pilots. In *Proceedings of the Human Factors and Ergonomics Society annual meeting* (Vol. 56, No. 1, pp. 1411-1415). Sage CA: Los Angeles, CA: Sage Publications.
- Beck, M., & Trafton, J. G. (2007). Local spatial layout consistency affects strategies but not memory during Visual Search. *Journal of Vision, 7*(9), 1060-1060.
- Bediou, B., Adams, D. M., Mayer, R. E., Tipton, E., Green, C. S., & Bavelier, D. (2018). Meta-analysis of action video game impact on perceptual, attentional, and cognitive skills. *Psychological bulletin, 144*(1), 77.
- Bravo, M. J., & Farid, H. (2004). Search for a category target in clutter. *Perception, 33*(6), 643-652.
- Brysbaert, M. (2019). How many participants do we have to include in properly powered experiments? A tutorial of power analysis with reference tables. *Journal of cognition, 2*(1).
- Caroux, L., Le Bigot, L., & Vibert, N. (2013). Impact of the motion and visual complexity of the background on players' performance in video game-like displays. *Ergonomics, 56*, 1863-1876.
- Caroux, L., Le Bigot, L., & Vibert, N. (2015). Impairment of shooting performance by background complexity and motion. *Experimental Psychology, 62*, 98-109. <https://doi.org/10.1027/1618-3169/a000277>

- Castel, A. D., Pratt, J., & Drummond, E. (2005). The effects of action video game experience on the time course of inhibition of return and the efficiency of visual search. *Acta psychologica, 119*(2), 217-230.
- Chisholm, J. D., & Kingstone, A. (2012). Improved top-down control reduces oculomotor capture: The case of action video game players. *Attention, Perception, & Psychophysics, 74*(2), 257-262.
- Chisholm, J. D., & Kingstone, A. (2015a). Action video game players' visual search advantage extends to biologically relevant stimuli. *Acta psychologica, 159*, 93-99.
- Chisholm, J. D., & Kingstone, A. (2015b). Action video games and improved attentional control: Disentangling selection-and response-based processes. *Psychonomic Bulletin & Review, 22*(5), 1430-1436.
- Chisholm, J. D., Hickey, C., Theeuwes, J., & Kingstone, A. (2010). Reduced attentional capture in action video game players. *Attention, Perception, & Psychophysics, 72*(3), 667-671.
- Duncan, J., & Humphreys, G. W. (1989). Visual search and stimulus similarity. *Psychological review, 96*(3), 433.
- Fan, X., Zhou, Q., Xie, F., & Liu, Z. (2017). Effects of Time Pressure and Task Difficulty on Visual Search. In *Advances in Human Factors in Robots and Unmanned Systems* (pp. 97-109). Springer, Cham.
- Faul, F., Erdfelder, E., Lang, A. G., & Buchner, A. (2007). G* Power 3: A flexible statistical power analysis program for the social, behavioral, and biomedical sciences. *Behavior Research Methods, 39*(2), 175–191. DOI: <https://doi.org/10.3758/BF03193146>
- Grahame, M., Laberge, J., & Scialfa, C. T. (2004). Age differences in search of web pages: The effects of link size, link number, and clutter. *Human Factors, 46*(3), 385-398.
- Itti, L. & Koch, C. (2000). A saliency-based search mechanism for overt and covert shifts of visual attention. *Vision research, 40*(10-12), 1489-1506.
- Jie, L., & Clark, J. J. (2008). Video game design using an eye-movement-dependent model of visual attention. *ACM Transactions on Multimedia Computing, Communications, and Applications (TOMM), 4*(3), 1-16.

- Kowal, M., Toth, A. J., Exton, C., & Campbell, M. J. (2018). Different cognitive abilities displayed by action video gamers and non-gamers. *Computers in Human Behavior, 88*, 255-262.
- Marre, Q., Caroux, L., & Sakdavong, J.-C. (2021). Video game interfaces and diegesis: The impact on experts and novices' performance and experience in virtual reality. *International Journal of Human-Computer Interaction, 37*, 1089-1103. <https://doi.org/10.1080/10447318.2020.1870819>
- Maturi, K. S., & Sheridan, H. (2020). Expertise effects on attention and eye-movement control during visual search: Evidence from the domain of music reading. *Attention, Perception, & Psychophysics, 1-8*.
- Moacdieh, N. M., & Sarter, N. (2017). The effects of data density, display organization, and stress on search performance: An eye tracking study of clutter. *IEEE Transactions on Human-Machine Systems, 47*(6), 886-895.
- Ognjanovic, S., Thüring, M., Murphy, R. O., & Hölscher, C. (2019). Display clutter and its effects on visual attention distribution and financial risk judgment. *Applied ergonomics, 80*, 168-174.
- Raj, R., Geisler, W. S., Frazor, R. A., & Bovik, A. C. (2005). Contrast statistics for foveated visual systems: Fixation selection by minimizing contrast entropy. *JOSA A, 22*(10), 2039-2049.
- Robson, S. G., Tangen, J. M., & Searston, R. A. (2021). The effect of expertise, target usefulness and image structure on visual search. *Cognitive Research: Principles and Implications, 6*(1), 1-19.
- Rosenholtz, R., Li, Y., & Nakano, L. (2007). Measuring visual clutter. *Journal of vision, 7*(2), 17-17.
- Treisman, A. M., & Gelade, G. (1980). A feature-integration theory of attention. *Cognitive psychology, 12*(1), 97-136.
- Walther, D. & Koch, C. (2006). Modeling attention to salient proto-objects. *Neural networks, 19*(9), 1395-1407.
- West, G. L., Al-Aidroos, N., & Pratt, J. (2013). Action video game experience affects oculomotor performance. *Acta psychologica, 142*(1), 38-42.

- Wolfe, J. M. (1998). What can 1 million trials tell us about visual search? *Psychological Science*, 9, 33-39. <https://doi.org/10.1111/1467-9280.00006>
- Wolfe, J. M., Oliva, A., Horowitz, T. S., Butcher, S. J., & Bompas, A. (2002). Segmentation of objects from backgrounds in visual search tasks. *Vision research*, 42(28), 2985-3004.
- Wu, S., & Spence, I. (2013). Playing shooter and driving videogames improves top-down guidance in visual search. *Attention, Perception, & Psychophysics*, 75(4), 673-686.