

Visual priming through a boost of the target signal: Evidence from saccadic landing positions

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Published online: 2 August 2013
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Repetition breeds success. This is the case over the long run, when repeating a certain act leads to learning, but also in the very short one: Over and over again, it has been found that the action that was performed last is primed to be performed again. In the visual search literature, such repetition priming has been studied extensively. Participants tend to find a target more easily when they have to search for the same target as on the previous trial than when the target changes relative to the previous trial (Goolsby & Suzuki, 2001; Huang, Holcombe, & Pashler, 2004; Kristjánsson, Wang, & Nakayama, 2002; Maljkovic & Nakayama, 1994, 2000; McPeck, Maljkovic, & Nakayama, 1999; Meeter & Olivers, 2006; Müller, Heller, & Ziegler, 1995).

Priming in visual search has been found for different target features: for the layout of the search scene, for its size, for the to-be given response, and for interactions between these factors (reviewed in Kristjánsson & Campana, 2010). Of these factors, priming by a target feature is the most extensively investigated effect, often in the form of *priming of pop-out* (PoP; Maljkovic & Nakayama, 1994). When the unique target feature is repeated on the subsequent trial, the target is found earlier, on average, than when the target feature is changed. Many researchers have argued that priming in visual search affects attentional selection, in that a repeated target is more likely to be selected early on in a trial than is a nonrepeated target (Becker, Ansorge, & Horstmann, 2009; Brascamp, Blake, & Kristjánsson, 2011; Kristjánsson & Campana 2010; Meeter & Olivers, 2006).

However, placing the locus of priming at the stage of attentional selection does not answer all questions, as it remains unclear what is changed by a previous trial such that attentional selection is speeded. One possibility is that target repetition strengthens the signal that the target elicits in visual brain areas. This is commonly conceptualized as a target having increased activation in a salience map that determines which element in the scene is selected (Becker, 2008; Fecteau & Munoz, 2003; Lee, Mozer, & Vecera, 2009; Meeter & Olivers, 2006). Another possibility is that target signals do not so much become strengthened, but rather that distractor signals are suppressed. Several studies have shown that distractor repetition speeds search independent of target repetition (e.g., Kristjánsson & Driver, 2008), suggesting that distractor feature suppression is at least a possible cause of PoP.

A third possibility is that no change takes place in attentional selection, but that postselection processes are more efficient for a repeated feature. For example, Huang et al. (2004) argued that after a target is selected, observers engage in a checking process to ascertain that they have truly found the target. Huang et al. suggested that this process is speeded specifically through priming.

Using reaction time measures, as is typically done in priming studies, these possibilities cannot be disentangled from one another, since the measures reflect both pre- and postattentional processing and cannot dissociate the strength of the individual signals of target and distractor. To this end, we used a novel measure of the effect of a previous trial: the strength of the *global effect*. The global effect is the finding in eye movement research that when two elements in a visual scene are in relatively close proximity, a fast saccade to one of them generally lands in between the two, instead of on either one (Findlay, 1982; Van der Stigchel, de Vries, Bethlehem, & Theeuwes, 2011; Van der Stigchel & Nijboer, 2011). The global effect is sensitive to the strengths of the signals of the two elements. For example, a saccade will land closer to an

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element of greater size (Findlay, 1982), greater intensity (Deubel, Wolf, & Hauske, 1984), or greater dissimilarity to the background (Deubel, Findlay, Jacobs, & Brogan, 1988).

We used this sensitivity of global-effect saccades to signal strength in order to investigate the accounts of priming set out above. We induced such saccades by placing a target and a distractor, defined by their shapes, within the so-called *integration zone*, the 20° of visual space in which the global effect occurs (Walker, Deubel, Schneider, & Findlay, 1997). We then varied the colors of the target and the distractor from trial to trial. If in this situation the colors of the previous trial were repeated, we expected priming to occur, even though color was not a defining feature in this study (e.g., Huang et al., 2004). The accounts of priming described above offer different predictions on how such priming would affect the global effect.

If priming increases the strengths of target signals, one would expect global-effect saccades to end closer to the distractor if it had the color of the target on the previous trial. In this situation, the increased strength of the signal associated with the previous target color would be transferred to the current distractor, resulting in a relatively strong distractor signal.

If priming leads to the suppression of distractor signals, one would expect the saccade endpoint to be biased away from the target on trials on which it had the distractor color of the previous trial. In this situation, the decreased strength of the signal associated with the previous distractor color would be transferred to the current target, resulting in a relatively weak target signal.

Of course, these accounts also could both be true at the same time. Moreover, both of them would be consistent with the third account, which states that no signal change takes place, but instead that postselection processes become faster or more reliable. Crucially, this postselection account predicts that the effects of priming only become visible after attention has been deployed. This is a testable prediction, since global-effect saccades tend to be fast, with latencies that are below those of a physiological indicator of the deployment of attention, the N2pc. Such saccades can have latencies below 150 ms, whereas the N2pc typically occurs at around 200 to 300 ms for pop-out targets (Eimer, 1996). Therefore, the third account predicts that the effects of priming would not be visible for fast saccades, but would for slower ones.

Here, we set out to test these predictions.

Method

Twelve naive participants (19–27 years old; eight female, four male) participated in the experiment. Informed consent was obtained prior to the study, in accordance with the

guidelines of the Helsinki Declaration. Eye movements were recorded by an EyeLink 1000 system.

Participants viewed a display containing a gray cross ($1.0 \times 1.0^\circ$) on a black background in the center of the display, which was used as a fixation point. The fixation point was removed after a random interval of 500–1,000 ms. Subsequently, two filled, colored elements were presented: a target circle (diameter 0.67°) and a distractor square ($1.0 \times 1.0^\circ$). The distance from the central fixation point to the stimuli was 7.7° . The target circle was randomly positioned on one of eight equidistant axes (polar coordinates: 22.5° , 67.5° , etc.). The distractor square was presented on the same imaginary circle and could be presented 22.5° either clockwise or counterclockwise from the target (e.g., if the target was presented at 67.5° , the distractor was presented at either 45° or 90° ; see Fig. 1). The target display was presented for 1,500 ms. Afterward, all objects were removed from the display.

Target and distractor could have one of six approximately isoluminant colors (around 20 cd/m^2): blue, green, yellow, brown, red, and purple. Five equally likely repetition conditions were presented:

Both colors different and new: Target and distractor had different colors that were both new relative to the previous trial. This condition functioned as the implicit benchmark condition, against which the effect of the other conditions was measured.

Both colors repeated: Target and distractor both had the same color as on the previous trial.

Distractor color becomes target color: The target had the color of the distractor on the previous trial, whereas the distractor had a new color.

Target color becomes distractor color: The distractor had the color of the target on the previous trial, whereas the target had a new color.

One new color: The target and the distractor had the same color, which had not appeared on the previous trial. This condition was included in order to check the extent to which color differences were used to differentiate target and distractor.

Participants were instructed to fixate on the central fixation cross and to move their eyes to the target on the monitor as quickly as possible. The sequence of trials was randomized. When either the target or the distractor changed for the current condition, the new color was chosen randomly from those that had not been used on the preceding trial. The experiment consisted of 640 experimental trials and 16 practice trials.

Data analysis

Saccade endpoint The saccadic landing position was computed as a proportion of the angle between the two stimuli,

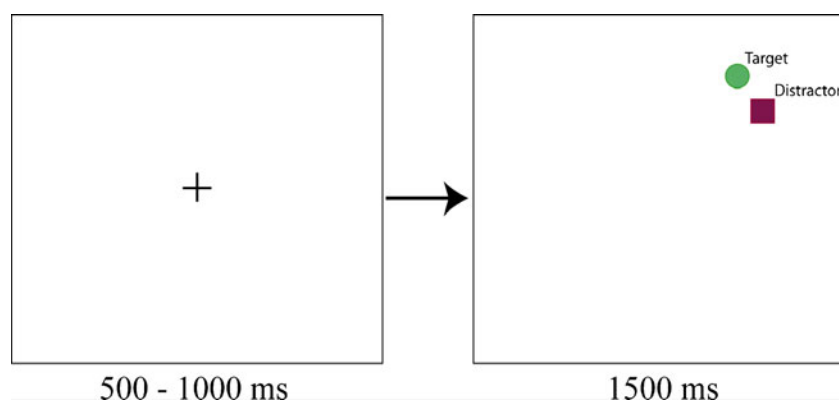


Fig. 1 Displays used in the experiment. Participants first saw a fixation cross that remained on the screen for a variable interval. This cross disappeared at the same time that a target and a distractor stimulus appeared in the periphery. The target was always a circle, and the distractor was always a square

which we will refer to as *endpoint deviation*, Φ . The target was used as a null reference, whereas the distractor had a deviation score of +1. Saccades with a Φ below 0.5 landed closer to the target than to the distractor, while the opposite was true for deviations above 0.5. Saccades with a Φ below -0.5 or above 1.5 (meaning that the saccade did not land in between the two stimuli by some margin) were excluded from the analysis; this was the case for, on average, less than four saccades per participant.

To examine the time courses of effects, each participant's saccades in each condition were rank-ordered from shortest to longest latency and partitioned into five equal-sized latency bins. The first bin contained the fastest 20 % of saccades that the participant made in a certain condition, whereas the last contained the slowest saccades. For each participant, the average saccade endpoints per condition and per latency bin were then calculated.

Saccade latency The saccade latency was defined as the interval between target onset and the initiation of the saccadic eye movement. Trials with a saccadic latency lower than 80 ms (anticipatory saccades) or higher than 800 ms (too slow saccades) were excluded. This led to a loss of data for 8.5 % of trials; on the majority of these, a saccade was initiated before target onset.

Results

Saccade endpoint An analysis of variance (ANOVA) with Repetition Condition and Bin as factors revealed a main effect of repetition condition, $F(4, 44) = 16.37$; $p < .0001$. To follow up, all conditions were compared to the *both colors new and different* condition. In this baseline condition, a strong and consistent global effect was observed (mean = $.44$; $SD = .04$), which was confirmed by a t test against a value of zero, $t(11) = 37.65$, $p < .0001$. Our follow-

up t tests revealed that the saccade endpoint deviated more toward the target in the *both colors repeated* condition than in the *both colors different and new* condition, $t(11) = 5.52$, $p < .001$ (see Fig. 2). Furthermore, the saccade endpoint deviated more toward the distractor in the *target color becomes distractor color* condition than in the *both colors different and new* condition, $t(11) = 5.10$, $p < .001$. Both effects were present in the individual data of all but one participant. We observed no differences between our reference *both colors different and new* condition and either the *distractor color becomes target color* or the *one new color* condition ($ps > .33$).¹

A linear effect of bin, $F(1, 11) = 23.38$; $p = .001$, indicated that the global effect decreased with increasing saccade latency (see Fig. 3). The global effect was strongest in the first bin (mean = $.48$; $SD = .03$) and weakest (but still strong) in the fifth bin (mean = $.38$; $SD = .07$). No significant interaction emerged between repetition condition and bin, $F(16, 176) = 1.15$, $p = .32$, nor did we find a difference between any pair of conditions in the linear effect of bin, $F_s < 2.67$, $ps > .13$ (i.e., no interaction took place between condition and bin when bin was treated as a linear factor). To confirm that the differences between conditions were already present in the very first bin, we repeated our follow-up t tests for this bin. Within the first bin, the difference between the *both colors repeated* condition and the *both colors different and new* condition was significant, $t(11) = 3.00$, $p < .02$, but not between our the latter condition and any of the others, $p > .255$.

Saccade latency The mean saccade latency was 164 ms ($SD = 16$ ms). For all five conditions, the mean latency varied between 163 ms (*both colors repeated* condition) and 165 ms

¹ We also analyzed saccade endpoint as a function of whether the target position was repeated, and found that saccades ended closer to the target position if this was the case. This effect did not interact with that of repetition condition.

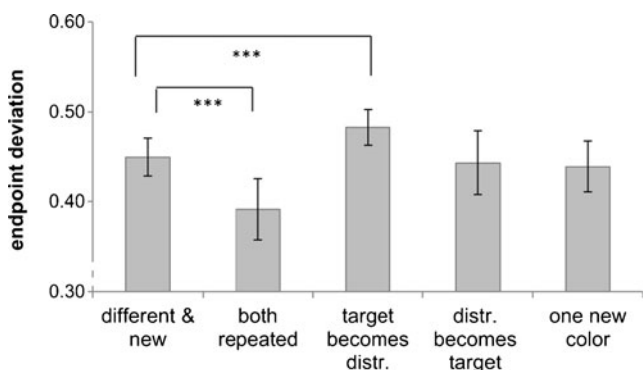


Fig. 2 Mean saccade endpoint deviation in the five conditions of the experiment. A value of 0 indicated a saccade on the target, and a value of 1 indicates a saccade to the distractor. Intermediate values indicate endpoints between the two. The error bars give 95 % confidence intervals. *** $p < .001$

(one new color condition). An ANOVA on saccade latencies showed no main effect of condition ($F < 1$).

Discussion

Here, we used a new measure to look at the effect of priming on visual selection. We induced a global effect by presenting a target and a distractor in close proximity in visual space, and looked for the effects of the previous trial on the endpoint of global-effect saccades. Global-effect saccades indeed dominated in our experiment, and showed clear signs of priming: Saccades landed closer to targets when the target and distractor had the same colors as on the previous trial than when both had a new color, in which case they ended close to the middle in between the two stimuli.

With this new measure, we set out to test three accounts of priming in visual search: one in which target signals are strengthened by priming, one in which priming acts to suppress distractor signals, and one in which priming affects

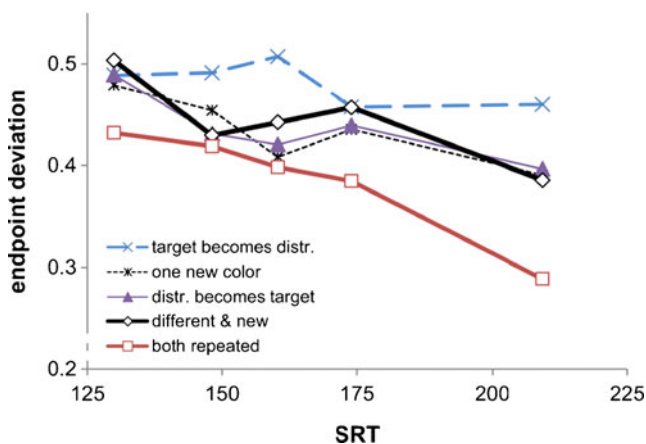


Fig. 3 Saccade endpoint deviation (on the same scale as in Fig. 2), as a function of condition and the mean saccadic reaction time (SRT), in five latency bins

postselection processes. Each account predicted different patterns of data for our experiment:

- The target-signal-strengthening account predicted that global-effect saccades would land close to the distractor if it has the color of a previous target (as in the *target color becomes distractor color* condition). This prediction was validated by the data.
- The distractor suppression account predicted that saccades would land closer to the distractor if the target had the color of a previous distractor (as in the *distractor color becomes target color* condition). This prediction was not supported.
- Postselection views predicted that whatever the effects of priming were, they would only be obvious in later saccades, when attention could be expected to be deployed to the target location. This prediction was not borne out by the data: Target repetition effects were not modulated by the latency of the saccade.

Taken together, these findings suggest that priming in the present experiment was the result of a boosted bottom-up signal emanating from the target (Becker, 2008; Fecteau & Munoz, 2003; Lee et al., 2009; Meeter & Olivers, 2006). The fastest saccades occurred at 130 ms. At this latency, in the range of express saccades (Hamm, Dyckman, Ethridge, McDowell, & Clementz, 2010), a saccade may result from the visual pulse provided by a sudden onset, without any intervening cognitive mechanisms (see also Meeter, Van der Stigchel, & Theeuwes, 2010). This suggests that the effects causing priming are rapid and can occur independent of postselection processes. Such an interpretation is consistent with evidence that priming relies on visual-processing areas, some occurring quite early in the visual-processing stream (e.g., Banissy, Walsh, & Muggleton, 2012; Campana, Cowey, & Walsh, 2002).

Our interpretation relies on the assumption that attention cannot be allocated to peripheral locations within the 130 ms needed for an express saccade. This assumption seems to have been contradicted by evidence that peripheral cues can transiently summon attention to their location, and that this leads to better perception of targets presented at SOAs of 50 ms or more (Nakayama & Mackeben, 1989). Although, superficially, this seems to indicate that attention could affect the processing of a 130-ms express saccade, this is not true, because visual signals need some time to reach the cortex. For example, V1 neurons in the macaque brain respond to a stimulus some 70 ms after its onset (Schmolesky et al., 1998), which would probably be somewhat later in the larger human brain. The results of Nakayama and Mackeben indicated that if one stimulus summons attention to its location, this can affect the processing of stimuli that reach the cortex 50 ms after the original processing starts. If a stimulus starts being processed in the human cortex 80 ms after its onset, attention may thus start affecting visual processing at its

location 130 ms after this onset. By that time, the motor burst in superior colliculus has already happened for an express saccade (the motor burst in the superior colliculus occurs some 25 ms before saccade onset; Munoz & Wurtz, 1995). We thus conclude that, although the target and distractor in our paradigm probably attracted attention to their location, attention cannot have affected processing for the fastest saccades that we observed.

Priming refers to a broad range of behavioral phenomena. It would be hard to argue that an enhancement of the target signal is the only mechanism involved in priming. For instance, distractor repetition speeds search even when target features are not repeated (e.g., Kristjánsson & Driver, 2008), suggesting that some form of distractor suppression or discounting also plays a role. Other evidence has suggested that priming can also happen at the response selection stage (Lamy, Yashar, & Ruderman, 2010; Olivers & Meeter, 2006). This has been observed in complex visual search arrays, which make it difficult to disentangle between the various possible mechanisms. In the present study, we therefore studied priming using a very simple setup in which only a single target and distractor were presented, simultaneously and in close proximity. Our results clearly showed that in this particular setup, the sole mechanism responsible for priming was the boosting of perceptual target feature signals. The present results suggest that this mechanism is powerful, and is one that affects overt shifts of attention even at the shortest latencies.

One caveat is that our findings address target and distractor color only as isolated features, although it is known that features may interact. For example the repetition of coupled features sometimes produces stronger priming than does repeating these features in isolation (Huang et al., 2004; but see Ásgeirsson & Kristjánsson, 2011), and even quite simple feature-based priming may be affected by a change in higher-level task variables (Thomson & Milliken, 2013). This possibility will have to be addressed in future experiments.

Author note This research was funded by two grants from the Netherlands Organization for Scientific Research: VENI Grant No. 451-09-019, to S.v.d.S., and VIDI Grant No. 452-09-007 to M.M.

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