Saccadic repulsion in pop-out search: How a target's dodgy history can push the eyes away from it

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Previous studies have shown that even in the context of fairly easy selection tasks, as is the case in a pop-out task, selection of the pop-out stimulus can be sped up (in terms of eye movements) when the target-defining feature repeats across trials. Here, we show that selection of a pop-out target can actually be delayed (in terms of saccadic latencies) and made less accurate (in terms of saccade accuracy) when the target-defining feature has recently been associated with distractor status. This effect was observed even though participants' task was to fixate color oddballs (when present) and simply press a button when their eyes reached the target to advance to the next trial. Importantly, the inter-trial effect was also observed in response time (time to advance to the next trial). In contrast, this response time effect was completely eliminated in a second experiment when eye movements were eliminated from the task. That is, when participants still had to press a button to advance to the next trial when an oddball target was present in the display (an oddball detection task experiment). This pattern of results closely links the "need for selection" in a task to the presence of an inter-trial bias of attention (and eye movements) in pop-out search.

Keywords: inter-trial effects, attention, top-down modulation, visual search, eye movements

Introduction

A primary endeavor of the vision research community has been to improve our understanding of visual search, the process through which an observer locates an item in the visual field. A wealth of research has investigated the role played by visual attention in search, from detecting objects in space (McCarley & Kramer, 2007; Wolfe & Horowitz, 2004) to identifying and subsequently acting upon them (Desimone & Duncan, 1995; Treisman, 1988). Two sources of information that drive attentional deployment in a scene are generally acknowledged: bottom-up information, often described as bottom-up "salience," which reflects various contrasts in the incoming stimulation (Itti & Koch, 2001; Treisman & Gelade, 1980; Wolfe, 1994), and top-down information, which reflects various aspects of the state of the observer such as knowledge and goals (Wolfe, 1994; Yantis, 1998). One additional top-down source of information that has lately been the focus of much research is recent experience, that is, how is it that our recent experience in a search task impacts our behavior in a similar search in the future (e.g., contextual cuing; Chun, 2000; Chun & Jiang, 1998; Lleras & Von Mühlenen, 2004). This influence extends to relatively "efficient" bottom-up search scenarios, such as the so-called "pop-out" search, in which observers are asked to detect (or identify) a uniquely salient oddball in a search

display. Reaction times (RTs) in pop-out search tasks are typically unaffected by set size (or sometimes even decrease with increasing set size), which has been taken as a crucial indication that the pop-out scene is being processed in a parallel (or extremely efficiently) manner and, further, that the "pop-out" item automatically captures attention. Yet, even in these search tasks, recent experience matters greatly. Groundbreaking work on this topic was performed by Maljkovic and Nakayama (1994, 1996, 2000) who first coined the term "priming of pop-out" (PoP), a term meant to illustrate the finding that repeating the oddball-defining feature in a pop-out search display across successive trials substantially decreases search times for the oddball target (see also Kristjánsson, Vuilleumier, Schwartz, Macaluso, & Driver, 2007; McPeek & Keller, 2001). That is to say, when looking for a color oddball, participants will find a red target faster on trial *N,* if on trial *N* − 1, the pop-out target was also red (even though, presumably, on both trials, the red target popped out). Furthermore, more recent research has also indicated that the repetition (or alternation) of the distractor color in a pop-out task also influences search: search facilitation also occurs following the repetition of distractor features across consecutive trials, and this effect can be methodologically separated from target-repetition effects (Kristjánsson & Driver, 2008; Lamy, Antebi, Aviani, & Carmel, 2008).

Similar to PoP, the distractor preview effect (DPE; Ariga & Kawahara, 2004; Goolsby, Grabowecky, &

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Suzuki, 2005; Lleras, Levinthal, & Kawahara, 2009) also describes an inter-trial effect on pop-out search. The DPE is observed when target-absent trials are interleaved with target-present trials in an oddball search task, just like the one used in PoP experiments. Crucially, the DPE refers to the inter-trial effect that arises when a target-present trial follows a target-absent trial, and more specifically, it is a relative slowing down in RT when the color of the current target is the same as that of the distractors on the preceding target-absent trial, and a relative speeding up in RT when the current distractors are of the same color as the distractors in the preceding target-absent trial (Figure 1), compared to a baseline condition where the color in the target-absent display is not used in the target-present display. For example, consider what happens following a target-absent trial in which all items are red. If the target on the next trial is red (target-color previewed condition), participants will be slow to identify the target. If, on the other hand, the target is green and accompanied by red distractors (distractor-color previewed condition), participants will be faster at identifying the target, compared to a neutral condition in which neither target color nor distractor color had been seen on the previous trial. In a recent study of conjunction search, in which viewers must integrate information from two stimulus dimensions, participants were again slower to respond on a target-present trial preceded by a target-absent trial if the target had been viewed on the preceding trial (Kristjánsson & Driver, 2008), suggesting that distractor repetition effects may be beneficial in situations beyond mere "pop-out" search tasks.

It is important to distinguish the DPE and PoP phenomena. At a theoretical level, many PoP studies have proposed that the effect reflects a bias to moving attention *toward* a recently selected feature (e.g., Huang, Holcombe, & Pashler, 2004; Kristjánsson et al., 2007; Maljkovic & Nakayama, 1994; Wolfe, Butcher, Lee, & Hyle, 2003). That is, the emphasis is on the repetition of the target feature across trials (but see Kristjánsson & Driver, 2008; Lamy et al., 2008 who more fully incorporate a role of distractor effects on PoP). In contrast, the DPE is proposed to reflect a bias toward keeping attention away from recently "failed" (distracting) features (Lleras, Kawahara, & Levinthal, 2009). At a methodological level, the DPE also affords the possibility to study attentional biases that apply to just one feature (or visual category) at a time, whereas in PoP two potential biases might arise on any given trial (one associated with the target feature and one with the distractor feature). Finally, at an empirical level, it is also the case that identical stimuli do not always give rise to both PoP and DPE. That is, a DPE can be observed with stimuli that fail to produce PoP effects (Ariga & Kawahara, 2004; Lleras, Beck, & Levinthal, in preparation).

Previous research has already established that repetition of a pop-out feature across consecutive trials affects the deployment of eye movements. Becker (2008) found that repeating the pop-out feature across consecutive trials reduces the time required by human participants to fixate the pop-out the second time around. Bichot and Schall (2002) observed the same effect in monkeys. These authors also measured neuronal activity in the frontal eye fields and found evidence of increased target discriminability when the pop-out feature was repeated. In sum, in PoP one observes an "attraction" effect of the repeated pop-out feature on eye movements: when the pop-out feature repeats across successive trials, the eyes find the target faster the second time around. Here we investigated whether and how the DPE influences eye movement behavior. We recorded eye movements while participants performed an oddball search task likely to elicit a DPE. Importantly, we compared two conditions. In Experiment 1, participants were asked to simply fixate the
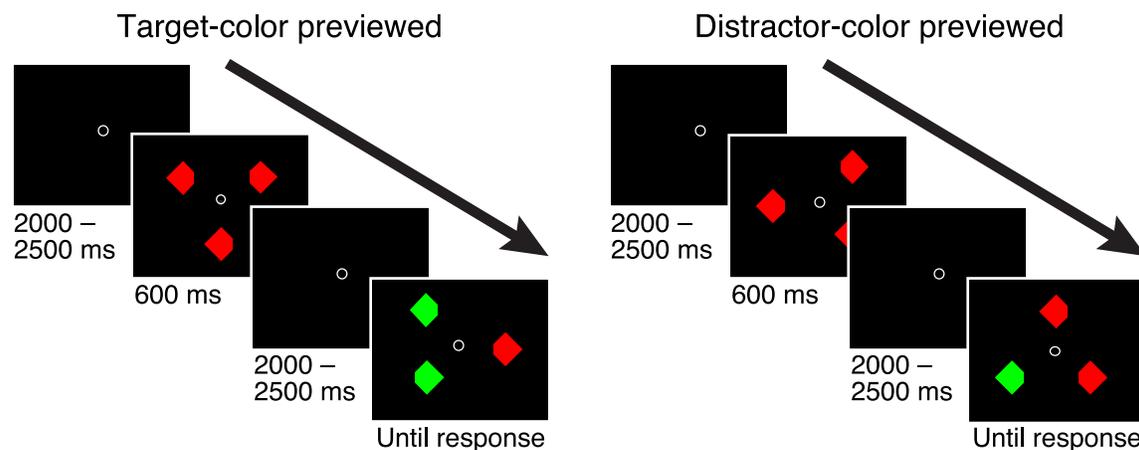

Figure 1. An example of the trial sequences in which the distractor preview effect (DPE) is observed. On the left, a trial in which the target color is red follows a target-absent trial with red objects (target-color previewed), resulting in slower and less accurate performance. On the right, a trial with a green target appears after a target-absent trial with red objects (distractor-color previewed), leading to faster and more accurate responses.

oddball item (when present) in the display, whereas in Experiment 2, participants were asked to maintain gaze at fixation and merely detect the presence (or absence) of an oddball in the periphery. To preview, our results show that observers have a measurable difficulty in fixating targets when targets are of the same color as the distractors in the preceding target-absent trial. That is to say, we observed a form of "repulsion" effect on eye behavior, whereby eyes initially tend to stay away from the feature that defined the preceding target-absent trial. Analogous to the DPE observed on overall RTs, this repulsion bias on eye movements seemed inextricably linked to the act of *selection*: when fixation of the oddball was not required in the task (Experiment 2), no such inter-trial effects were observed.

Experiment 1

In typical DPE tasks, participants are asked to find an oddball target along one feature dimension (say color) and then report a second feature about this target that belongs to an orthogonal (i.e., uncorrelated) feature dimension (say shape). It is in this task context that the DPE is measured, as the difference in response time (RT) between target-color previewed and distractor-color previewed conditions (Ariga & Kawahara, 2004; Goolsby et al., 2005; Lleras, Levinthal et al., 2009). That said, if the DPE truly reflects biases in the deployment of attention, it should be observed independently of the response dimension (and response task). In fact, it should be observed prior to the start of any form of response selection in a trial, yet it ought to critically depend on whether or not a stimulus is selected by attention in the first place (see Lleras, Kawahara, Wan, & Ariga, 2008). That is, one should be able to observe a DPE when participants are merely asked to fixate the oddball item in the search display, given that successful foveation requires attentional selection of the to-be-fixated stimulus (Hoffman & Subramaniam, 1995), irrespective of what action participants should produce once the target has been selected. In Experiment 1, we tested this hypothesis with a purely "selection" task. Participants were required to fixate a color singleton, when one was present, and then press a button to complete the trial. Thus, unlike previous DPE studies, here we did not ask participants to inspect the target (after selection) and report a second attribute of this object but simply to visually select the oddball. We expected to observe RT differences in the time to terminate the trial, in accordance with the DPE, but, further, we expected to see a difference in the eye movement patterns between conditions: participants should exhibit some degree of difficulty in fixating targets in the target-color previewed trials, compared to distractor-color previewed trials.

Methods

The stimuli and trial sequencing used in the current experiments are based on those used by Goolsby et al. (2005) and were generated using VisionEgg (Straw, 2008). Each display consisted of three diamonds, arranged at equal intervals along an imaginary isoacuity ellipse centered at fixation. The diamonds could be either red or green and were missing a corner on the left or right side. On target-absent trials, all diamonds on the display were of the same color, and on target-present trials, one diamond was of a different color from the other two: this oddball-colored diamond was the target. Experimental sessions consisted of 5 blocks of 64 trials each. Each trial began with the presentation of a fixation point at the center of the screen, followed by a variable interval of 2000–2500 ms, itself followed by the onset of the search display. Target-absent displays were presented for 600 ms (no response required), whereas target-present displays remained visible until the participant's response.

Participants were instructed to respond by directly gazing at the color singleton, when one was present, and pressing a button immediately afterward. They were also instructed to maintain fixation at the center of the screen during target-absent trials. Gaze location was recorded for the duration of the trial using an EyeLink 1000 system (SR Research), and a drift correction procedure was performed between blocks of trials to ensure an accurate recording of eye position. Two experimental conditions were of particular interest, as determined by the relation between two consecutive trials: the "distractor-color previewed" condition, when the color of items in the target-absent display coincided with the color of the distractors in the following target-present display; and the "target-color previewed" condition when the color of items in the target-absent display coincided with the color of the target in the following target-present display.

The trial sequence was generated for each participant by concatenating 10 sets of 32 trials; each set consisted of 8 pairs of trials (a red or green target-absent or target-present trial, followed by a red or green target-present trial) randomly interleaved with 8 additional target-absent trials (4 red and 4 green) and 8 target-present trials (4 red and 4 green targets). This random process resulted in an average of 83 trials of interest for each participant, with on average about 40 "target-color previewed" trials and 43 "distractor-color previewed" trials. Trials were excluded from analysis if the participant blinked, failed to fixate the center point prior to search array onset, or failed to saccade to any display items on target-present trials. There was no significant difference in the average number of trials excluded per subject between the target-color and distractor-color previewed conditions (11.45 vs. 12.91, $t(11) = 1.99$, $p > 0.05$).

Results

Participants' button-pressing accuracy was perfect; with both a mean hit rate of and correct rejection rate of 100%, which is not surprising given the ease of the task. As in previous studies of the DPE, response times (measured here by button presses to terminate the trial) to target-color previewed and distractor-color previewed trials showed a substantial difference, with participants pressing the "target-present" button 56 ms slower in the target-color previewed condition (746 ms) than in the distractor-color previewed condition (690 ms), $t(10) = 5.42$, $p < 0.01$. A similar difference was found between conditions in terms of saccade latencies—defined as the time between search array onset and the first saccade away from fixation with a magnitude greater than 2 degrees of visual angle, a velocity greater than 30 degrees/s, and acceleration over 8000 degrees/s^2: participants initiated their eye movements 24 ms slower in the target-color previewed condition than in the distractor-color previewed condition (356 ms vs. 332 ms; $t(10) = 3.77$, $p < 0.01$). Additionally, the accuracy of this initial saccade was much worse on target-color previewed trials. To compute saccade accuracy, we defined region of interests in the search displays as regions subtending 2 degrees of visual angle around each item. As such, only 72% of first saccades in the target-color previewed condition landed in the target region of interest, compared to 88% of saccades on distractor-color previewed trials, $t(10) = -3.22$, $p < 0.01$. In fact, on target-color previewed trials, observers directed a saccade to a distractor region prior to fixating the target region on 12% of trials, compared to only 2% of trials on distractor-color previewed trials, $t(10) = 5.98$, $p < 0.01$. The difference in saccade latencies remained significant when only those trials in which the first saccade correctly landed on the target were considered (372 ms vs. 335 ms; $t(10) = 4.42$, $p < 0.05$).

Saccade latencies and accuracies were also analyzed for evidence of priming of pop-out (PoP). The second of two consecutive target-present trials were compared for the cases in which the target-defining color remained the same (e.g., a red target was present on two trials in a row) or switched (e.g., a green target was present on a trial following a trial containing a red target). In a replication of previous work investigating eye movements and PoP (Becker, 2008), saccades during target-feature repeat trials were faster (321 ms vs. 333 ms; $t(10) = -3.04$, $p < 0.05$) and more accurate (83% vs. 72%; $t(10) = 2.49$, $p < 0.05$) than those in target-feature switch trials.

Finally, to assess the relationship between the DPE and PoP, we calculated the correlation of both of these effect sizes across participants. No significant correlation was observed in saccade latency effects ($r(9) = 0.12$, $p > 0.1$); however, marginal correlations were obtained for both overall reaction time differences ($r(9) = 0.55$, $p < 0.1$) and saccade accuracy effects ($r(9) = 0.54$, $p < 0.1$).

Discussion

The results of Experiment 1 clearly show that the DPE can be observed in the context of a purely selection task, in the sense that there was no processing of the target that was needed other than what was required for localizing it and fixating it. This result indicates that the biases instantiated by the visual system following a target-absent trial strongly affect the process of attentional selection. This bias emerges sufficiently early on during a trial that it even affects saccade latencies to move the eyes away from fixation and, further, impacts the accuracy of those initial saccades. Further, the DPE was still observed in saccade latencies when only trials in which the first saccade correctly landed on the target were considered. This is evidence that the act of preparing an eye movement to the target was more difficult (or more time consuming) on target-previewed trials than on distractor-previewed trials. This is important because it means that a form of "capture" by distractors on target-previewed trials is not responsible for the DPE: that is, one could conceive that on target-previewed trials, distractors may be more salient or more likely to capture attention than on distractor-previewed trials. If so, participants may move the eyes (or attention) to these distractors prior to redirecting them toward the target (see Hickey, McDonald, & Theeuwes, 2006, for an analogous account of within-trial attentional capture). If so, then the DPE (in RTs) would simply reflect a measure of this extra travel time to reach the target after first landing at a distractor. That said, our data clearly argue against such an account. Participants more readily go to distractors on target-previewed trials, not because the distractors are particularly salient (or capturing) but rather because, on target-previewed trials, it is relatively harder to actually move the eyes to the target, as reflected by the longer saccade preparation times on correct-first-saccade trials.

The presence of a bias in eye movement accuracies and latencies is particularly striking given the very simple nature of the task: fixate a salient color oddball in the periphery, which sits fairly far away from any competing distractors for the eye movement system. Yet, our results show that "selection" of an item (here operationalized as fixation of the item) is sufficient to produce strong inter-trial biases of attention, like the DPE. Experiment 2 investigates whether this form of selection is in fact required for the bias to emerge.

Experiment 2

In this experiment, we used identical displays and procedures as in Experiment 1, the only difference being the task participants were asked to perform on the search displays: rather than fixating the oddball (when present),

participants were simply asked to press a button when they detected the presence of an oddball in the display. In other words, the only difference between Experiments 1 and 2 is whether observers executed (Experiment 1) or not (Experiment 2) a saccade toward the oddball. Importantly, behavior on target-absent trials was identical in both experiments: keep eyes at fixation and wait for the next trial. Here, we assumed that detection of the oddball could be performed without actually moving attention to the oddball itself, very much in line with the findings of Bravo and Nakayama (1992), who used very similar displays to ours. We instructed participants to maintain their gaze at fixation throughout the experiment and excluded any trials when they moved their eyes (which happened rarely). If attentional selection is required for the DPE bias to emerge, we would not expect to find it in this experiment where neither eye movements nor presumably attention was directed to the peripheral targets.

Methods

The display and trial sequencing used in Experiment 2 were identical to those used in the previous experiment. Participants were instructed to respond by pressing a button to indicate the presence of the color singleton when one was present. They were also instructed to maintain fixation at the center of the screen throughout the course of the experiment. Trials were excluded from analysis if the participant blinked or failed to fixate the center point prior to search array onset.

Results

Button-pressing accuracy was again high; participants achieved a hit rate of 100% while maintaining a correct rejection rate above 98%. However, no significant reaction time difference was seen between the target-color previewed (534 ms) and distractor-color previewed conditions (531 ms; $t < 1.00$). Participants failed to maintain fixation and made a saccade to an item in the display on less than 1% of the trials in both conditions.

General discussion

The results of Experiment 2 were strikingly different from those of Experiment 1, given that the only difference between experiments was the execution of an eye movement toward a peripheral stimulus: when eye movements are required of the task, strong attentional biases emerge that modify performance as a function of recent history with the task, whereas when no eye movements are executed—and detection of oddballs in the periphery is still being performed by the observer—no such experience-dependent attentional biases emerged. Based on these two studies, we can conclude that "selection" is both sufficient and required for DPE biases to emerge.

To better provide a context for the current result, we should also make reference to a third experimental condition that was run in a separate study in our laboratory. In Shin, Wan, Fabiani, Gratton, and Lleras (2008), we conducted a traditional DPE experiment (find the color oddball and report its identity) but with one important difference: like in Experiment 2, participants were never allowed to move their eyes to the target oddball. This was necessary because we were interested in measuring electrophysiological activity during the DPE task without eye movement artifacts and because we were interested in lateralized brain activity to the target. We examined whether the behavioral DPE mirrored modulations in electrophysiological indices like the N2pc (an index of lateralized attentional selection, see Eimer, 1996) as well as the P1/N1 complex (see Luck, Woodman, & Vogel, 2000). Crucial to our current findings, a DPE was observed in that selection task even though participants never moved their eyes to the oddball. To sum up, a DPE emerges when (a) participants are merely asked to select a color oddball in order to fixate it (Experiment 1) or (b) when they must select a color oddball to report some attribute of it, even in the absence of eye movements (Shin et al., 2008); yet the DPE is absent when participants do not move their eyes to the oddball and are merely asked to detect the presence of the oddball in the periphery (Experiment 2). Together, these results strongly suggest that the need for selecting a target is necessary and sufficient to produce a DPE. This pattern of results also helps us to rule out the possibility that the DPE is an inhibitory effect that solely resides in the eye movement system. If that were the case, the DPE would not have emerged in Shin et al.'s experiment, where eye movements were not allowed. In other words, the underlying mechanism responsible for the DPE subserves both selection by the eye movement system and selection by the covert attention system.

As for the electrophysiological data in Shin et al.'s (2008) study, we found that the N2pc (but no other components) systematically varied by DPE condition such that the N2pc on target-previewed trials was in fact delayed and of smaller magnitude than the N2pc on distractor-previewed trials. This result provides nice converging evidence that (a) the DPE does affect early selection processes and (b) it can occur even when fixation must be accurately maintained throughout the experiment. Also complementing the current findings, Shin et al. failed to observe any history effects on response selection processes (as indexed by the Lateralized Readiness Potential, an index of response preparation). That is to say, whatever inhibitory effects are present in the DPE, they do not differentially modulate response selection processes. This fits nicely with our present findings because we observed a

normal DPE in Experiment 1 in which there was no "response selection stage" per se, only a response execution stage. Overall, all these results place the locus of the DPE effect well before the response selection stage.

We have previously proposed that the DPE reflects a bias to keep attention away from colors, features, or indeed visual categories that have recently been associated with a search failure (Lleras, Kawahara et al., 2009; Lleras, Levinthal et al., 2009). This proposal puts an emphasis, then, on the "repelling" effect that a visual feature can have on the selection system when it has had a "dodgy" history, that is to say, when it was recently associated with distractor status and with the *absence* of a target. That is, we believe the DPE is crucially dependent on the fact that on target-absent trials the color of the items in the display becomes associated with the impossibility to complete an act of "selection" (which is what the visual system is set out to do in this task on every trial). This association makes it so that the selection system becomes less willing to select that particular feature in the future. As a result, we expect most of the DPE to be observed on target-previewed trials, when this repelling bias runs exactly counter to the current behavioral goal: the observer is to select that one item attention does not want to select because of its checkered history (e.g., a red target following a target-absent display filled with red items). In contrast, this effect ought to be less pronounced on distractor-previewed trials, insofar as the repelling effect (stay away from, say, red items, when the current distractors are red) is in line with the current behavioral goal. This prediction has been validated multiple times in RT measures (Goolsby et al., 2005; Lleras et al., 2008) but is more strikingly clear in accuracy measures when a temporal search task is used instead of a spatial search task: in Lleras, Kawahara et al. (2009), participants had to identify a color oddball in an RSVP stream of characters and the results showed a substantial drop in identification accuracy of about 30% on the target-color previewed trials compared to neither-color previewed trials, which had almost equivalent levels of performance to the distractor-color previewed trials. This same pattern was observed when visual categories were used as stimuli in the RSVP stream (the task being to identify the category-oddball item, using letter and numbers as visual categories). Importantly, we have also shown that the DPE bias on temporal search tasks is of the exact same nature as the DPE bias on spatial search tasks (as used in this study): selection biases formed in one type of task transfer almost entirely to the other type of task (Lleras, Levinthal et al., 2009). That is, when spatial and temporal search tasks are randomly interleaved, biases against selecting a color in one type of task affect selection of that same color in the other task (i.e., when a spatial search trial follows a temporal search trial or a temporal search trial follows spatial search task) almost to the same extent that biases formed in the same type of task (when a temporal search trial follows another temporal search trial or when a spatial search trial follows another spatial search trial). In sum, all this evidence does point in the direction that the DPE is a "repulsion" of attention effect, aimed at keeping attention away from items that are associated with recent failed searches (or failures of selection).

The eye movement behavior of participants in Experiment 1 is certainly consistent with the view that the DPE represents an attention repulsion effect, taking eye behavior as a proxy for attention deployment in this task. In contrast, when participants in Experiment 2 were required to maintain fixation while detecting target presence in the periphery, no overall response time differences were observed between the target- and distractor-color previewed conditions. Attentional biases in this experiment were either unrelated to recent search history or non-existent. The results of Experiment 2 suggest that the DPE is not a "salience"-based effect of recent experience on perception: it is *not* the case that the target seems more or less salient as a function of search history (being less salient in target-color previewed trials). If so, one would have then expected overall detection RTs in Experiment 2 to be influenced by changes in distractor salience across conditions. In other words, merely seeing a display filled with red items does not make a subsequent red target less salient (target-color previewed condition). This result is consistent with previous studies in which a DPE failed to appear in other oddball detection tasks (Lleras, Kawahara et al., 2009; Lleras et al., 2008) as well as with findings suggesting that the salience of the target itself is unrelated to the DPE (Wan & Lleras, 2010). Modeling work on the DPE further supports these conclusions; recent results suggest that the DPE is due to changes in decision thresholds as opposed to rates of evidence accumulation (Tseng, Glaser, & Lleras, 2010). In plain words, if a pop-out's defining feature has recently been associated with "target absentness" (as in the target-color previewed condition of the DPE), selection of that pop-out will be relatively difficult (longer saccadic latencies) and inaccurate (the eyes will be more likely to land away from the target), and this effect reflects attentional biases, not modulations at the perceptual (or encoding) level of the pop-out feature.

It is worth considering the possibility that Experiments 1 and 2 may differ along a dimension other than the presence of "selection" in the task: perhaps selection and detection tasks also differ in terms of what can be considered "behavioral success" at the task. When performing a selection task (Experiment 1), the goal of which is to select one object in the display, target-absent trials represent a sort of behavioral failure: the environment does not afford selection of a target. Thus, even though the selection system is set and ready to quickly select one oddball on every trial, it cannot execute this goal in the absence of an oddball target. This form of behavioral "failure" might be responsible for creating the attentional bias to stay away from the features associated with the search failure. In contrast, in detection tasks, all

trials are a form of behavioral success: whether a target is present or absent, both types of displays are valid inputs to the task goal defined as "detect presence/absence of oddball." Consistent with this possibility is data from Lleras, Levinthal et al. (2009) showing that the direction of the inter-trial bias (whether target-color previewed trials are slower or faster than distractor-color previewed trials) can be determined by simply changing the task participants perform on target-absent displays: when these become associated with some form of behavioral success, now target-color previewed RTs become faster than distractor-color previewed trials. Krummenacher, Müller, Zehetleitner, and Geyer (2009) also recently documented that inter-trial attentional effects can differ greatly by the type of task participants do with the displays (detection vs. identification) in the context of a pop-out task where dimensional priming was studied: in detection tasks, dimensional priming is much stronger than in identification tasks, whereas location priming increases greatly from detection to identification tasks. Overall though, when interpreting the difference between Experiments 1 and 2, we currently favor the more straightforward and more parsimonious account that it is the "need for selection" that drives the difference between the two experiments, particularly, given the background literature on this type of search task (there is a large body of research using these displays in both detection and discrimination tasks, e.g., Bravo & Nakayama, 1992; Lleras et al., 2008; Lleras, Levinthal et al., 2009) and the appeal of subtraction logic: the methodological difference between the experiments (execution or not of eye movement to target) maps well to the underlying theoretical mechanism (need for spatial selection of one location among many).

Lastly, and as mentioned in the Introduction section, the work of Lamy et al. has identified two independent components in PoP (Lamy et al., 2008): one component that modulates target activation (driven by the repetition or alternation of the target feature across successive trials) as well as a component that modulates distractor inhibition (driven by the repetition or alternation of distractor features). In their paper, the authors found no significant correlation between these two different components, when measured in isolation. Thus, it is worth asking whether the DPE is in fact the same effect or driven by the same mechanism as the distractor inhibition component measured by Lamy et al. Consistent with a certain degree of independence, we found no significant correlation between an observer's PoP and its DPE on saccadic latencies, though we did find marginal correlations in saccade accuracy and response time. This is not entirely surprising, given that our measure of PoP must include both target and distractor repetition components (our design precluded us from separately evaluating the contributions of these two possible components). Thus, our results seem at least in part consistent with Lamy et al.'s claim that these two sources of attentional biases are independent. In fact, our modeling work also suggest

so: in Tseng et al. (2010), we found that saccadic latencies in a PoP task were best explained by changes to both evidence accumulation rates as well as attentional decision thresholds,[1] whereas saccadic latencies in a DPE task were entirely accounted for in terms of modulations of the attentional decision thresholds. Moreover, if the distractor repulsion observed in the DPE was identical to the inhibitory component of PoP, it should not be possible for stimuli to elicit a DPE without also showing a PoP; however, early work on the effect identified conditions under which exactly this occurs, such as the selection of a gender oddball face (Ariga & Kawahara, 2004). Our results also show that the saccade latency difference in the DPE is larger in magnitude (24 ms) than that in PoP (12 ms), further suggesting that the former is not a subcomponent of the latter. All that being said, we should also reemphasize that, at a theoretical level, we do not believe that the DPE is merely a "repetition vs. change" effect, as proposed by Lamy et al. That is, the DPE does not arise simply because the feature shared by distractors on one trial became the feature that describes the target on the following trial. Distractor/target status is important. However, we believe that the DPE also occurs partly because the attentional system incorporates the outcome of the trial into its assessment of whether the feature that was viewed during that trial should be sought or averted in the near future. To test that idea, we have run experiments in which we manipulate how the outcome of the interaction with target-absent displays is perceived by the participants (without changing the nature of those displays). When the outcome is perceived as positive (i.e., when the attentional system gets to do what it was set out to do), we observed *positive* priming across trials: the feature in the target-absent display now positively primes selection of that feature in the subsequent trial (see Lleras, Levinthal et al., 2009). This corresponds to a complete reversal of the DPE. In sum, we believe that, yes, some of the inhibitory mechanisms that produce distractor repetition effects in situations like PoP are probably similar to the ones that underlie the DPE. That said, we believe that the DPE is sensitive to more than just "search status" (target vs. distractor) and is an effect that incorporates the outcome of the interaction between the attention system and the environment: if a feature is associated with a failure to find and select a target, then a bias against orienting toward that feature is created (this would be the case for distractors in general). If, on the other hand, the feature is associated with a positive "selection" outcome, then a bias to orienting toward that feature may, in fact, be created, in spite of the feature's "distractor" status.

Conclusion

Our study directly adds to the literature on inter-trial effects on selective attention. Whereas previous research

has shown that trial history can positively bias attention and eye movements toward a repeated target (Becker, 2008; Bichot & Schall, 2002), ours is the first study showing that a target's recent history can actually push the eyes away from it, even when the target is quite easy to select in the first place: if a target's defining feature (here color) has recently been associated with the "absence" of a target, the eyes will be slow and less accurate at fixating that target, compared to targets with a relatively "cleaner slate." Further, comparing performance across Experiments 1 and 2 provides strong evidence that attentional selection is closely intertwined with this inter-trial effect: when selection is required in the task, the inter-trial effect is observed, and when selection does not happen, or is not required to complete the task, the inter-trial effect vanishes. In this way, we are beginning to better understand what it is that "attention remembers" and when it is that attention becomes amnesic.

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Footnote

[1]The PoP and DPE tasks were identical to the one we used here in Experiment 1, so the confound of target and distractor repetition effects in the PoP measure was also present.

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