Placeholder objects shape spatial attention effects before eye movements

Michael Puntiroli
Faculty of Psychology and Educational Sciences, University of Geneva, Geneva, Switzerland
Faculty of Economics and Business, Enterprise Institute, University of Neuchâtel, Neuchâtel, Switzerland

Dirk Kerzel
Faculty of Psychology and Educational Sciences, University of Geneva, Geneva, Switzerland

Sabine Born
Faculty of Psychology and Educational Sciences, University of Geneva, Geneva, Switzerland

In the time leading up to a saccade, the saccade target is perceptually enhanced compared to other objects in the visual field. This enhancement is attributed to a shift of spatial attention toward the target. We examined whether the presence of visual objects is critical for the perceptual enhancement at the saccade target to occur. We hypothesized that attention may need an object to focus on in order to be effective. We conducted four experiments using a dual-task design, where participants performed eye movements either to a location demarked by a placeholder or to an empty screen location where no object was displayed. At the same time, they discriminated a probe flashed at the location targeted by the eye movement or at one of two control locations. A strong perceptual advantage at the saccade target location was observed only when placeholders were displayed at the time of probe presentation. The complete absence of placeholders (Experiment 1), the presence of placeholders before but not during probe presentation (Experiment 3), and the presence of objects only around the saccade target (Experiments 3 and 4) led to a strong reduction in the saccade-target benefit. We conclude that placeholders may indeed be necessary to observe presaccadic enhancement at the saccade target. However, this is not because placeholders provide an object to focus attention on, but rather because they produce a masking (or crowding) effect. This detrimental effect is overcome by the presaccadic shift of attention, resulting in heightened perception only at the saccade target object.

Introduction

Forced by design of the visual system, we shift our gaze several times per second. Each time, we select a visual element of interest from the low-resolution periphery and bring it into focus in order to obtain more fine-grained visual information. When an object or location from the periphery is selected over another as the target of the next gaze shift, it becomes perceptually enhanced compared to other objects in the visual field (e.g., Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler, Anderson, Dosher, & Blaser, 1995; Shepherd, Findlay, & Hockey, 1986). The process underlying this enhancement is thought to be a shift of covert attention just before the eye movement is launched, allowing for some of the object's fine visual features to be obtained even before it is foveated. For instance, in the classic study by Deubel and Schneider (1996), participants executed eye movements toward a cued saccade target, presented among nontarget objects, while also discriminating an attentional probe (E or Ǝ) briefly flashed before the eye movement. The probe could appear either at the saccade target or at one of the nontarget objects. The results showed that discrimination performance was much better at the saccade target compared to the other objects. This perceptual benefit was narrowly centered on the saccade target. Probes as close as 1.1° of visual angle (va) away from the designated landing point of the eye movement were not better discriminated than more distant ones. Virtually identical observations have been reported in other studies, with enhancement at the saccade target always confined within a small area (Baldauf & Deubel, 2008; Godijn & Theeuwes, 2003; Kowler et al., 1995).

The enhancement at the saccade target is tightly linked to the execution of the saccade, suggesting an obligatory coupling between attention and gaze shifts:

Citation: Puntiroli, M., Kerzel, D., & Born, S. (2018). Placeholder objects shape spatial attention effects before eye movements. *Journal of Vision*, *18*(6):1, 1–20, https://doi.org/10.1167/18.6.1.

https://doi.org/10.1167/18.6.1 Received September 20, 2017; published June 1, 2018 ISSN 1534-7362

The attentional prioritization of the saccade target is robustly found with attentional resources spatially distributed—that is, when the attentional probe appears in any location with equal probability. However, it is also found with attention focused—that is, when a spatial cue or a fixed location across trials validly indicates the location of the perceptual probe (Born, Ansorge, & Kerzel, 2013; Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995). Thus, although some attentional resources may be directed elsewhere (Born et al., 2013; Doré-Mazars, Pouget, & Beauvillain, 2004; Jonikaitis, Klapetek, & Deubel, 2017; Kowler et al., 1995; Montagnini & Castet, 2007), there will always be a substantial share focused on the saccade target. Further, the saccade-target benefit occurs even for error saccades directed toward the wrong item (Klapetek, Jonikaitis, & Deubel, 2016; Puntiroli, Kerzel, & Born, 2015), but is eliminated (or at least reduced) when the saccade is canceled (Born, Mottet, & Kerzel, 2014; Hunt & Kingstone, 2003; Khan, Blohm, Pisella, & Munoz, 2015; Klein & Pontefract, 1994). Finally, it typically follows a specific time course: The closer in time the perceptual probe is flashed to saccade onset, the more perceptual sensitivity will be heightened at the saccade target compared to other locations (Deubel, 2008; Rolfs, Jonikaitis, Deubel, & Cavanagh, 2010).

However, all of the studies we have mentioned so far used structured visual fields, where placeholder objects demarked, from the very beginning of a trial, the possible locations of the saccade target as well as the locations where the attentional probe could appear. Visual objects present in the periphery are likely to aid selection when it comes to programming the metrics of the upcoming eye movement. Is the presence of visual objects necessary for the narrow presaccadic enhancement at the saccade target? Or is it possible to evenly distribute perceptual resources when no objects are there to bind attention prior to an eye movement?

In the saccade literature, there is indeed evidence that the presence of visual objects prior to the eye movement affects some aspects of attention, perception, and memory. Tas, Luck, and Hollingworth (2016) have shown that saccading toward a visual object during the retention interval interfered with a concurrent visual working memory task. Presenting the same object while participants kept fixation did not cause interference. In contrast, memory performance was not different across saccade and fixation conditions in a block of trials without a visible saccade target—that is, when saccades were either made toward an empty location on the screen or withheld, depending on a central cue. Thus, it was not the saccade per se but the combination of an eye movement and the presence of a visual object at its landing site that caused the interference. Further, Zimmermann, Morrone, and Burr (2014) showed that saccadic compression of space (i.e., the mislocalization of probes briefly flashed during saccades; Ross, Morrone, & Burr, 1997) is reduced when no visual object is present at the saccade landing point. And Lisi, Cavanagh, and Zorzi (2015) found that placeholder objects are critical for attention to be sustained in spatiotopic coordinates in a transsaccadic-cuing paradigm. Taken together, these studies demonstrate that the presence or absence of visual objects may affect visual processing in the context of saccades. However, none have explicitly examined the distribution of attention before eye movements.

Several covert attention studies, on the other hand, have provided evidence that visual objects affect the distribution of spatial attention. For instance, Taylor, Chan, Bennett, and Pratt (2015) measured manual reaction times in an exogenous cuing procedure with various cue–target asynchronies to generate a detailed spatiotemporal mapping of involuntary attention when placeholders were present or absent. With placeholders acting as visual anchors, the well-established pattern of early facilitation and late inhibition at the cued placeholders compared to the uncued placeholders was observed. Without placeholder objects, however, there was no early facilitation at the cued placeholder, but inhibition prevailed from the shortest (100 ms) to the longest cue–target asynchronies. Thus, the absence of placeholders seems to cancel or at least reduce the benefit of visual cues. Another example comes from Woodman, Arita, and Luck (2009), who measured lateralized event-related brain potentials (ERPs) to examine the deployment of visual attention in a symbolic-cuing paradigm. A 100% valid central word cue guided attention to the upcoming target among distractors. Either target and distractor locations were demarked by placeholder objects or there were no objects from the beginning of the trial until the target display. During the cue–target interval, lateralized activity in anticipation of the target occurred when visual objects were present; but this anticipatory component did not emerge when the locations of the upcoming target and distractors were not marked by placeholders. The researchers concluded that covert attention (as indexed by lateralized ERP components) is deployed to objects, not empty locations in space.

Covert attention and presaccadic attention may differ to some extent in the ways they are controlled (Blangero et al., 2010) and the ways they affect perception (Khan et al., 2015). Still, the robust finding that it is not possible to fully deploy attentional resources covertly away from the saccade target shortly before an eye movement attests that covert and presaccadic attention rely on largely overlapping systems (see also Awh, Armstrong, & Moore, 2006; Corbetta, 1998).

In the current project, we therefore set out to explore whether visual objects present before an eye movement modulate the classic presaccadic attention effect, where perceptual benefits are narrowly centered on the saccade target. We hypothesized that placeholders provide visual anchors upon which attention can focus. Without placeholders, the focusing of attentional resources on the saccade target location prior to the eye movement may not be possible, as there is no object present to bind or hold those resources. As a consequence, an even distribution of perceptual performance may be observed.

To anticipate the results: Although we found a pattern that was in line with our hypothesis in a first experiment, subsequent results suggested that this finding was more likely to reflect spatiotemporal interference by the placeholders in the processing of the perceptual probes—the placeholders made our probes harder to discriminate, akin to a masking or crowding effect. This interference seemed to be stronger at nontarget locations and reduced at the saccade target, resulting in a saccade-target benefit. More research will be necessary to link our results more firmly to specific masking phenomena previously described in the literature.

Experiment 1

The aim of Experiment 1 was to determine whether the attentional distribution before eye movements, with its characteristic perceptual benefit at the saccade target, is dependent on the presence of placeholder objects. We hypothesized that placeholders are necessary to focus and bind attentional resources to an object at the saccade target location. We used a dual-task paradigm very similar to those employed in previous presaccadic attention studies (e.g., Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995). We presented participants with two conditions: one where eye movements were made toward a central placeholder and one where eye movements were made toward the empty screen center (see also Zimmermann et al., 2014), with no placeholders presented in or around it.

Method

Participants

In all experiments in the current study, we tested 10–15 participants. This number was chosen based on our previous research using similar procedures, where we were able to demonstrate not only the presaccadic enhancement at the saccade target but also modulations of the effect (Born et al., 2012; Born et al., 2014; Puntiroli et al., 2015).

In Experiment 1, data were gathered from 14 participants (ranging from 18 to 31 years of age), who performed the task for a minimum of two to a maximum of four 1-hr sessions, depending on availability and the individual rate of trials that had to be excluded from analysis (see criteria later). All participants reported normal or corrected-to-normal vision.

For all experiments described in this article, participants were paid or given course credits for their efforts. Ethical assent to the project was awarded by the ethics committee of the Faculty of Psychology and Educational Sciences of the University of Geneva, and all participants gave their signed consent for participation. All procedures followed the principles laid down in the Code of Ethics of the World Medical Association (Declaration of Helsinki).

Apparatus

The experiment was written in MATLAB (MathWorks, Natick, MA) using the Psychophysics and Eyelink Toolbox extensions (Brainard, 1997; Cornelissen, Peters, & Palmer, 2002; Kleiner, Brainard, & Pelli, 2007) and run on a Dell Optiplex 755 computer (Dell Inc., Round Rock, TX). The stimuli were displayed on a 21-in. CRT monitor (NEC MultiSync FE2111SB; NEC Corporation, Tokyo, Japan), which ran at 85 Hz and was set to a spatial resolution of $1{,}280 \times 1{,}024$ pixels. Viewing distance was 70 cm. The EyeLink1000 desk-mounted eye tracker was used to record eye movements (SR Research Ltd., Ottawa, Ontario, Canada) at a sampling rate of 1,000 Hz. Participants were seated in a dimly lit room and placed their head within a fixed chin and forehead rest. Viewing was binocular, but eye movements were recorded from only one eye.

Stimuli, design, and procedure

The procedure of Experiment 1 is illustrated in Figure 1A. Each trial started with the fixation cross appearing on a gray background (16.4 cd/m^2) 5° va left of the center of the screen for 600 ms. Next, the fixation cross disappeared, serving as the signal to the participants to now move their eyes toward the center of the screen as quickly as possible.

In the *placeholder Present* condition, simultaneous with fixation offset appeared three dark-gray placeholder circles (10.1 cd/m^2) of radius 0.8° va (outline: 5 pixels thick). One circle was displayed at the center of the screen, acting as the saccade target object. The central placeholder was flanked by two further circles, one above and one below, both at an angle of 40° from the horizontal saccade axis (Euclidian distance: 3.5° va

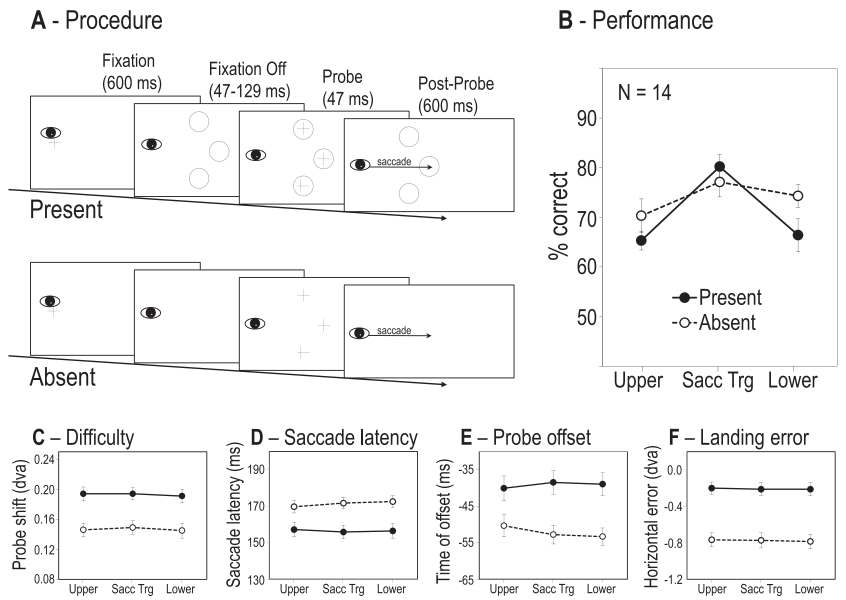

Figure 1. Results of Experiment 1. (A) Schematic illustration of the procedure. (B) Percentage of correct responses in the discrimination of the perceptual probe (asymmetric cross), as a function of probe location on the abscissa (Upper/Lower control locations; Sacc Trg: saccade target) and placeholder condition (lines). (C) Difficulty: Degree of asymmetry of the probe required to obtain 71% correct responses in a block. (D) Average saccade latency. (E) Average time of probe offset with respect to saccade onset (negative values: probe offset before saccade onset). (F) Average horizontal saccade landing error (negative values: saccade fell short of the target). All error bars: standard error of the mean.

center to center from the central placeholder) and, like the central saccade target circle, displayed at 5° va from fixation. The empty circles remained on screen for 47, 59, 71, 82, 106, or 129 ms. Then crosses were flashed inside the three placeholders. Two of the crosses were perfectly symmetric (length of the horizontal and vertical bars: 0.8° va), while one was asymmetric and could appear randomly at any of the three locations. This asymmetric cross served as the perceptual probe. Its vertical bar did not bisect the horizontal bar at the center, but was slightly shifted to the left or right (see probe display in Figure 1A for an illustration: The cross in the Lower location shows a slight shift to the left). The crosses were displayed for 47 ms, followed by the empty placeholders, which remained on screen for another 600 ms. Afterward, observers responded with a key press (left or right arrow keys) whether the probe's vertical bar was shifted leftward or rightward from center.

In the *placeholder Absent* condition the procedure was identical, but no placeholders were displayed, and participants were asked to move their eyes toward the empty screen center as soon as possible after the fixation cross disappeared.

The placeholder Absent and Present conditions were blocked. Each block was made up of 90 trials. Participants started with one or two Present blocks to get an overall idea of the spatial layout and then switched back and forth between conditions after two or three blocks in the same condition. In total, participants completed at least 10 blocks (16 on average, depending on trial-exclusion rate).

The participants were instructed that carrying out correct eye movements had priority over the perceptual discrimination task. Accordingly, they received a written feedback message on screen just before the response display if (a) saccades were anticipatory—that is, launched less than 50 ms after fixation offset; (b) saccade latencies were longer than 350 ms or no saccade was detected within 500 ms after fixation offset; (c) blinks were detected during a time window 250 ms before to 400 ms after fixation offset; (d) gaze coordinates at saccade onset were more than 1.5° va off the fixation location; or (e) saccades did not land within 1.5° va of the screen center. Note, however, that the saccade latency and landing position feedback was primarily given to help participants make their eye movements at the right time and to the right place. Different criteria, in particular different temporal and spatial windows, were used for trial exclusion (see later).

Concerning the lateral shift in the vertical probe bar that determined the degree of asymmetry (and thus the discriminability) of the probe, the initial shift in each block was set to 0.175° va from the center of the horizontal bar, and the maximal allowed shift was 0.4° va (i.e., at the end of the horizontal bar). A two-down one-up staircase procedure was used throughout the experiment: With every incorrect response, the shift was increased by 0.025° va (= 1 pixel), making the probe more asymmetric and thus easier to discriminate; with every two correct responses in a row, the shift was decreased by 0.025° va (minimum offset fixed at 0.025° va), making the probe more symmetric and thus more difficult to discriminate (and more similar to the symmetric distractor crosses flashed at the other locations). Note that this procedure was used not to determine perceptual thresholds but to ensure discrimination performance for all participants at approximately 71% correct in each block and across probe locations, to avoid floor and ceiling effects. Importantly, probe location was random from trial to trial, allowing us to compare how the 71% correct overall performance in a block was distributed across the saccade target and nontarget locations. Thus, our measure of attentional deployment across locations within a given block (i.e., placeholder Present or Absent condition) is accuracy (% correct) in the discrimination task. (See Supplementary Material for more information on the staircase procedure.)

Results

Excluded trials

For trial exclusion in our main analysis, we did not strictly follow the same criteria as the ones we applied for feedback to the participants. First, it has been shown that presaccadic-attention effects develop over time, building up slowly toward saccade onset (Deubel, 2008; Rolfs et al., 2010). That is, the presaccadic benefit emerges only when probes are presented shortly before the saccade is executed. If the perceptual probe is flashed long before the saccade, performance is roughly equal across locations. Consequently, we analyzed only trials where the perceptual probe was offset in the last 100 ms before saccade onset, irrespective of saccade latency (i.e., including trials marked as anticipations or with latencies up to 500 ms, which was the time the eye-tracker recording was stopped on each trial). Second, it is well known that saccades often do not land precisely on target; they fall systematically short of the target (Becker, 1989), and there is more variability in landing position along the saccade axis than orthogonal to it (van Opstal & van Gisbergen, 1989). Importantly, however, previous research suggests that presaccadic perceptual benefits are centered on the intended saccade target location and are largely independent of the true landing position on a given trial (Deubel & Schneider, 1996; Van der Stigchel & de Vries, 2015). With these observations in mind, we enlarged the window for acceptance along the horizontal (saccade) axis, including trials with landing-position errors up to 2° va horizontally; for the vertical axis, the 1.5° va criterion remained.

Following these criteria, 50.3% of trials (Present: 45.7%, Absent: 54.7%) were excluded from the main analysis: 8.8% due to breaks of fixation or blinks, 40.5% due to perceptual probes being presented more than 100 ms before or after saccade onset, and 1.1% due to saccades landing more than 2° va horizontally or 1.5° va vertically from the screen center. After trial exclusion, the means that were entered into the analyses of variance (ANOVAs; see later) were based on a minimum of 22 trials per condition and participant (119 trials on average). Note that we ran additional analyses to explore performance across time as well as space (see later), including many more trials that were not considered in the main analysis.

Presaccadic perceptual discrimination performance

Our main interest was to determine whether the well-known presaccadic attentional enhancement at the saccade target depends on the presence of a visual object (placeholder). To this end, we tested whether discrimination performance across the three probe locations differed between the placeholder Present and the placeholder Absent conditions. Figure 1B illustrates the average discrimination performance in our six conditions, which were entered into a 2 (placeholder condition: Present vs. Absent) $\times$ 3 (probe location: saccade target, Upper control, and Lower control) within-subject ANOVA. The analysis revealed a significant main effect for probe location, $F(2, 26) = 4.01$, $p = 0.030$, partial $\eta^2 = 0.24$. Figure 1B suggests that this was due to overall better performance at the saccade target than the other two locations. There was also a significant main effect of placeholder condition, $F(2, 13) = 5.91$, $p = 0.030$, partial $\eta^2 = 0.31$, revealing that despite the blockwise staircase targeting 71% over all locations in both conditions, performance was slightly better in the Absent than the Present condition (73.9% vs. 70.6% correct, respectively). Most interestingly, however, there was a significant interaction between the two factors, $F(2, 26) = 6.03$, $p = 0.007$, partial $\eta^2 = 0.32$. Confirming previous studies, post hoc t tests revealed significantly better performance at the saccade target than the nontarget locations when placeholders were present—saccade target vs. Upper control: 80.2% vs. 65.3%, $t(13) = 4.72$, $p < 0.001$, Cohen's $d = 1.26$; saccade target vs. Lower control: 80.2% vs. 66.4%, $t(13) = 2.72$, $p = 0.017$, Cohen's $d = 0.73$. However, in the placeholder Absent condition, the advantage at the saccade target was markedly reduced and no longer reached significance—saccade target vs. Upper control: 77.1% vs. 70.3%, $t(13) = 1.62$, $p = 0.129$, Cohen's $d = 0.43$; saccade target vs. Lower control: 77.1% vs. 74.3%, $t(13) = 0.59$, $p = 0.562$, Cohen's $d = 0.16$.

Perceptual difficulty and temporal and spatial probe/saccade characteristics

Figure 1C–1F illustrates further characteristics of the tested conditions. Note that for all of these measures, the same trial-exclusion criteria were applied as for the analysis on discrimination performance. We performed the same 2 × 3 within-subject ANOVA on all of them. Figure 1C illustrates perceptual difficulty in all conditions—that is, the degree of probe asymmetry required to obtain roughly 71% correct. This is assessed through the average shift in the vertical probe bar that was adjusted by blockwise staircase procedures. Figure 1D shows average saccade latencies. Figure 1E illustrates by how much time the probe preceded the saccade on average (time of probe offset with respect to saccade onset). Finally, Figure 1F shows the average horizontal landing error of the saccade. The graphs demonstrate that the placeholder Present and Absent conditions differed along all of these measures. The respective ANOVAs confirmed that the Present condition was overall more difficult (required shift: 0.19° va) than the Absent condition (0.15° va), $F(1, 13) = 18.58$, $p = 0.001$, partial $\eta^2 = 0.59$; that saccade latency was shorter in the Present (157 ms) than the Absent condition (171 ms), $F(1, 13) = 10.74$, $p = 0.006$, partial $\eta^2 = 0.45$; that the perceptual target was offset, on average, closer in time to saccade initiation in the Present (39 ms) compared to the Absent condition (52 ms), $F(1, 13) = 11.17$, $p = 0.005$, partial $\eta^2 = 0.46$; and that saccades landed closer to the target in the Present (0.21° va short of the target's center) compared to the Absent condition (0.78°), $F(1, 13) = 109.26$, $p < 0.001$, partial $\eta^2 = 0.89$.

The main effect of probe location approached significance for difficulty, $F(2, 26) = 3.29$, $p = 0.053$, partial $\eta^2 = 0.20$. Note, however, that numerically the differences across locations were very small (Figure 1C). Further, the two temporal variables showed significant interactions between the two factors—saccade latency: $F(2, 26) = 4.36$, $p = 0.023$, partial $\eta^2 = 0.25$; probe-to-saccade: $F(2, 26) = 4.32$, $p = 0.024$, partial $\eta^2 = 0.25$. No further effects or interactions reached significance (all Fs < 1.02, all ps > 0.373).

In sum, not only the distribution of discrimination performance differed across the Present and Absent conditions; the two conditions were also characterized by different spatial and temporal profiles. We therefore ran additional analyses to determine whether those covariates may account for the differences in discrimination performance. (See Supplementary Material for an analysis across different probe shifts.)

Performance across time and space

Results across probe offset time (with respect to saccade onset) are depicted in Figure 2A. Previous research suggests that the perceptual benefit at the saccade target should increase the closer in time the perceptual target is flashed before the initiation of the saccade (Deubel, 2008; Rolfs et al., 2010). Data from

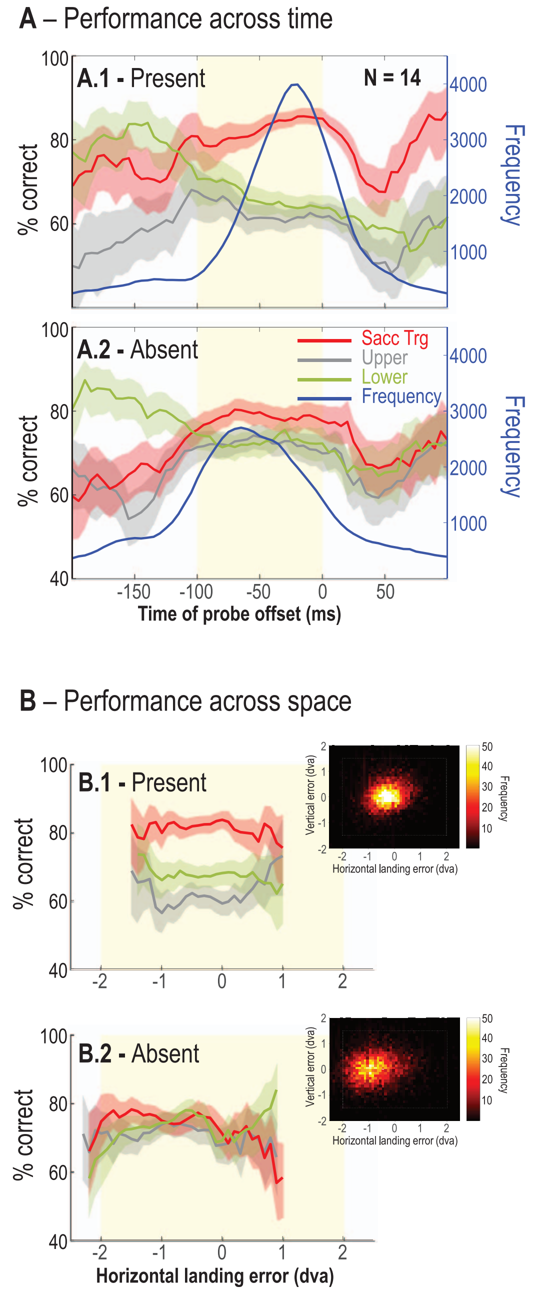

Figure 2. Discrimination performance in Experiment 1 across (A) probe offset time (negative: probe offset before saccade onset) and (B) horizontal saccadic landing error (negative: saccade falls short of the target) at the three probe locations (Upper control: green, saccade target: red, Lower control: gray). The distribution of trials in the Present/Absent conditions is illustrated through an additional blue line in (A), right axis for reference, and insets depicting two-dimensional frequency heat maps in (B). Shaded areas around the data lines represent 95% bootstrapped confidence interval (sampling 1,000 times with replacement); yellow shaded rectangles illustrate the trial-inclusion criteria employed in the main analysis.

all 14 participants were combined in Figure 2A; we used a moving-window technique, summing up across bins 50 ms wide and proceeding in steps of 5 ms, from 200 ms before to 100 ms after saccade onset. Note that the figure takes more data (78.4% of all trials) into account than the main analysis (same exclusion criteria, except for probe offset time). The frequency curves (blue) show that on most trials, probe offset fell within our critical time window 100 ms before saccade initiation (−100 to 0 ms; yellow shaded area). In the Present condition, a benefit at the saccade target emerged around 75 ms before saccade onset and persisted until after the saccade. Within the last 75 ms before saccade onset, performance in the Absent condition was also frequently best at the saccade target, but the benefit was substantially smaller. Looking at the period long before saccade initiation (−200 to −100 ms; left end of the graphs) and during and after the saccade (0 to 100 ms; right end of the graph), the data become much noisier (compare width of confidence intervals), reflecting the reduced number of trials. Quite peculiarly, the Lower control location shows unusually high performance long before the saccade. Note, however, that given the noise and the low number of trials, this pattern may stem from a small subset of participants. Also, we did not find the same pattern in the following experiments, and thus we think it should not be interpreted any further.

Although previous research suggests that presaccadic perceptual effects are largely independent of the true landing position on a given trial (Deubel & Schneider, 1996; Van der Stigchel & de Vries, 2015), the difference in average horizontal landing error between our Present and Absent conditions nevertheless made us explore effects across landing position as well. Figure 2B illustrates performance in the tested conditions across horizontal saccade landing error (line graphs; moving window: 0.5° va bin width, proceeding in steps of 0.1° va; data are depicted from the first to the last bin containing at least 50 trials). The yellow shading represents the large spatial window for trial acceptance in the main analysis. All trials with probe offset prior to the saccade are included. The data thus represent 67.5% of all trials. For each blocked condition (Present vs. Absent), the insets show two-dimensional frequency heat maps of saccadic landing error. Those heat maps illustrate the slightly larger undershoot and wider spread of landing points in the Absent condition. They also show that vertical landing error was comparable across conditions (confirmed through additional analysis), which is why we present only performance across horizontal error here. The line graphs show that probe discrimination in all conditions remained more or less stable across horizontal landing error, except for some fluctuations at either end of the distributions, where means were based on fewer trials and therefore noisier. A saccade-target benefit is evident across a wide range (approximately −1° va to 0.5° va) of landing errors in the Present condition, whereas no such benefit emerges in the Absent condition.

The important point to be taken from Figure 2 is that across almost the entire temporal and spatial range of trials that were included in our main analysis (yellow shaded areas), there was a robust benefit at the saccade target in the Present condition. Across the same range, this benefit was much smaller in the Absent condition. Thus, the small differences in average probe offset time and horizontal landing error (see Figure 1E and 1F) cannot explain the differences in performance.

Discussion

As we had hypothesized, the placeholders' presence changed how performance varied across the probed locations: When placeholders were present, a large perceptual advantage at the saccade target was found, with discrimination performance better at that location than at the two control locations. When no placeholders were presented, the advantage at the saccade target was strongly reduced. Percentage of correct responses was roughly equal at all locations, with only small (and nonsignificant) benefits at the saccade target. The effect size for the reduction in the saccade-target benefit, as given by partial $\eta^2 = 0.32$ for the interaction, was slightly but not substantially smaller than what we previously observed when comparing conditions with or without saccades, where partial η^2 ranged between 0.35 and 0.50 (Born et al., 2012; Born et al., 2014; Puntiroli et al., 2015).

Our results are in line with our *object-selection hypothesis* as laid out in the Introduction: The presence of visual objects upon which attentional resources can be focused may be necessary during the saccade-preparation phase to see benefits at the saccade target (see also Lisi et al., 2015; Woodman et al., 2009). However, our results may also be explained by an alternative account, which we term the *masking hypothesis*. Note that while the placeholders had a positive effect on saccade precision (less undershoot), they were overall detrimental to the perceptual task: The shift of the probe's vertical bar that defined the probe's degree of asymmetry and therefore its discriminability had to be larger when the objects were present than in the condition without placeholders in order to achieve a similar overall percentage of correct responses. This may be because the placeholders render the visual landscape richer and increase visual clutter, producing masking or crowding effects (for overviews, see Breitmeyer & Öğmen, 2006; Pelli, Palomares, & Majaj, 2004). It has been suggested that masking or

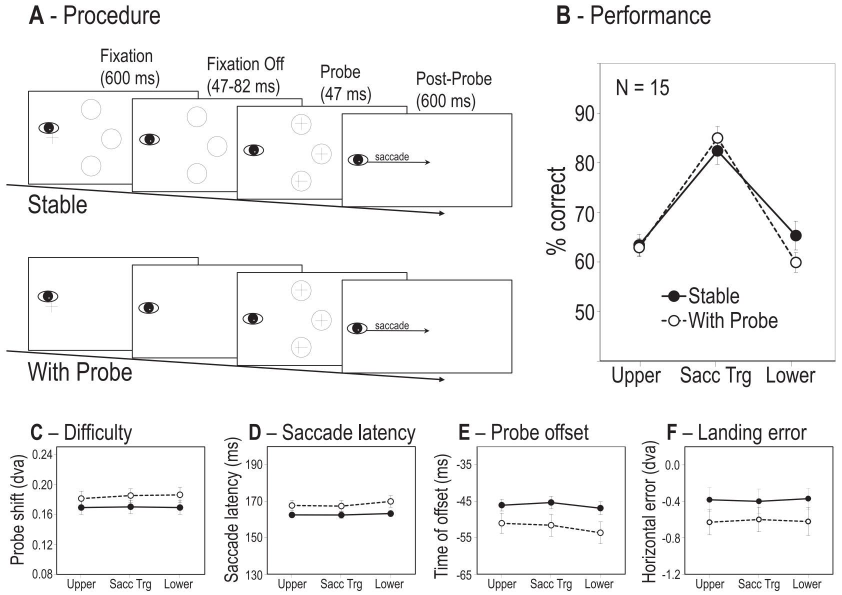

Figure 3. Results of Experiment 2. (A) Schematic illustration of the procedure. (B) Percentage of correct responses as a function of probe location and placeholder condition. (C) Difficulty: Degree of asymmetry of the probe required to obtain 71% correct responses in a block. (D) Average saccade latency. (E) Average time of probe offset with respect to saccade onset. (F) Average horizontal saccade landing error. Conventions as in Figure 2.

crowding effects are diminished at the saccade target in the presaccadic interval (Ağaoğlu, Öğmen, & Chung, 2016; Harrison, Mattingley, & Remington, 2013; Wolfe & Whitney, 2014). Thus, perhaps our placeholders produced a spatiotemporal-interference effect that made the probes harder to discriminate. The benefit at the saccade target may then reflect that this interference can be overcome by the presaccadic shift of attention. Experiment 2 was designed to exclude this alternative explanation of our results. Note that when in the following we refer to the masking hypothesis, we think of masking in very broad terms as some kind of spatiotemporal interference, without focusing on a specific masking mechanism.

Experiment 2

Critically, the object-selection hypothesis assumes that visual objects need to be present early during the presaccadic interval to bind attentional resources and thus create a perceptual advantage at the saccade target. In Experiment 2, we therefore compared a condition in which the placeholders were presented from the beginning of a trial to a condition in which placeholders were presented later in time together with the perceptual probe (see Figure 3A). According to the object-selection hypothesis, a presaccadic benefit should emerge only in the condition with placeholders early on. Note that masking may still occur when the placeholders appear only simultaneously with the perceptual probe. Many masking phenomena show characteristic profiles across different asynchronies between mask and perceptual probe, but most are still strong or even strongest when mask and probe appear simultaneously (Breitmeyer & Öğmen, 2006).

Method

All of the following experiments employed the same apparatus, stimuli, feedback, and saccade-rejection criteria as Experiment 1. Participants were 15 students from the University of Geneva, ranging from 21 to 32 years of age. The procedure is schematically illustrated in Figure 3A. During the fixation phase (600 ms), participants were instructed to prepare an eye movement to the central placeholder (Stable condition) or to the empty center of the screen (With Probe condition), and to trigger the movement once the fixation cross disappeared. The perceptual probe and distractors were presented 47, 59, 71, or 82 ms after fixation offset. In contrast to the Absent condition in Experiment 1, in the With Probe condition placeholder circles were presented during the time the perceptual probe was flashed. As before, participants were instructed to state at the end of the trial whether the asymmetric probe cross had the vertical bar displaced to the left or right. Duration of the experiments was reduced to one or two sessions of maximum 1 hr each. Participants completed at least five blocks (eight blocks on average) of 90 trials. Conditions were blocked, and participants alternated between blocks of each condition.

Results

Excluded trials

The same criteria for trial exclusion were applied as in Experiment 1. Accordingly, 51.5% of trials (Stable: 54.3%, With Probe: 48.2%) were excluded from analysis in Experiment 2: 7.0% due to breaks of fixation or blinks, 41.6% due to perceptual probes being presented more than 100 ms before or after saccade onset, and 3.0% due to saccades landing more than 2° va horizontally or 1.5° va vertically from the screen center. There was one condition (Stable, probe at Upper location) where only seven trials remained for one participant after trial exclusion; otherwise, the means entered into the ANOVAs were based on a minimum of 18 trials per condition and participant (57 trials on average).

Presaccadic perceptual discrimination performance

Perceptual performance was analyzed with a 2×3 repeated-measures ANOVA, with placeholder condition (Stable, With Probe) and probe location (saccade target, Upper control, and Lower control) as within-subject factors. Results are illustrated in Figure 3B. The analysis highlighted a significant main effect of probe location, $F(2, 28) = 31.07$, $p < 0.001$, partial $\eta^2 = 0.69$. Neither the main effect of placeholder condition, $F(1, 14) = 1.32$, $p = 0.269$, partial $\eta^2 = 0.09$, nor the interaction, $F(2, 28) = 1.85$, $p = 0.176$, partial $\eta^2 = 0.12$, reached significance. Follow-up *t* tests confirmed better performance at the saccade target compared to the control locations—saccade target vs. Upper control: 83.7% vs. 63.1%, $t(14) = 7.05$, $p < 0.001$, Cohen's $d = 1.82$; saccade target vs. Lower control: 83.7% vs. 62.6%, $t(14) = 5.58$, $p < 0.001$, Cohen's $d = 1.44$—but no significant difference between the two control locations, $t(14) = 0.23$, $p = 0.819$, Cohen's $d = 0.06$. Thus, we obtained a strong perceptual benefit at the saccade target that was not modulated by whether objects were present at the beginning of a trial (Stable) or not (With Probe).

Perceptual difficulty and temporal and spatial probe/saccade characteristics

Figure 3C–3F illustrates average perceptual difficulty, saccade latency, time of saccade offset, and horizontal saccade landing error in the different conditions. Again, the same trial-exclusion criteria were applied as for the analysis on discrimination performance. Perceptual difficulty seemed slightly higher in the With Probe condition. The corresponding main effect of placeholder condition only approached significance, though: $F(1, 14) = 3.28$, $p = 0.092$, partial $\eta^2 = 0.19$. Figure 3D–3F shows that in the Stable condition compared to the With Probe condition, saccade latencies were significantly shorter, $F(1, 14) = 6.79$, $p = 0.021$, partial $\eta^2 = 0.33$; the perceptual target was presented closer in time to saccade initiation, $F(1, 14) = 7.87$, $p = 0.014$, partial $\eta^2 = 0.36$; and saccades landed closer to the target, $F(1, 14) = 5.50$, $p = 0.034$, partial $\eta^2 = 0.28$. Those results mimic the comparison between the Present and Absent conditions in Experiment 1, although numerically the differences are smaller.

For time of probe offset, there was additionally a significant main effect of probe location, $F(2, 28) = 3.69$, $p = 0.038$, partial $\eta^2 = 0.21$. No further effects or interactions reached significance for any of the variables (all Fs < 1.90, all ps > 0.167, all partial η^2s < 0.12).

Performance across time and space

Results across probe offset time and horizontal landing error are depicted in Figure 4. The same procedures were applied as in Figure 2. The time-course data illustrated in Figure 4A represent 76.0% of all trials. Both conditions show a benefit at the saccade target across a large range of probe offset times. Similarly, Figure 4B demonstrates a saccade-target benefit across a wide range of horizontal saccadic landing sites. The means are based on 69.9% of all trials.

Discussion

In Experiment 2, a perceptual advantage at the saccade target occurred regardless of whether objects were presented from the beginning of the trial, offering the visual system an object to focus on.[1] These findings speak against the object-selection hypothesis. Instead, the presence of the visual object at the time of the perceptual probe appeared to be driving the benefits found at the saccade target. This is in line with the notion that the placeholders were interfering with the perceptual task, an alternative we called the masking hypothesis. Just as for the interaction in Experiment 1, the effect size of the observed benefit at the saccade target (partial $\eta^2 = 0.69$ for the main effect of probe location) was comparable, but at the lower end of what we had observed in previous studies (between 0.70 and 0.85 for corresponding main effects without concurrent interactions; Born et al., 2012; Born et al., 2014; Puntiroli et al., 2015). Further, the saccade-target advantage was comparable across the Stable and With Probe conditions, despite differences in saccade latency, probe-to-saccade interval, and saccade landing error. It must be said, however, that those differences across conditions were numerically smaller than in Experiment 1. To consolidate our findings, we tested further predictions of the masking and object-selection hypotheses in Experiments 3 and 4.

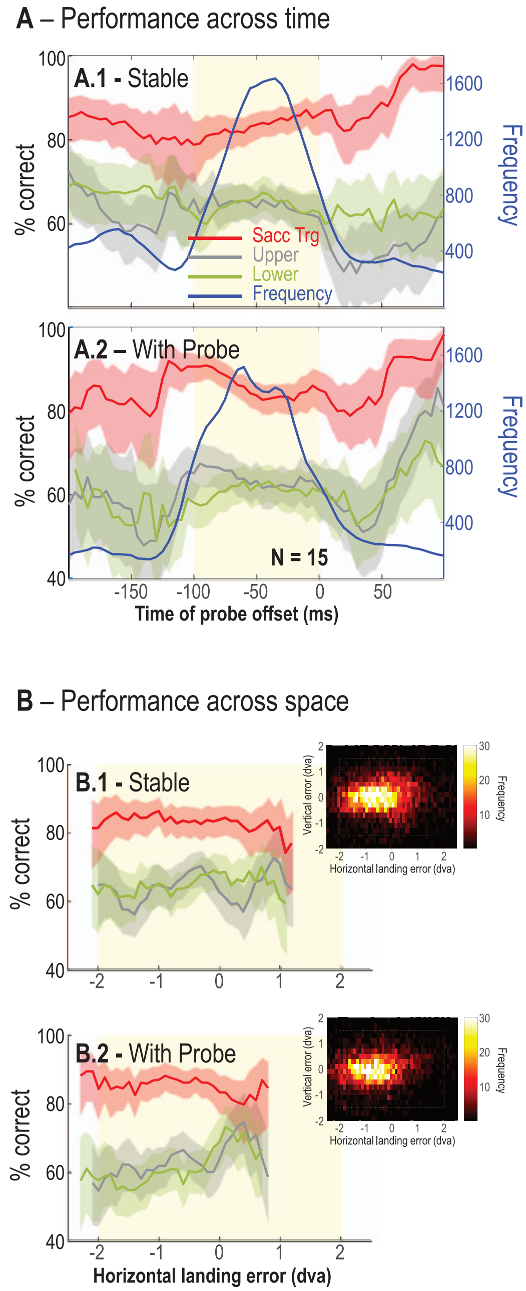

Figure 4. Discrimination performance in Experiment 2 across (A) probe offset time and (B) horizontal saccadic landing error. Conventions as in Figure 2.

Experiment 3

We tested three conditions in Experiment 3: First, we presented placeholders only at the two control locations (Stable Flankers), never at the saccade target. Without an object to focus on prior to the saccade, our object-selection hypothesis thus predicts no benefit at the saccade target. In contrast, the masking hypothesis predicts a large perceptual benefit at the saccade target, because it is the only location that is not masked by a placeholder and thus the only location that should not suffer from interference. Second, we presented placeholders at all three locations before, but not simultaneously with, the perceptual stimulus (Before Probe). Here the object-selection hypothesis predicts a stronger advantage at the saccade target than in the Stable Flankers condition, because an object is provided at the saccade target location to focus and bind attention prior to the saccade. In contrast, the masking hypothesis predicts a smaller advantage or none at all, as forward masking (i.e., presenting the mask before the target) is often weaker than the interference when mask and target temporally overlap (Breitmeyer & Öğmen, 2006). Third, we presented a single placeholder only around the saccade target and only during the time of probe presentation (Central Transient). Without an object to focus on prior to the saccade, the object-selection hypothesis predicts no perceptual benefit but also no disadvantage at the saccade target. In contrast, according to the masking hypothesis this condition may even lead to worse performance at the saccade target, as it is the only location with a masking placeholder and thus the only location that can suffer from its interference.

Method

Participants were 11 students of the University of Geneva (similar age range as in the previous experiments). The timing of events followed the previous experiments in that a 600-ms fixation display was followed by a 47- to 82-ms delay between fixation offset and probe display onset. The perceptual probes and distractors were presented for 47 ms, followed by a 600-ms delay before the response display was shown. Participants were tested across the three conditions described (see also Figure 5A). As before, participants were instructed in all three conditions to make an eye movement to the center of the screen as soon as the fixation cross disappeared and to judge the direction of the probe's lateral shift at the end of the trial. Participants completed six to nine blocks of 90 trials in total (at least two in each condition) for a total duration of around 60 to 90 min (one or two sessions).

Results

Excluded trials

The same criteria for participant feedback and exclusion of trials were applied as in Experiments 1 and 2. Accordingly, 46.4% of trials (Stable Flankers: 41.9%, Before Probe: 55.6%, Central Transient: 37.3%) were excluded from analysis in Experiment 3: 7.8% due to breaks of fixation or blinks, 37.9% due to perceptual probes being presented more than 100 ms before

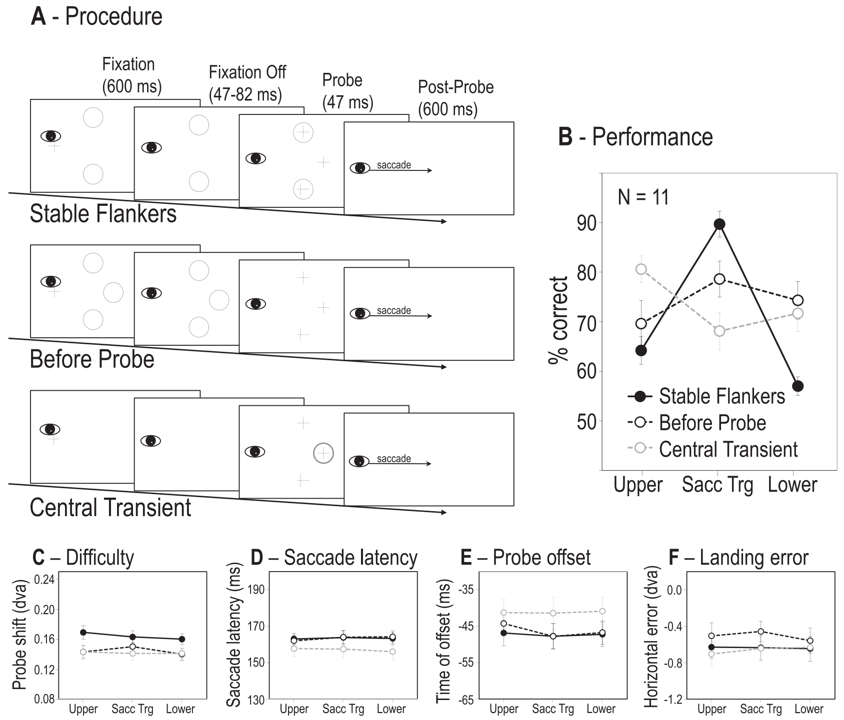

Figure 5. Results of Experiment 3. (A) Schematic illustration of the procedure. (B) Percentage of correct responses as a function of probe location and placeholder condition. (C) Difficulty: Degree of asymmetry of the probe required to obtain 71% correct responses in a block. (D) Average saccade latency. (E) Average time of probe offset with respect to saccade onset. (F) Average horizontal saccade landing error. Conventions as in Figure 2.

saccade onset or during or after the saccade, and 0.8% due to saccades landing more than 2° va horizontally or 1.5° va vertically from the screen center. There were two participants with a comparable low number of valid trials in all conditions: seven to 22 trials. On average, the means entered into ANOVAs of the main analysis were based on 40 trials per condition and participant.

Presaccadic perceptual discrimination performance

Figure 5B shows performance in the different conditions of Experiment 3. The corresponding 3 (placeholder condition: Stable Flankers, Before Probe, Central Transient) × 3 (probe position: Upper, saccade target, Lower) repeated-measures ANOVA on perceptual performance revealed no significant main effect of placeholder condition, $F(2, 20) = 2.74$, $p = 0.089$, partial $\eta^2 = 0.22$, but a significant main effect of probe location, $F(2, 20) = 4.04$, $p = 0.034$, partial $\eta^2 = 0.29$, and a significant interaction, $F(4, 40) = 12.87$, $p < 0.001$, partial $\eta^2 = 0.56$. Follow-up paired-samples t tests confirmed significantly better performance at the saccade target (89.7% correct) than both control locations in the Stable Flankers condition, $ts(10) > 5.61$, $ps < 0.001$, Cohen's $ds > 1.69$, and likewise significantly better performance at the Upper (64.2%) compared to the Lower control location (57.0%), $t(10) = 2.65$, $p = 0.024$, Cohen's $d = 0.80$. In contrast, there were no significant differences across locations in the Before Probe condition (Upper, saccade target, and Lower: 69.6%, 78.6%, and 74.3%), $ts(10) < 1.43$, $ps > 0.183$, Cohen's $ds < 0.43$. For the Central Transient condition, performance at the saccade target (68.1%) was significantly worse than at the Upper control location (80.6%), $t(10) = 2.38$, $p = 0.038$, Cohen's $d = 0.72$, but the difference from the Lower control was not significant (71.7%), $t(10) = 0.54$, $p = 0.599$, Cohen's $d = 0.16$. The differences between Upper and Lower control locations was also not significant, $t(10) = 1.73$, $p = 0.115$, Cohen's $d = 0.52$.

Perceptual difficulty and temporal and spatial probe/saccade characteristics

Figure 5C–5F illustrates average perceptual difficulty, saccade latency, time of saccade offset, and horizontal saccade landing error in the different conditions. Perceptual difficulty seemed slightly higher in the Stable Flankers condition compared to the other two. The main effect of placeholder condition only approached significance, $F(2, 20) = 3.03$, $p = 0.071$, partial $\eta^2 = 0.23$. This main effect also approached significance for saccade latency, $F(2, 20) = 2.68$, $p = 0.093$, partial $\eta^2 = 0.21$, and saccade landing error, $F(2, 20) = 3.14$, $p = 0.065$, partial $\eta^2 = 0.24$. No further main effects or interactions were significant (all other Fs < 2.34, ps > 0.120, partial η^2s < 0.19).

Performance across time and space

Results across probe offset time and horizontal landing error are depicted in Figure 6. The same procedures were applied as in the previous experiments. The time-course data illustrated in Figure 6A represent 85.0% of all trials (lines are truncated in Figure 6A, as data are depicted only from the first to the last bin containing at least 50 trials, just as for performance across space; in the previous experiments, none of the bins between –200 and +100 ms had fewer than 50 trials). The data across horizontal landing error are based on 71.2% of all trials. Whereas the Stable Flankers condition showed a benefit at the saccade target across both time and space, the small advantage in the Before Probe condition and the small disadvantage in the Central Transient condition rarely if ever reached a level where the confidence intervals did not overlap with those from the other conditions.

Discussion

Overall, the predictions from our object-selection hypothesis did not hold, but results broadly confirmed the alternative masking hypothesis: Even without an object being present at the saccade target location upon which attentional resources could focus, there was a huge perceptual advantage when only the control locations were demarked by placeholders (Stable Flankers). On the contrary, in the Before Probe condition—where placeholders were presented before the probe display—the advantage was strongly reduced, to the extent that it was no longer statistically significant, just as in the Absent condition of Experiment 1. In the third condition—where a placeholder was presented only at the saccade target at the time of the probe (Central Transient)—performance was again similar across probed locations. Figure 5B illustrates that the saccade target location was associated with the worst performance, which is what we predicted according to the masking hypothesis. Statistically, it was only the Upper control location that differed significantly from the saccade target, and the result should therefore be regarded with some caution. We speculate that the rather weak disadvantage could mean that the interference from the placeholder at the saccade target can almost be completely overcome by presaccadic attention.

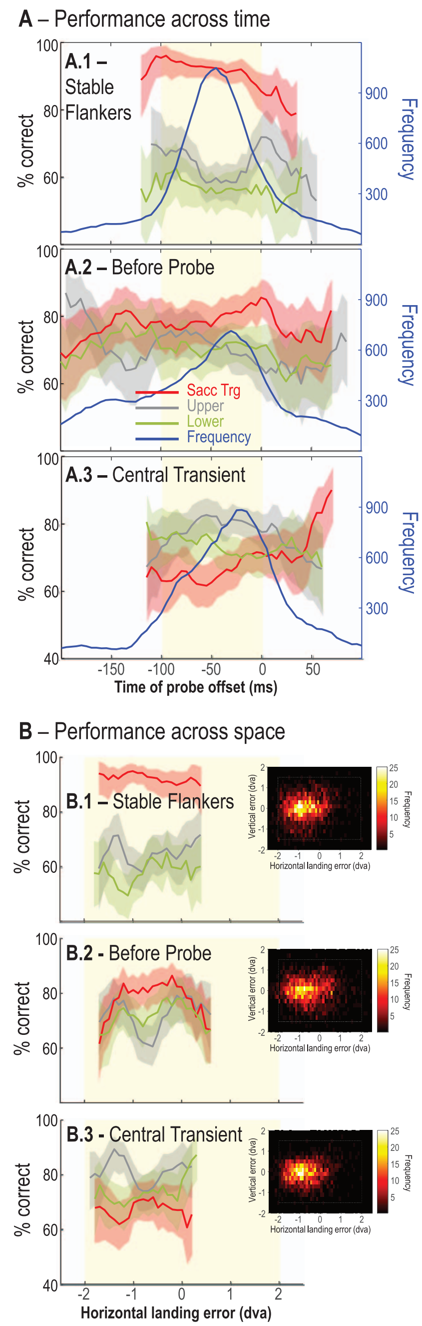

Figure 6. Discrimination performance in Experiment 3 across (A) probe offset time and (B) horizontal saccadic landing error. Conventions as in Figure 2.

Experiment 4

In a final experiment pitting our object-selection hypothesis against the alternative masking hypothesis, we examined whether the placeholders necessarily needed to surround the perceptual stimuli to produce a presaccadic benefit. Two stimulus configurations were compared (see Figure 7A). In the Radial condition, the saccade target was flanked by two circles on the

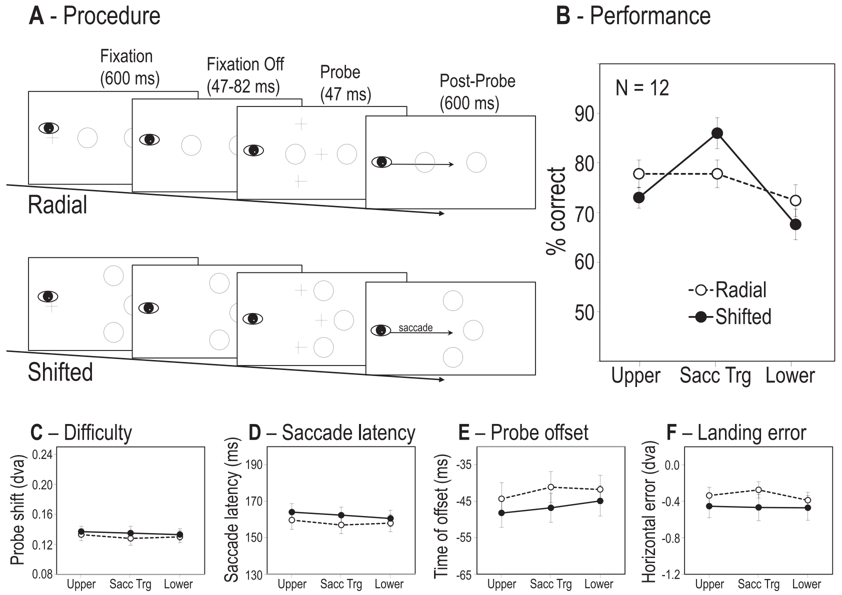

Figure 7. Results of Experiment 4. (A) Schematic illustration of the procedure. (B) Percentage of correct responses as a function of probe location and placeholder condition. (C) Difficulty: Degree of asymmetry of the probe required to obtain 71% correct responses in a block. (D) Average saccade latency. (E) Average time of probe offset with respect to saccade onset. (F) Average horizontal saccade landing error. Conventions as in Figure 2.

horizontal meridian, one closer to and one farther from fixation. From a masking perspective, radially arranged stimuli are known to produce more interference than tangentially arranged stimuli (Toet & Levi, 1992). Therefore, this arrangement should mostly affect the saccade target and thus produce similar results as the Central Transient condition from Experiment 3. In the Shifted condition, one circle was placed beside each cross, which may give rise to lateral masking of all crosses and thus result again in a perceptual advantage at the saccade target. From an object-selection perspective, neither of the two arrangements may produce a saccade-target benefit, since none of the circles demarks the location targeted by the saccade; thus, if attention is deployed to objects (i.e., one of the circles), a probe presented not within but only nearby the object may not benefit from it. Recall that enhancement at the saccade target in previous studies was always narrowly confined within a small area (Baldauf & Deubel, 2008; Deubel & Schneider, 1996; Godijn & Theeuwes, 2003; Kowler et al., 1995). Alternatively, one may also assume that if no object is presented exactly at the intended location targeted by the saccade, focused attention may not be deployed at all.

Method

Participants in Experiment 4 were 12 students at the University of Geneva. The timing of events was the same as in Experiments 2 and 3 (see Figure 7A). In the Radial condition, placeholders were present on either side (2° va left and right) of the saccade target from the beginning of the trial. In the Shifted condition, placeholders were displayed 2° va to the right (i.e., more peripheral) of the tested locations. Participants were told in advance that none of the circles was displayed at the tested locations. In both conditions, participants were instructed to make an eye movement to the center of the screen (i.e., between the two placeholders in the Radial condition, slightly short of the central placeholder in the Shifted condition) when the fixation cross disappeared. Participants completed four to six blocks of 90 trials (at least two in in each condition) for a total duration of around 30 to 60 min, run in a single session.

Results

Trial exclusion

In total, 42.6% of trials (Radial: 43.0%, Shifted: 42.2%) were excluded from analysis in Experiment 4: 3.5% due to breaks of fixation or blinks, 38.0% due to perceptual probes being presented more than 100 ms before or after saccade onset, and 1.1% due to saccades landing more than 2° va horizontally or 1.5° va vertically from the screen center. After trial exclusion, the means entered into the ANOVAs were based on a minimum of 17 trials per condition and participant (37 trials on average).

Presaccadic perceptual discrimination performance

Figure 7B shows performance in the different conditions of Experiment 4. The 2 (placeholder condition: Radial, Shifted) × 3 (Probe position: Upper control, saccade target, Lower control) repeated-measures ANOVA revealed a significant main effect of probe location, $F(2, 22) = 4.30$, $p = 0.027$, partial $\eta^2 = 0.28$, and a significant interaction, $F(2,22) = 4.41$, $p = 0.025$, partial $\eta^2 = 0.29$. The main effect of placeholder condition was not significant, $F(1,11) = 0.18$, $p = 0.678$, partial $\eta^2 = 0.02$. Paired-samples t tests to follow up on the interaction revealed that there were no significant differences in performance across location in the Radial condition (Upper, saccade target, and Lower: 77.8%, 77.8%, and 72.4%), ts(11) < 1.07, ps > 0.308, Cohen's ds < 0.31. In contrast, performance in the Shifted condition was significantly better at the saccade target (86.0%) than either control location, ts(11) > 2.94, ps < 0.013, Cohen's ds > 0.85. The difference between Upper (73.0%) and Lower (67.6%) control locations was not significant, $t(11) = 1.28$, $p = 0.226$, Cohen's $d = 0.37$.

Perceptual difficulty and temporal and spatial probe/saccade characteristics

Figure 7C–7F illustrates average perceptual difficulty, saccade latency, time of saccade offset, and horizontal saccade landing error. Perceptual difficulty seemed more or less equal across locations. For the average saccade latency, time of probe offset, and saccade landing error, small differences were observed. Accordingly, for latency and time of probe offset, significant main effects of placeholder condition emerged—latency: $F(1, 11) = 4.81$, $p = 0.051$, partial $\eta^2 = 0.30$; probe-to-saccade: $F(1, 11) = 6.27$, $p = 0.029$, partial $\eta^2 = 0.36$—as did significant (or nearly significant) main effects of probe position—latency: $F(2, 22) = 2.77$, $p = 0.084$, partial $\eta^2 = 0.20$; probe-to-saccade: $F(2, 22) = 4.10$, $p = 0.031$, partial $\eta^2 = 0.27$). For landing error, a significant interaction emerged, $F(2, 22) = 6.01$, $p = 0.008$, partial $\eta^2 = 0.35$. No further main effect or interaction was significant for any of the measures (Fs < 2.55, ps > 0.101, partial η^2s < 0.19).

Performance across time and space

Results across probe offset time and horizontal landing error are depicted in Figure 8. The same procedures were applied as in the previous experiments. The time-course data illustrated in Figure 8A represent 90.9% of all trials. The data across horizontal landing error are based on 69.5% of all trials. Whereas the Shifted condition showed a benefit at the saccade target consistently across both time and space, the Radial condition did not show such a benefit.

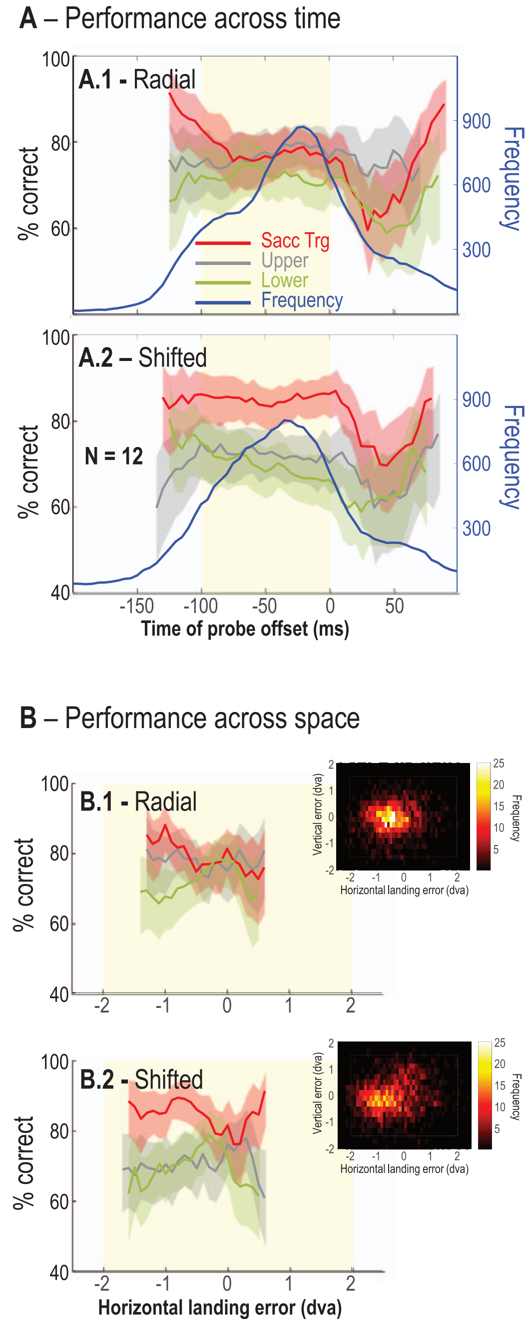

Figure 8. Discrimination performance in Experiment 4 across (A) probe offset time and (B) horizontal saccadic landing error. Conventions as in Figure 2.

Discussion

The results from Experiment 4 did not follow the object-selection hypothesis, but rather the alternative masking hypothesis. Further, Experiment 4 showed that the presaccadic advantage at the saccade target can be found even when the masking objects do not surround the probes, but instead only appear beside them. Similar to the previous experiments, a presaccadic benefit at the saccade target occurred when all three potential probe locations were masked by nearby placeholders (Shifted condition). The benefit was significantly reduced when only the saccade target was masked (Radial condition). Overall, the results emphasize that the placeholders affected the stimuli beyond the boundaries of their contours—that is, even when mask and perceptual target were most likely interpreted as two separate objects.

General discussion

In four experiments, we have found that the presence of placeholder objects promotes a perceptual advantage at the target for a saccadic eye movement compared to other locations. Initially, we hypothesized that placeholders might be critical as anchors to focus and bind visual attention to the saccade target prior to the eye movement. However, the object-selection hypothesis did not provide a good explanation for the observed differences between conditions with and without placeholders. Probably the strongest evidence against this hypothesis is seen when comparing Experiments 1 and 2: In both the Absent and With Probe conditions, there were no objects to bind attention prior to the presentation of the perceptual probe. Nevertheless, the With Probe condition produced enhancement of the saccade target similar to a condition with placeholders from the beginning of the trial. In the Absent condition, however, this enhancement was greatly reduced. In contrast, in the Before Probe condition from Experiment 3 placeholders were presented at the beginning of a trial and no strong saccade target benefit was observed.

Instead, our findings are better explained by an alternative account we termed the masking hypothesis. Placeholders may produce spatiotemporal interference that diminishes the discriminability of the perceptual probe, akin to a masking or crowding effect. This interference may be overcome at the saccade target through the presaccadic attention shift. Accordingly, whenever placeholders temporally overlapped with the probe and were presented either at all three locations or at only the two control locations, the saccade-target benefit was strong. Conversely, when objects were presented only around the saccade target (the Central Transient condition in Experiment 3 and the Radial condition in Experiment 4), the benefit was substantially reduced.

Object-selection effects in other studies

In the current study, masking or crowding provided a better explanation for our findings than object selection. In other paradigms, however, the use of placeholders has been manipulated, and results interpreted in terms of object selection. Can these results also be interpreted as masking effects?

For instance, in a transsaccadic-cuing paradigm, Lisi et al. (2015) found a benefit in discriminating the orientation of a Gabor target at the spatiotopic location of a previously presented cue only when placeholders were continuously presented. They argued that spatial updating of attention across saccades is promoted by visual objects. In light of the current findings, an alternative explanation of their findings could be that attention was deployed (and successfully updated) in both the placeholder-present and -absent conditions. But in the placeholder-absent condition it did not show, as there was no way for attention to improve the perceptual representation by diminishing the placeholder's masking effect on target identification. Unlike our own study, however, there is no indication in the data of Lisi et al. that the placeholders did actually have a detrimental effect in their particular task: Performance at noncued locations was similar with and without placeholders.

As a further example, Woodman et al. (2009) observed a lateralized anticipatory ERP component related to a previously presented 100% valid cue when the locations of the upcoming target and distractors were marked by placeholders. This component was not observed without placeholders, and the researchers concluded that the corresponding attentional mechanism is deployed to objects, not locations in space. This finding is hard to explain by a masking account, unless one assumes that the ERP component reflects some sort of anticipatory mechanism to prepare for the detrimental masking effect of the placeholder on the upcoming target. And even this account could be rephrased as reflecting an attentional mechanism needing an object to focus on to be effective. Thus, we acknowledge that although the current findings could not be explained by object selection, this does not exclude the possibility that object selection may have played a role in other studies.

Masking by placeholders in previous presaccadic-attention studies?

In sum, our results indicate that a contributing factor to the well-known presaccadic benefit at the saccade target is a process that diminishes the masking effect that arises from placeholder objects surrounding perceptual stimuli. May previous findings also be explained by such an effect? Indeed, the use of placeholders is ubiquitous in presaccadic-attention studies, although some studies did not necessarily present outline placeholders that surrounded the stimuli (e.g., the "pre-masks" of Kowler et al., 1995). From the studies using a similar dual saccade/discrimination task as we did here, we are unaware of any single presaccadic-attention study that did not use placeholders (but see Puntiroli, Deubel, & Szinte, 2017). However, to conclude that previous effects can entirely be explained through masking by placeholders would be premature based on the current findings. First, the outline placeholders we used were quite thick, whereas previous studies often used finer outlines. Second, in most studies, not only placeholders but also additional forward and/or backward masks were used (e.g., figure 8s in Deubel & Schneider, 1996). It is not clear what outline placeholders can do over and above the effect of those temporal masks. While our Before Probe condition suggests that forward masking has only a small impact, backward masking may have very specific effects before eye movements (see later). Third, we used high-contrast probes consisting of two lines. In this respect, they were similar to the letters or digital numbers used in early studies (Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995). It remains to be seen, however, whether our results generalize to other stimuli (e.g., Gabor patches; see next subsection).

Mechanisms of presaccadic enhancement

Having rejected the object-selection hypothesis, and given the overwhelming evidence from previous studies that the presaccadic attention shift is obligatory, we assume that attention has shifted toward the saccade target in all our conditions. If so, how can the lack of benefit at the saccade target be explained when no placeholders were presented simultaneously with the probe? We believe that in this situation, the presaccadic attention shift may simply not have been effective in improving the probe's perceptual representation in a way that could increase performance. This ineffectiveness of attention is a result of the specific probe stimuli (i.e., high-contrast crosses) and discrimination task (i.e., judgement of asymmetry) we chose, along with the mechanism behind presaccadic facilitation.

In principle, the same processes have been evoked to explain presaccadic perceptual facilitation and effects of covert attention. To give just one example, it has been suggested that covert as well as presaccadic attention increases contrast sensitivity (for reviews, see Carrasco, 2011; Zhao, Gersch, Schnitzer, Dosher, & Kowler, 2012). If we assume that our placeholders produced masking effects that reduced the visibility of the perceptual probes within (Breitmeyer & Öğmen, 2006), including their perceived contrast, then higher contrast sensitivity at the saccade target may produce a benefit. In the Absent condition, however—where no placeholders reduced the perceived contrast—higher contrast sensitivity at the saccade target may simply not have any effect, as the contrast of the probes was well above threshold and thus no presaccadic advantage was found. Following this reasoning, saccade-target benefits without placeholders could potentially be observed if probes that profit more from contrast enhancement, such as Gabors, are used in saccadic tasks. Note that this is only an example to illustrate how presaccadic attention may be ineffective on some stimuli. It is important to keep in mind that, just as for covert attention, multiple mechanisms are likely to be at play in presaccadic facilitation (Zhao et al., 2012). By comparing different stimuli and different tasks, we may be able to isolate or at least narrow down the underlying processes.

In comparison with previous studies, one aspect of our findings could initially appear surprising: We did not find the typical buildup of presaccadic attention effects across time (i.e., increasing performance as the probe was presented closer to saccade onset). One possibility is that, in general, we probed too close to saccade onset. While most previous studies have found a buildup across the last 150–200 ms before the saccade (e.g., Born et al., 2013; Jonikaitis et al., 2017; Rolfs et al., 2010), an earlier buildup with stable performance across the last 200 ms has been observed as well (see Deubel, 2008, experiment 1). The lack of modulation across time may also have been due to the saccade target location being fixed. In studies reporting the typical buildup, the location of the saccade target has usually varied across trials (e.g., Born et al., 2013; Deubel, 2008; Jonikaitis et al., 2017; Rolfs et al., 2010). Also, stimuli were presented in only one hemifield in our study, whereas previous studies have mostly arranged the stimuli in a circle around fixation. Continuously high performance at the saccade target has been reported in one condition (Deubel, 2008, experiment 2). In this condition, the saccade target location was fixed, and an exogenous cue indicated with 100% validity that the perceptual probe would also appear in that location, such that attention could be narrowly focused on the corresponding object. One may wonder whether the lack of modulation across time in our experiments indicates that participants simply never tried to spread covert attention evenly across locations in the conditions where we found a presaccadic benefit. Instead, participants may have decided to concentrate only on the saccade target throughout those blocks. While this might be the case, we cannot think of a good explanation why participants should use this strategy, for instance, in the With Probe condition of Experiment 2 but not the Absent condition of Experiment 1.

Potential mechanisms of masking by placeholders

In the current experiments, we focused on disentangling the object-selection hypothesis from the alternative masking hypothesis. Many different masking phenomena have been described in the literature (Breitmeyer & Öğmen, 2006), and our experiments were not designed to discern any of those in particular. Reminiscent of procedures used to study para- or metacontrast masking (Breitmeyer & Öğmen, 2006; Enns, 2004), lateral masking (Lev & Polat, 2015), and crowding (Herzog, Sayim, Chicherov, & Manassi, 2015; Pelli et al., 2004; Whitney & Levi, 2011), our placeholders did not spatially overlap with the discrimination stimuli; rather, they either surrounded them (Experiments 1–3) or were presented beside them (Experiment 4). One difficulty in comparing our findings to typical masking effects is that the latter are often examined and characterized by comparing their time course across conditions (Breitmeyer & Öğmen, 2006): The target and mask are only briefly flashed, and presented at different stimulus-onset asynchronies. Based on the current findings, we do not think it possible to pinpoint a specific phenomenon. To test which specific masking mechanisms may affect our probes and be overcome by presaccadic attention, future experiments should, for instance, include a manipulation of stimulus asynchrony between the placeholders and the probe. Further, to differentiate between masking and crowding, a manipulation of similarity between placeholders and probes (e.g., squares instead of circles) could be done. This could be compared to conditions where the strength of mask and probe signals are manipulated. Crowding is strongest when targets and flankers are similar; masking is strongest when the mask signal is stronger than the target signal (Ağaoğlu & Chung, 2017; Pelli et al., 2004).

It needs to be mentioned that there is now an abundance of recent studies that have examined how masking or crowding effects are modulated in the context of saccades (Ağaoğlu et al., 2016; Ağaoğlu & Chung, 2017; Buonocore, Fracasso, & Melcher, 2017; De Pisapia, Kaunitz, & Melcher, 2010; Fracasso, Kaunitz, & Melcher, 2015; Harrison, Mattingley, & Remington, 2013; Harrison, Retell, Remington, & Mattingley, 2013; Hunt & Cavanagh, 2011; Wolfe & Whitney, 2014). However, we do not think the current results can contribute to the specific debates opened up by these studies, as those studies differ in one important aspect from the current experiments: They tested performance at one single location (either the saccade target or elsewhere) and compared it to a fixation condition or across time to saccade onset. In other words, they did not compare performance at the saccade target to nontarget locations,[2] as we did in the current studies. Further, the authors of those studies relate their findings to saccade-specific phenomena like saccadic suppression (Matin, 1974; Ross, Morrone, Goldberg, & Burr, 2001), saccadic compression of space (Ross et al., 1997), the influence of receptive-field shifts and corollary discharge on perception (Sommer & Wurtz, 2008), and predictive remapping of attention (Cavanagh, Hunt, Afraz, & Rolfs, 2010). It is to a large degree unclear how those effects and the underlying processes differ across different locations. Also, most accounts depend on an asynchronous presentation of probe and mask (e.g., such that only one or the other falls into the critical interval for suppression) and/or even shorter presentation durations of the perceptual stimuli than our 47 ms (Born, Krüger, Zimmermann, & Cavanagh, 2016). Our own study followed in its design the classic presaccadic-attention studies that compare performance at the saccade target to performance at other locations (e.g., Deubel & Schneider, 1996; Hoffman & Subramaniam, 1995; Kowler et al., 1995). The saccade-target benefit is attributed to a shift of covert attention that cannot be suppressed. The rationale for terming it a saccadic effect is that a substantial share of attentional resources is deployed to the saccade target despite a strong incentive to spread attention broadly across multiple objects because all objects have the same chance of containing the target. The nature and origin of those effects are not necessarily different from those of covert attention without eye movements (although they may be of different strength; Khan et al., 2015).

In sum, our experiments contribute to the growing body of evidence indicating that the use or nonuse of placeholders in the design of a study can have substantial influence on the outcome. We conclude by agreeing with Taylor et al. (2015) that, given the ubiquitous use of placeholders in many perceptual or cognitive paradigms, one is left to wonder how the outcome and standard interpretation of some classic tasks would differ if placeholders had not been presented.

Keywords: spatial attention, saccades, perceptual enhancement, object selection, masking, placeholders

Acknowledgments

This work was supported by the Swiss National Science Foundation (MP, DK and SB: 100014_140379 and SB: PZ00P1_161224).

Commercial relationships: none.
Corresponding author: Sabine Born.
Email: sabine.born@unige.ch.

Address: Faculty of Psychology and Educational Sciences, University of Geneva, Geneva, Switzerland.

Footnotes

[1] A second variant of Experiment 2 was run with nine participants where the placeholders were not extinguished together with the perceptual probes but stayed on during the 600-ms postprobe delay period in both conditions. Results of this variant were the same as for the experiment described in the text. Further, putting data from both versions together and including variant as a between-subjects factor in the analyses confirmed the described effects and did not reveal any further result that may affect our main conclusions. For brevity, we therefore report only the first variant.

[2] An exception is the study by Buonocore et al. (2017). In their experiment 4, they compared performance in a Gabor tilt-discrimination task at the saccade goal and a nontarget location. There was a general benefit at the saccade goal and increasing interference from flankers with decreasing probe-to-saccade intervals. It remains somewhat unclear whether those two effects interacted.

References

Ağaoğlu, M. N., & Chung, S. T. (2017). Interaction between stimulus contrast and pre-saccadic crowding. *Royal Society Open Science*, *4*(2), 160559, https://doi.org/10.1098/rsos.160559.

Ağaoğlu, M. N., Öğmen, H., & Chung, S. T. (2016). Unmasking saccadic uncrowding. *Vision Research*, *127*, 152–164, https://doi.org/10.1016/j.visres.2016.08.003.

Awh, E., Armstrong, K. M., & Moore, T. (2006). Visual and oculomotor selection: Links, causes and implications for spatial attention. *Trends in Cognitive Sciences*, *10*(3), 124–130, https://doi.org/10.1016/j.tics.2006.01.001.

Baldauf, D., & Deubel, H. (2008). Properties of attentional selection during the preparation of sequential saccades. *Experimental Brain Research*, *184*(3), 411–425, https://doi.org/10.1007/s00221-007-1114-x.

Becker, W. (1989). Metrics. In R. H. Wurtz & M. E. Goldberg (Eds.), *The neurobiology of saccadic eye movements* (pp. 13–67). Amsterdam: Elsevier.

Blangero, A., Khan, A. Z., Salemme, R., Deubel, H., Schneider, W. X., Rode, G., … Pisella, L. (2010). Pre-saccadic perceptual facilitation can occur without covert orienting of attention. *Cortex*, *46*(9), 1132–1137, https://doi.org/10.1016/j.cortex.2009.06.014.

Born, S., Ansorge, U., & Kerzel, D. (2012). Feature-based effects in the coupling between attention and saccades. *Journal of Vision*, *12*(11):27, 1–17, https://doi.org/10.1167/12.11.27. [PubMed] [Article]

Born, S., Ansorge, U., & Kerzel, D. (2013). Predictability of spatial and non-spatial target properties improves perception in the pre-saccadic interval. *Vision Research*, *91*, 93–101, https://doi.org/10.1016/j.visres.2013.08.003.

Born, S., Krüger, H. M., Zimmermann, E., & Cavanagh, P. (2016). Compression of space for low visibility probes. *Frontiers in Systems Neuroscience*, *10*, 21, https://doi.org/10.3389/fnsys.2016.00021.

Born, S., Mottet, I., & Kerzel, D. (2014). Presaccadic perceptual facilitation effects depend on saccade execution: Evidence from the stop-signal paradigm. *Journal of Vision*, *14*(3):7, 1–10, https://doi.org/10.1167/14.3.7. [PubMed] [Article]

Brainard, D. H. (1997). The Psychophysics Toolbox. *Spatial Vision*, *10*(4), 433–436, https://doi.org/10.1163/156856897X00357.

Breitmeyer, B. G., & Öğmen, H. (2006). *Visual masking: Time slices through conscious and unconscious vision* (2nd ed.). Oxford, UK: Oxford University Press.

Buonocore, A., Fracasso, A., & Melcher, D. (2017). Pre-saccadic perception: Separate time courses for enhancement and spatial pooling at the saccade target. *PLoS One*, *12*(6), e0178902, https://doi.org/10.1371/journal.pone.0178902.

Carrasco, M. (2011). Visual attention: The past 25 years. *Vision Research*, *51*(13), 1484–1525, https://doi.org/10.1016/j.visres.2011.04.012.

Cavanagh, P., Hunt, A. R., Afraz, A., & Rolfs, M. (2010). Visual stability based on remapping of attention pointers. *Trends in Cognitive Sciences*, *14*(4), 147–153, https://doi.org/10.1016/j.tics.2010.01.007.

Corbetta, M. (1998). Frontoparietal cortical networks for directing attention and the eye to visual locations: Identical, independent, or overlapping neural systems? *Proceedings of the National Academy of Sciences, USA*, *95*(3), 831–838.

Cornelissen, F. W., Peters, E. M., & Palmer, J. (2002). The Eyelink Toolbox: Eye tracking with MATLAB and the Psychophysics Toolbox. *Behavior Research Methods, Instruments and Computers*, *34*(4), 613–617, https://doi.org/10.3758/BF03195489.

De Pisapia, N., Kaunitz, L., & Melcher, D. (2010).

Backward masking and unmasking across saccadic eye movements. *Current Biology*, *20*(7), 613–617, https://doi.org/10.1016/j.cub.2010.01.056.

Deubel, H. (2008). The time course of presaccadic attention shifts. *Psychological Research*, *72*(6), 630–640, https://doi.org/10.1007/s00426-008-0165-3.

Deubel, H., & Schneider, W. X. (1996). Saccade target selection and object recognition: Evidence for a common attentional mechanism. *Vision Research*, *36*(12), 1827–1837, https://doi.org/10.1016/0042-6989(95)00294-4.

Doré-Mazars, K., Pouget, P., & Beauvillain, C. (2004). Attentional selection during preparation of eye movements. *Psychological Research*, *69*(1–2), 67–76, https://doi.org/10.1007/s00426-003-0166-1.

Enns, J. T. (2004). Object substitution and its relation to other forms of visual masking. *Vision Research*, *44*(12), 1321–1331, https://doi.org/10.1016/j.visres.2003.10.024.

Fracasso, A., Kaunitz, L., & Melcher, D. (2015). Saccade kinematics modulate perisaccadic perception. *Journal of Vision*, *15*(3):4, 1–12, https://doi.org/10.1167/15.3.4. [PubMed] [Article]

Godijn, R., & Theeuwes, J. (2003). Parallel allocation of attention prior to the execution of saccade sequences. *Journal of Experimental Psychology: Human Perception and Performance*, *29*(5), 882–896, https://doi.org/10.1037/0096-1523.29.5.882.

Harrison, W. J., Mattingley, J. B., & Remington, R. W. (2013). Eye movement targets are released from visual crowding. *The Journal of Neuroscience*, *33*(7), 2927–2933, https://doi.org/10.1523/JNEUROSCI.4172-12.2013.

Harrison, W. J., Retell, J. D., Remington, R. W., & Mattingley, J. B. (2013). Visual crowding at a distance during predictive remapping. *Current Biology*, *23*(9), 793–798, https://doi.org/10.1016/j.cub.2013.03.050.

Herzog, M. H., Sayim, B., Chicherov, V., & Manassi, M. (2015). Crowding, grouping, and object recognition: A matter of appearance. *Journal of Vision*, *15*(6):5, 1–18, https://doi.org/10.1167/15.6.5. [PubMed] [Article]

Hoffman, J. E., & Subramaniam, B. (1995). The role of visual attention in saccadic eye movements. *Perception and Psychophysics*, *57*(6), 787–795, https://doi.org/10.3758/BF03206794.

Hunt, A. R., & Cavanagh, P. (2011). Remapped visual masking. *Journal of Vision*, *11*(1):13, 1–8, https://doi.org/10.1167/11.1.13. [PubMed] [Article]

Hunt, A. R., & Kingstone, A. (2003). Covert and overt voluntary attention: Linked or independent? *Cognitive Brain Research*, *18*(1), 102–105, https://doi.org/10.1016/j.cogbrainres.2003.08.006.

Jonikaitis, D., Klapetek, A., & Deubel, H. (2017). Spatial attention during saccade decisions. *Journal of Neurophysiology*, *118*(1), 149–160, https://doi.org/10.1152/jn.00665.2016.

Khan, A. Z., Blohm, G., Pisella, L., & Munoz, D. P. (2015). Saccade execution suppresses discrimination at distractor locations rather than enhancing the saccade goal location. *European Journal of Neuroscience*, *41*(12), 1624–1634, https://doi.org/10.1111/ejn.12923.

Klapetek, A., Jonikaitis, D., & Deubel, H. (2016). Attention allocation before antisaccades. *Journal of Vision*, *16*(1):11, 1–16, https://doi.org/10.1167/16.1.11. [PubMed] [Article]

Klein, R. M., & Pontefract, A. (1994). Does oculomotor readiness mediate cognitive control of visual attention? Revisited! In C. Umilta & M. Moscovitch (Eds.), *Attention & performance XV: Conscious and unconscious processing* (pp. 333–350). Cambridge, MA: MIT Press.

Kleiner, M., Brainard, D., & Pelli, D. (2007). What's new in Psychtoolbox-3? *Perception*, *36*, ECVP abstract supplement.

Kowler, E., Anderson, E., Dosher, B., & Blaser, E. (1995). The role of attention in the programming of saccades. *Vision Research*, *35*(13), 1897–1916, https://doi.org/10.1016/0042-6989(94)00279-U.

Lev, M., & Polat, U. (2015). Space and time in masking and crowding. *Journal of Vision*, *15*(13):10, 1–25, https://doi.org/10.1167/15.13.10. [PubMed] [Article]

Lisi, M., Cavanagh, P., & Zorzi, M. (2015). Spatial constancy of attention across eye movements is mediated by the presence of visual objects. *Attention, Perception & Psychophysics*, *77*(4), 1159–1169, https://doi.org/10.3758/s13414-015-0861-1.

Matin, E. (1974). Saccadic suppression: A review and an analysis. *Psychological Bulletin*, *81*(12), 899–917.

Montagnini, A., & Castet, E. (2007). Spatiotemporal dynamics of visual attention during saccade preparation: Independence and coupling between attention and movement planning. *Journal of Vision*, *7*(14):8, 1–16, https://doi.org/10.1167/7.14.8. [PubMed] [Article]

Pelli, D. G., Palomares, M., & Majaj, N. J. (2004). Crowding is unlike ordinary masking: Distinguishing feature integration from detection. *Journal of Vision*, *4*(12):12, 1136–1169, https://doi.org/10.1167/4.12.12. [PubMed] [Article]

Puntiroli, M., Deubel, H., & Szinte, M. (2018). *Visual* *targets prevent presaccadic attention from spreading to the periphery*. Manuscript in preparation.

Puntiroli, M., Kerzel, D., & Born, S. (2015). Perceptual enhancement prior to intended and involuntary saccades. *Journal of Vision*, *15*(4):2, 1–20, https://doi.org/10.1167/15.4.2. [PubMed] [Article]

Rolfs, M., Jonikaitis, D., Deubel, H., & Cavanagh, P. (2010). Predictive remapping of attention across eye movements. *Nature Neuroscience*, *14*(2), 252–256, https://doi.org/10.1038/nn.2711.

Ross, J., Morrone, M. C., & Burr, D. C. (1997). Compression of visual space before saccades. *Nature*, *386*(6625), 598–601, https://doi.org/10.1038/386598a0.

Ross, J., Morrone, M. C., Goldberg, M. E., & Burr, D. C. (2001). Changes in visual perception at the time of saccades. *Trends in Neurosciences*, *24*(2), 113–121, https://doi.org/S0166-2236(00)01685-4.

Shepherd, M., Findlay, J. M., & Hockey, R. J. (1986). The relationship between eye movements and spatial attention. *Quarterly Journal of Experimental Psychology A: Human Experimental Psychology*, *38*(3), 475–491, https://doi.org/10.1080/14640748608401609.

Sommer, M. A., & Wurtz, R. H. (2008). Brain circuits for the internal monitoring of movements. *Annual Review of Neuroscience*, *31*, 317–338, https://doi.org/10.1146/annurev.neuro.31.060407.125627.

Tas, A. C., Luck, S. J., & Hollingworth, A. (2016). The relationship between visual attention and visual working memory encoding: A dissociation between covert and overt orienting. *Journal of Experimental Psychology: Human Perception and Performance*, *42*(8), 1121–1138, https://doi.org/10.1037/xhp0000212.

Taylor, J. E., Chan, D., Bennett, P. J., & Pratt, J. (2015). Attentional cartography: Mapping the distribution of attention across time and space. *Attention, Perception & Psychophysics*, *77*(7), 2240–2246, https://doi.org/10.3758/s13414-015-0943-0.

Toet, A., & Levi, D. M. (1992). The two-dimensional shape of spatial interaction zones in the parafovea. *Vision Research*, *32*(7), 1349–1357.

Van der Stigchel, S., & de Vries, J. P. (2015). There is no attentional global effect: Attentional shifts are independent of the saccade endpoint. *Journal of Vision*, *15*(15):17, 1–12, https://doi.org/10.1167/15.15.17. [PubMed] [Article]

van Opstal, A. J., & van Gisbergen, J. A. (1989). Scatter in the metrics of saccades and properties of the collicular motor map. *Vision Research*, *29*(9), 1183–1196.

Whitney, D., & Levi, D. M. (2011). Visual crowding: A fundamental limit on conscious perception and object recognition. *Trends in Cognitive Sciences*, *15*(4), 160–168, https://doi.org/10.1016/j.tics.2011.02.005.

Wolfe, B. A., & Whitney, D. (2014). Facilitating recognition of crowded faces with presaccadic attention. *Frontiers in Human Neuroscience*, *8*, 103, https://doi.org/10.3389/fnhum.2014.00103.

Woodman, G. F., Arita, J. T., & Luck, S. J. (2009). A cuing study of the N2pc component: An index of attentional deployment to objects rather than spatial locations. *Brain Research*, *1297*, 101–111, https://doi.org/10.1016/j.brainres.2009.08.011.

Zhao, M., Gersch, T. M., Schnitzer, B. S., Dosher, B. A., & Kowler, E. (2012). Eye movements and attention: The role of pre-saccadic shifts of attention in perception, memory and the control of saccades. *Vision Research*, *74*, 40–60, https://doi.org/10.1016/j.visres.2012.06.017.

Zimmermann, E., Morrone, M. C., & Burr, D. C. (2014). The visual component to saccadic compression. *Journal of Vision*, *14*(12):13, 1–9, https://doi.org/10.1167/14.12.13. [PubMed] [Article]