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The Effect of the First Glimpse at a Scene on Eye Movements During Search

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Abstract

Previewing scenes briefly makes finding target objects more efficient when viewing is through a gaze-contingent window (windowed viewing). In contrast, showing a preview of a randomly arranged search display does not benefit search efficiency when viewing during search is of the full display. Here we tested whether a scene preview is beneficial when the scene is fully visible during search. Scene previews, when presented, were 250ms in duration. During search, the scene was either fully visible or windowed. A preview always provided an advantage in terms of decreased time to initially fixate and respond to targets and total number of fixations. In windowed visibility, a preview reduced the distance of fixations from the target positions until at least the fourth fixation. In full visibility, previewing reduced the distance of the second fixation but no later fixations. The gist information derived from the initial glimpse of a scene allowed placement of the first one or two fixations at information-rich locations, but when non-foveal information was available, subsequent eye movements were only guided by online information.

The Effect of the First Glimpse at a Scene on Eye Movements During Search

Searching through scenes, one encounters more guidance-relevant information than searching through random arrays of objects. This results in behaviour differences. For instance, a preview of a random search array before one knows the identity of the search target has been found to provide no benefit to search efficiency (Becker & Pashler, 2005; Wolfe, Klempen & Dahlen, 2000). In contrast, a preview of a real scene does provide a search benefit (Hollingworth, 2009). Hollingworth found that a preview of 500ms to 10sec benefitted search both because of memory for the general scene layout and memory for the specific location of the target item.

Research about scene-preview benefits has often focussed on the benefit of brief previews, as this informs about what information can be extracted about the scene very rapidly, and how useful that information is. The "gist" of a scene – a coarse understanding of the spatial and conceptual layout of the scene – can be determined with even a very brief exposure to the scene. After only 50ms, people can categorize the kind of scene that was presented (Biederman, Rabinowitz, Glass, & Stacy, 1974; Greene & Oliva, 2009; Rousselet, Joubert, & Fabre-Thorpe, 2005; Schyns & Oliva, 1994), and perform better than chance on recognition memory for the scene (Potter & Levy, 1979). This ability no doubt contributes to efficient visual processing of new environments: If we turn a blind corner and see a new scene, we immediately gather enough visual information to assess whether to continue our progress without stopping and scanning the environment. Of course, we do not typically close our eyes after our first glimpse at a scene, and so when studying natural behaviour it is difficult to distinguish the impact of the first glimpse from the impact of the inflow of information about the scene as we continue looking at it.

The term gist has been used to refer to both conceptually driven (Underwood, Crundall & Hodson, 2005) and perceptually driven global visual properties of the scene (Greene & Oliva, 2009; Torralba, Oliva, Castelhano & Henderson, 2006). Global visual properties include spatial layout information and statistical regularities in the visual properties. Conceptual information may derive from information about quickly recognised objects (e.g., Biederman et al, 1974), but the fact that sometimes scenes can be categorised faster than objects in them suggests that the development of gist information need not require full identification of any object (Green & Oliva; Joubert, Rousselet, Fize & Fabre-Thorpe, 2007; Oliva & Torralba, 2006).

According to both the visual and conceptual definitions, recognition of gist allows the observer to draw on learned knowledge about where objects might belong in scenes. For instance, when searching for a knife, knowledge about kitchens suggests it is likely to be on a worktop and unlikely to be on the floor. In addition, based on our previous visual experience with kitchens, Bayesian priors indicate that knives would likely appear more toward the middle of the room than at the bottom of the room. Castelhano and Henderson (2007) studied how scene gist affected target localization by using a 250ms preview of the scene, followed by target naming, and then followed by search. During search, displaying the scene via a small gaze-contingent window (2° of visual angle in diameter) removed the influence of peripheral visual information available during normal search. Thus, search was guided only by the information acquired from the preview. Results from the study showed that with a scene preview, search was faster, there were fewer fixations, and the summed length of all saccades was shorter. This was true when compared to conditions in which the search display was preceded by (a) a scene differing in identity and layout, (b) a scene with the same identity but a different layout, and (c) a scrambled picture containing parts of many scenes. In some of their experiments, the preview of the scene contained the target; in other experiments, the preview did not show the target. Removing the target from the preview reduced but did not eliminate the benefit of the preview. Finally, when the preview was smaller in scale than the search display, there was still a preview benefit, suggesting that the representation of the scene that the initial glimpse delivers is not metric. Together, these studies indicate that the first glimpse of a scene allows the observer to learn the spatial layout of the scene and use it to plan the oculomotor behaviour of search. Võ and Henderson (2010) demonstrated qualitatively similar benefits of a preview on windowed search when the preview was shortened to as little as 75 ms.

Another study used the same paradigm, with previews that were either identical to the search display (but without showing the target), contained scene structure without objects, contained objects without structure, or were scrambled mosaics from many scenes (Võ & Schneider (2010). They found that previewing only objects did not benefit search, that participants with relatively slow visual processing benefited most from the identical previews, and that participants with relatively fast visual processing benefited most from a preview of only the structure of the scene. Fast visual processing was measured both by whether the observer noticed and could describe the different kinds of previews used in search trials, and by obtaining an estimate of visual processing speed by finding the best fit version of the Theory of Visual Attention model to a simple perceptual task for each participant (Bundesen, Habekost, & Kyllingsbaek, 2005). They concluded that fast processors drew local as well as global information from the preview and the local information interfered with efficient processing of the global information in identifying likely target locations. They speculated that the local information acquired from the preview may have widened the range of previously encountered scenes that contributed to the Bayesian probabilities of where a target might be. On the other hand, slow processors drew only global information from the preview and benefitted from the structural information available in the global information regardless of whether some local information changed.

These experiments point to universally fast processing of the global structure of the scene that enables better planning of eye movements as the scene is searched. However, it is important to note that the flash-preview windowed-search paradigm imposes a high demand on memory for the scene in order for search to be efficient. Although the results for this kind of search are important, everyday search through scenes is not limited in terms of how much of the scene is visible while the eyes move. Since peripherally available information influences saccade planning (e.g., Loschky & McConkie, 2002; van Diepen, De Graef & d'Ydewalle, 1995; van Diepen & d'Ydewalle, 2003), it is important to determine whether the enduring influence of the first glimpse of the scene in windowed search generalizes to search in which observers also can be guided by peripheral visible information. In tasks where goals develop over time, there is evidence that rather than using working memory to retain as full an understanding of the visual environment as possible during an entire task, people's eye movements are used to gather "just in time" the information required for the next step in the task (Ballard, Hayhoe & Pelz, 1995). The results of Becker and Pashler (2005) and Wolfe, Klempen and Dahlen (2000) are consistent with this understanding of the use of vision versus memory in visual search. If this just-in-time strategy applies to search through scenes, then there may be reason to believe that the planning of eye movements during search is not as strongly influenced by scene gist as the results of studies using windowed search might imply.

With this in mind, it is worth considering whether the preview benefit found by Hollingworth (2009) generalises windowed search results to search through fully visible displays. There were a number of differences between the studies that make it difficult to compare Hollingworth to Castelhano and Henderson (2007) directly. Most importantly, the longer previews used by Hollingworth allowed the observer to make multiple eye movements during the preview and thus to establish a firmer representation of the entire scene than a single fixation allows. Thus, it can be argued that Hollingworth's effects may not have been due to gist processing, but instead to more fully developed memory for a scene. Secondly, the target object itself rather than its name was shown to indicate the goal of search. This modality change could have affected the use of the preview, in that the representation of the target may have competed with the representation of the scene in visual working memory. Thirdly, the scenes used were schematic rather than photographs, which may have had subtle effects on processing choices. Finally, the Hollingworth study did not explore whether the preview provided a head start or influenced saccade planning throughout search. For these reasons, it was important to run a study in which observers search both windowed displays and full-view displays, with and without a preview, and with all other aspects consistent, in order to make a clear comparison of the effect of the information extracted from the first glance on subsequent eye movement sampling strategies under the two presentation conditions.

The goal of this experiment, then, was to explore whether eye movements when searching scenes are influenced by the gist extracted in the first fixation on the scene. The flash-preview windowed-search paradigm was broken down into a manipulation of two factors: scene *visibility* (whether the scene was fully visible during search or visible only through a peephole) and scene *preview* (whether or not a preview of the scene was presented before the target name was given to the participants). If planning of eye movements is strongly influenced by the scene gist extracted from preview, then one should see a similar influence of preview for an extended time regardless of scene visibility. However, if people rely more on information currently being seen rather than on the gist of the scene remembered from the first fixation, then the effect of the preview should be weak or even nonexistent when the scene is fully visible during search.

Method

Design

Scene preview (present versus absent) and scene visibility (fully visible versus gaze-contingent window) were manipulated within subjects. Each scene was seen once by each participant. The assignment of scenes to experimental conditions was counterbalanced across participants.

Participants

Twenty participants (three male) participated in the study either for partial fulfillment of course credit or for £5. Mean age was 31.35 (range was 19 to 57). All reported having normal or corrected to normal vision.

Stimuli and Equipment

A computer controlled by Experiment Builder software (SR Research, Ltd, Osgoode Canada) presented stimuli on a 19" ViewSonic G90b CRT monitor running at a 120 Hz screen refresh rate. A second, linked computer controlled the eye-tracker. Manual responses were made on a game pad. An EyeLink 1000 eye tracker (SR Research, Ltd, Osgoode Canada) running at a 500 Hz rate tracked eye movements. A chin-rest stabilized the eyes 50 cm from the display.

Ninety-nine scenes (internal and external) were taken from a variety of sources; 32 were used in the original study by Castelhano and Henderson (2007). The primary criterion for choosing the scenes was the presence of an object in the image that could serve as an unambiguous target that people would recognize by name. Pictures, 800 x 600 pixels, were presented to fill the screen. Figure 1 shows two scenes that were used in the study, where finding the target was relatively easy in Figure 1a and relatively difficult in Figure 1b.

------------------------ Insert Figure 1 about here. -------------------------

The 800 x 600 pixel post-preview mask was composed of 50 x 50 pixel regions clipped from the original images and arranged randomly in an approximate grid, with some overlap between regions.

The target name was presented as a one to four word description centered on the monitor in a large, clearly visible font. Over 90% of target names were one or two words in length. The background of the target name and of all message screens presented during the experiment was set at a medium gray (RGB = [117,117,117]) to minimize abrupt luminance changes.

The mean distance from the center of the display to the center of a target was 7.45°, ranging from 2.58° to 12.32°. Targets were on average 3.3° to a side, ranging from 0.9° to 7°. In all, 21 targets were in the top left quadrant of the scene, 24 were in the top right quadrant, 29 were in the bottom left quadrant, and 25 were in the bottom right quadrant.

Procedure

After the participant was introduced to the task, the eye-tracker was calibrated to less than 0.5° error. The participant then searched through 99 scenes ordered randomly. Calibration accuracy was checked after every search display, and recalibrations were carried out whenever necessary. Trials for all four viewing conditions (with and without preview, windowed versus full view) were presented in a single block in random order.

Each trial sequence was as follows. First a spot was presented at the centre of the display until the participant looked at it steadily. Either a preview of the scene (identical to the searched scene, and so including the target object) or a gray screen was presented for 250ms, followed by the mask for 50ms. Then the name of the target was presented for 2000ms, followed by the scene until the participant pressed a button while looking at where they believed the target to be. During search, the scene was either fully visible or a circular region was visible centered at the point of gaze with diameter of 2.1°. The gaze-contingent window followed the point of gaze as the participant searched the display.

Results

Due to tracker loss, 4% of the data was excluded from the analyses.

Responses were considered accurate if the participant looked at the target when pressing the button or immediately before pressing the button. Participants responded accurately on 81.8% of trials (ranging from 61% to 97%). Participants' accuracy in the four conditions, averaged across scenes, was submitted to an ANOVA with scene visibility and preview as factors. This analysis showed that responses were more accurate when searching through a fully visible scene (91.2%, sd = 7.2) than when searching through a window (72.2%, sd = 14.3), $F(1,19) = 61.86$, $p < .001$, $\eta^2 = .77$. Neither preview nor the interaction between scene visibility and preview affected accuracy, Fs < 1 for both.

Response time and oculomotor behavior were analyzed only for trials that ended with correct responses. The period analyzed began with the (re)appearance of the scene after the target description was shown. Fixations shorter than 50ms were excluded from analyses. For each analysis of a measure, a trial was omitted if the measure for that trial was more than 2 standard deviations above or below the mean of that measure. Figure 2 shows average response time, average number of fixations, time until the first fixation on the target, average fixation duration, decision time (response time minus time of first target fixation), and first saccade amplitude in the four experimental conditions. Table 1 presents the means and standard deviations for the same measures.

------------------------ Insert Figure 2 and Table 1 about here. --------------------------

An ANOVA was conducted on each dependent variable to look for effects of preview and scene visibility. To summarize the results, visibility affected all measures significantly, but preview and the interaction between preview and visibility were significant for some but not all measures. For all significant interactions, preview had a significant effect both for full visibility and windowed visibility, so the interaction reflected a difference in magnitude of the preview effect.

Details of the ANOVA results follow. With full scene visibility compared to windowed viewing, responses were considerably faster, $F(1,19) = 235.89$, $p < .001$, $\eta^2 = .93$; there were fewer fixations, $F(1,19) = 233.87$, $p < .001$, , $\eta^2 = .93$; the target was fixated sooner, $F(1,19) = 218.85$, $p < .001$, $\eta^2 = .92$; fixation durations were shorter; $F(1,19) = 59.03$, $p < .001$, $\eta^2 = .76$; decisions to respond to seen targets were made faster, $F(1,19) = 47.00$, $p < .001$, $\eta^2 = .71$; and the first saccade was longer in amplitude, $F(1,19) = 244.04$, $p < .001$, $\eta^2 =.93$. With a preview, responses were faster, $F(1,19) = 68.20$, $p < .001$, $\eta^2 = .78$; there were fewer fixations, $F(1,19) = 55.24$, $p < .001$, $\eta^2 = .74$, and the time to first fixate the target was shorter, $F(1,19) = 45.96$, $p < .001$, $\eta^2 = .71$, than without a preview. There was no significant effect of preview on fixation duration, $F(1,19) = 3.54$, $p = .075$, decision time, $F(1,19) = 2.68$, $p = .118$, or on amplitude of the first saccade, $F(1,19) = 1.70$, $p = .208$. There was a significant interaction between visibility and preview for response time, number of fixations and latency to first target fixation, $F(1,19) =$

40.10, $p < .001$, $\eta^2 = .68$, $F(1,19) = 31.44$, $p < .001$, $\eta^2 = .62$, $F(1,19) = 25.97$, $p < .001$, $\eta^2 = .58$, respectively. Follow-up t-tests showed that information gathered from a preview speeded responses both for windowed viewing, $t(19) = 7.54$, $p < .001$, and for full-scene viewing, $t(19) = 2.65$, $p = .016$; reduced the number of fixations for both windowed viewing, $t(19) = 6.72$, $p < .001$, and for full scene viewing, $t(19) = 3.40$, $p = .003$; and speeded the first fixation of the target both for windowed viewing, $t(19) = 6.04$, $p < .001$, and for full-scene viewing, $t(19) = 4.59$, $p < .001$. For first saccade amplitude, decision time, and fixation duration, there was no significant interaction, $F(1,19) = 2.81$, $p = .110$, $F(1,19) = 3.19$, $p = .090$, and $F(1,19) < 1$, respectively.

Shorter fixations during full scene viewing compared to windowed viewing are consistent with using parafoveal and peripheral vision to partially pre-process information at the next saccade target location. The lack of effect of preview on average fixation duration suggests that the information from the preview was insufficient to facilitate object identification robustly across all fixations. The lack of an effect of preview on first saccade amplitude suggests that the information extracted from the preview, the scene gist, was insufficient to influence saccade targeting. To assess the impact of preview on the initial approach to the target, we considered whether the first few saccades were directed towards the target to a greater extent with than without a preview. Student's t-tests were carried out to examine the effect of preview for each fixation in each of the guidance by visibility conditions. A Bonferroni correction for multiple tests established $p=.006$ as the criterion for significance. As can be observed in Figure 3 and Table 1, for windowed visibility fixations were closer to the target in the second, third and fourth fixations with a preview than without a preview, $t(19) = 3.21$, 4.33, and 4.23; $p = .005$, $< .001$ and $< .001$, respectively. The first fixation, however, was not closer, $t(19) = 2.01$, $p = .059$. For fully visible scenes, the second fixation was closer to the target with a preview than without, *t*(19) = 4.23, $p < .001$, but the first, third and fourth fixation were unaffected by a preview, *t*(19) = 2.49, 2.77 and -0.35; *p* = .022, .012 and .728, respectively. Thus, the influence of the information gleaned from the preview guided eye movements through the fourth fixation when no peripheral information was available, but the same guidance occurred to a far lesser extent when non-foveal information was available.

------------------------ Insert Figure 3 about here. -------------------------

Discussion

This experiment compared the influence of a brief scene preview, roughly the duration of a short fixation during scene perception (Rayner, 1998), on search behavior when the scene was fully visible compared with when only a small part of the scene was visible at any one time during search. The goal was to determine whether gist derived from a preview of a scene influenced search efficiency and strategy equivalently in naturalistic viewing and in windowed viewing conditions. In both viewing conditions, previews led to fewer fixations, faster response times, and shorter times until the target was first fixated, with a greater magnitude of effect in the windowed condition than in the full visibility condition. In neither viewing conditions did a preview affect decision time, saccade duration, or first saccade amplitude. Where we used the same or similar measures, these results are consistent with what has been reported by Castelhano and Henderson (2007), Hollingworth (2009) and Võ and Henderson (2010). The one inconsistency is that Võ and Henderson found an effect of preview on first saccade amplitude in windowed visibility. To see whether this inconsistency of results was due to our choice of scene/target combinations (perhaps our scenes provided less information about potential target locations), we reran analyses on the half of the scenes that had fewer than the median number of fixations in the preview, windowed condition. This removed images in which the preview gave very little information about where the target might be. The same pattern of results obtained. Therefore, we speculate that the lack of effect of preview on first saccade amplitude may be due to mixing windowed visibility trials with full visibility trials, thereby weakening participants' motivation to try to visually process the preview in the windowed condition.

There was, however, a difference between windowed and full visibility conditions in the effect of preview on the proximity of the first four fixations to the target. Windowed viewing without a preview was aimless. There was no evidence that early successive fixations move progressively closer to the target. Adding a preview to windowed viewing led to fixations being closer to the target overall and the first few fixations moving progressively closer to the target.

Searching fully visible scenes was efficient even without a preview. Search was rapid and fixations moved progressively closer to the target. Adding a preview benefitted only the second fixation. Thus, the effect of the preview under normal scene viewing conditions had a very limited duration. When peripheral information was available during search, participants relied much more on the visible characteristics of the scene than on gist from preview when planning their eye movements. It is also possible that the effect of the preview is larger in this study than it would be in real life, for two reasons. First, the target was present in all previews, and although it is unlikely that the full preview effect was due to seeing the target, it may have played a role in some trials. Second, the mixture of full visibility and windowed viewing conditions may have led participants to pay more attention to the preview than they would have if they did not anticipate the possibility that search would be difficult because of windowing. Without running a condition in which viewing type during search is blocked, we cannot be sure whether this is the case.

Castelhano and Henderson (2007) showed that when non-foveal information is not available during fixations, gist information extracted from a preview of a scene guides eye movements. Hollingworth (2009) showed that in search through a fully visible scene, scene memory from a long-duration preview (memory that is possibly richer than the gist of the scene) makes search more efficient. We have extended this work by showing that in search through a fully visible scene, scene gist information, too, can guide eye movements for a short time and make search more efficient. The first one or two fixations are placed in a more information-rich location of the display. After that, however, search is guided by the non-foveal information obtained online from those and subsequent fixations.

Although the source of guidance may differ according to visibility, search through a scene is made more efficiency by a brief scene preview, regardless of whether visibility is windowed and full. In contrast, foreknowledge from a brief or even a longer preview of a randomly ordered search array does not improve search efficiency when the display is fully visible during search (Becker & Pashler, 2005; Wolfe et al, 2000. This adds indirectly to the volume of evidence accumulating showing that scanning of meaningful environments is driven more by prior knowledge than by stimulus salience.

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Table 1

Performance Measures in the Four Display Conditions

	Full Scene Visible				Windowed View			
	With Preview		Without Preview		With Preview		Without Preview	
Measure	M	SD	M	SD	M	SD	M	SD
Response time (msec)	1217.2	294.9	1364.4	272.3	3812.8	1225.5	5299.6	1175.5
Number of fixations	5.2	1.0	5.8	0.9	13.5	3.9	18.2	4.1
Time until target fixation (msec)	592.7	134.3	771.5	137.5	2648.0	946.7	3928.3	963.8
Average fixation duration (msec)	211.8	38.4	214.5	32.1	256.2	35.0	260.7	36.2
Decision time (msec)	624.5	232.7	592.9	164.3	1164.9	486.6	1371.3	678.5
First saccade amplitude (°)	4.2	1.0	4.2	0.7	1.9	0.5	1.5	0.4
Distance from target: fixation 1 (°)	6.6	1.0	7.6	0.9	6.9	0.9	7.6	0.9
Distance from target: fixation 2 (°)	5.2	0.9	6.5	0.9	6.4	1.0	7.7	0.9
Distance from target: fixation 3 (°)	4.1	1.1	4.9	0.9	6.2	1.0	7.7	0.8
Distance from target: fixation 4 (°)	3.6	1.0	3.5	0.9	6.4	1.2	7.8	0.7

Figure 1. Two representative sample scenes. In Panel A, the target was the bench. In Panel B, the target was the flag. Search was easier in the scene in Panel A than the scene in Panel B.

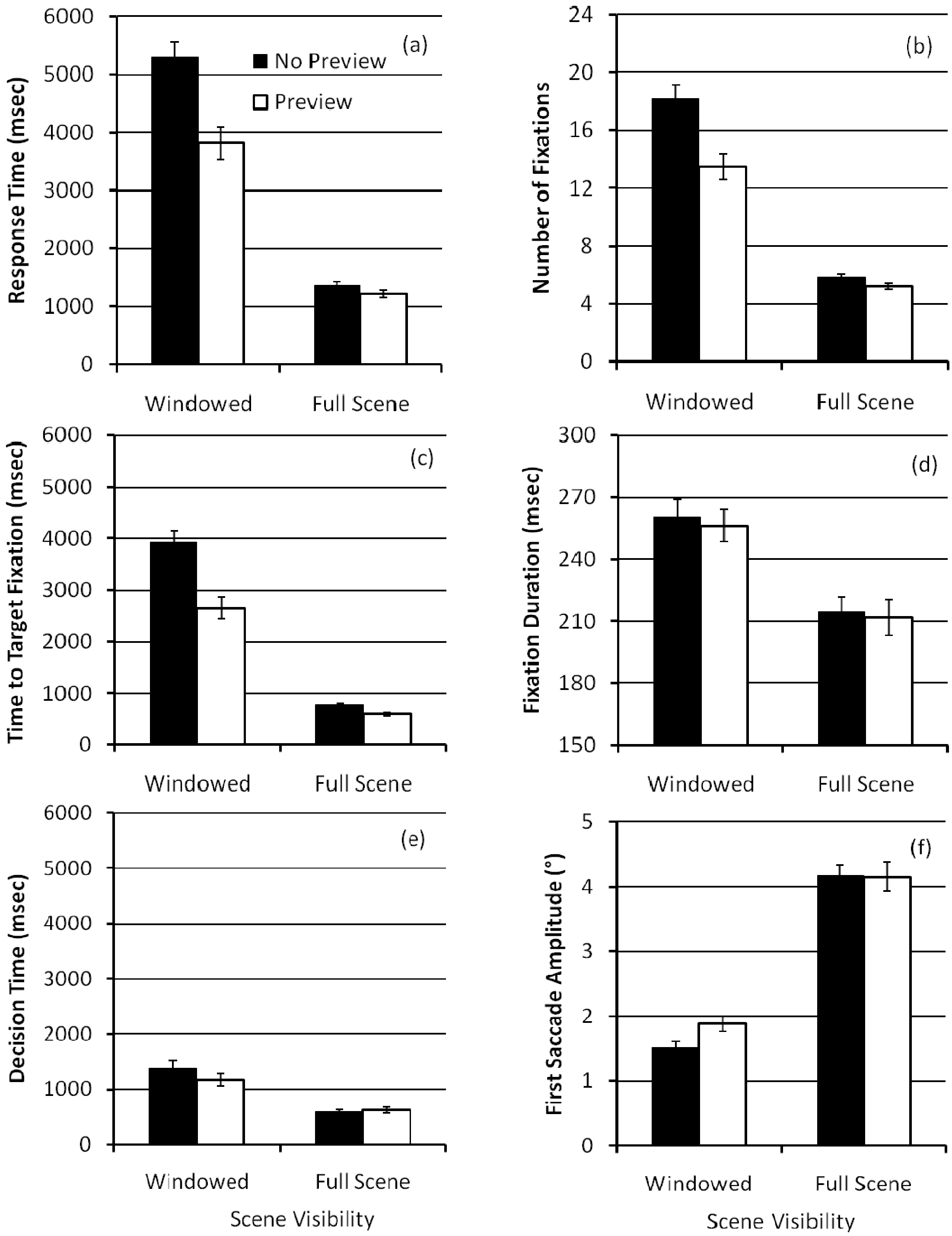

Figure 2. Data for the four display conditions. Panel A shows response times. Panel B shows number of fixations. Panel C shows time until the target was first fixated. Panel D shows average fixation durations. Panel E shows decision time (time between the first fixation of the target and the response). Panel F shows average saccade amplitudes. Error bars represent 1 standard error of the mean.

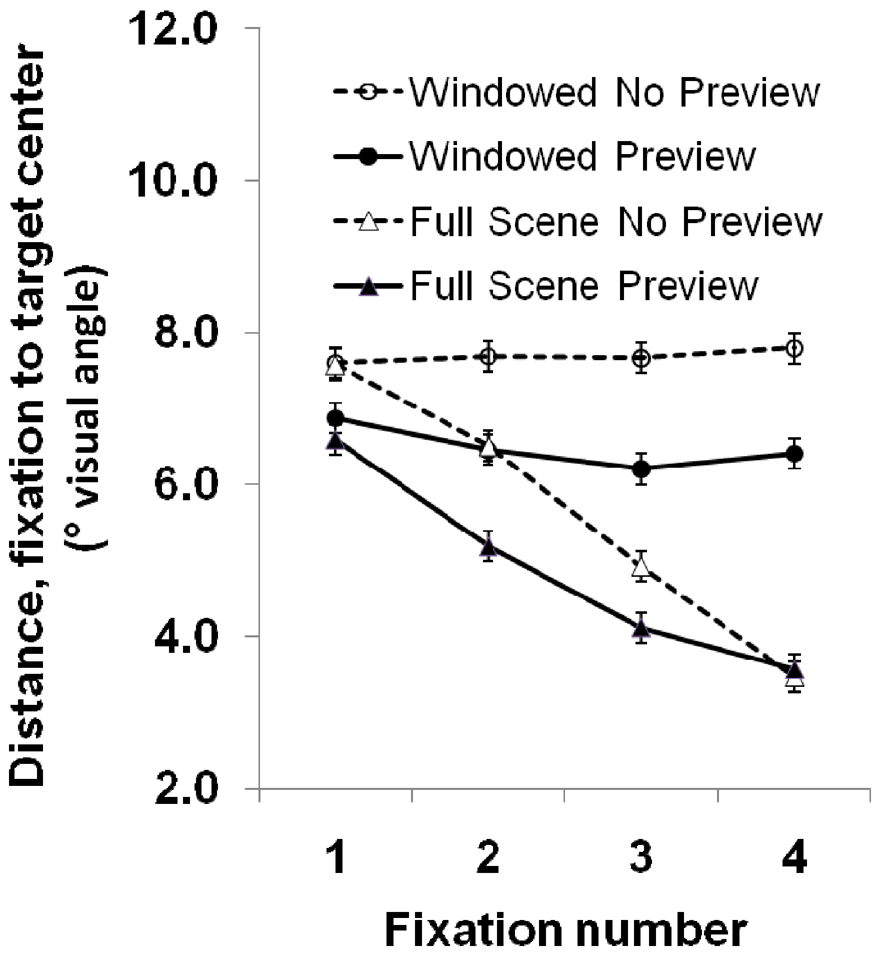

Figure 3. Fixation distance during early stages of search for the four display conditions. Error bars represent 1 standard error of the mean.