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Intertrial Repetition Facilitates Selection in Time: Common Mechanisms Underlie Spatial and Temporal Search

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Abstract

Recent research has demonstrated that what observers attend to at a given time affects how their attention is deployed in the few moments that follow. When an observer searches for a discrepant target, repetition of the target feature from the previous trial speeds search, an effect known as priming of pop-out (PoP). Previous PoP studies have relied exclusively on spatial search tasks. Here, using a rapid serial visual presentation task, we show that PoP also occurs when temporal uncertainty makes search necessary, and that when spatial and temporal search trials are interleaved, the PoP effect transfers from one task to the other. The results suggest that common mechanisms of target-feature activation and distractor-feature inhibition underlie spatial and temporal visual search. They elucidate the role of PoP in visual search by showing that it speeds engagement of attention to the selected target, rather than earlier stages involving target localization and attention focusing.

Keywords

attention, visual search, priming of pop-out, temporal search, intertrial priming

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Imagine a security man in a busy airport, searching bags through an X-ray machine. His target is any security-threatening item that might be hidden in one of the bags. As he does not know what particular item he may have to detect, he searches for an odd item among the garments and other commonly packed items, which he continually needs to disregard. It is reasonable to assume that he would be more efficient at his task the more easily he could ignore features that he has just ignored or attend to features that also characterize an item that he found intriguing or threatening a moment ago. The results from a study by Maljkovic and Nakayama (1994) showed that, indeed, what observers attend to at a given time affects how their attention is deployed in the few moments that follow. Observers had to look for a target defined as the uniquely colored item among homogeneously colored distractors and make a discrimination response regarding its shape. Target and distractor colors switched unpredictably from trial to trial, such that observers had to perform their search with no knowledge of the upcoming target color. Reaction times (RTs) were substantially faster when the target and distractor colors were repeated from the previous trial than when they switched, an effect known as *priming of pop-out* (PoP). RT benefits occurred both when only the target color was repeated and when only the distractor color was repeated (e.g., Kristjánsson & Driver, 2008), which suggests that mechanisms of target-feature activation and of distractor-feature inhibition are involved in the PoP effect (Lamy, Antebi, Aviani, & Carmel, 2008).

The PoP effect has been replicated in several labs, with target-defining features from a large variety of dimensions, such as color (Becker, 2008; Kristjánsson, Vuilleumier, Schwartz, Macaluso, & Driver, 2007; Lamy, Antebi, et al., 2008), orientation (Huang & Pashler, 2005), spatial frequency (Kristjánsson, 2006), shape (Fecteau, 2007; Lamy, Bar-Anan, Egeth, & Carmel, 2006), size (Becker, 2008; Huang, Holcombe, & Pashler, 2004), and facial expression of emotion (Lamy, Amunts, & Bar-Haim, 2008).

The findings from several studies suggest that PoP speeds target selection. Maljkovic and Nakayama (1994, 1996) showed that repetition of only those features that are important for target selection produces intertrial-repetition effects. In particular, they found PoP with repetition of the target-defining feature and of the target location, but not with repetition of

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the response feature (but see Lamy, Bar-Anan, & Egeth, 2008, who found significant effects of response-feature repetition).

Goolsby and Suzuki (2001) provided a more direct test of the notion that PoP aids selection. In a study similar to Maljkovic and Nakayama's (1994), they used a spatial cue that appeared on half of the trials and indicated the location of the upcoming target with 100% validity. Thus, on cued trials, observers could focus their attention on the location of the upcoming target, therefore bypassing the search process. Whereas a large PoP effect was observed on no-cue trials, this effect was eliminated—that is, repetition of the target feature from the previous trial did not reduce RTs—when the target's location was cued. The authors concluded that PoP facilitates the shifting of attention to the target, because such facilitation did not occur when shifting attention to the target was not needed (i.e., when a 100%-valid cue preceded the search display). Note that a small PoP effect was also reported in this study when the target appeared without distractors and its position changed unpredictably from trial to trial. By contrast, Wolfe, Butcher, Lee, and Hyle (2003) reported no PoP when the target appeared alone in a fixed position that was therefore known on each trial.

Taken together, these findings indicate that PoP occurs only when search is needed and therefore suggest that PoP speeds selection. However, they do not provide fine-grained information as to what aspect of selection is facilitated by PoP. On the one hand, PoP might speed localization of the target, or how fast attention is attracted to its location. On the other hand, PoP might speed target selection regardless of whether it entails target localization.

In the present study, we examined this issue by investigating whether PoP is also observed when search is required but target localization is not, as is the case when search occurs in the temporal rather than the spatial domain. Displays consisted of rapid serial visual presentation (RSVP) streams of digits at the center of the screen. The target was defined as the uniquely colored digit among homogeneously colored distractor digits. Observers had to report whether the target was an odd or an even number. If PoP speeds attentional selection in general regardless of whether it operates in the spatial or in the temporal domain, then search performance would be better when the color of a target embedded in the RSVP stream was repeated on successive trials than when it changed. If, in contrast, PoP speeds mechanisms specific to spatial search, such as the movement of attention or the narrowing of its focus on the target location, then no PoP would be expected in this task.

It was necessary to use more than two possible colors so that the color of the distractors on a given trial would not be predictive of the color of the target on that trial. Indeed, had we used only two colors, the observers would have been able to guess the color of the upcoming target as soon as the first distractor appeared. We used four possible colors, as in Lamy, Antebi, et al. (2008). This enabled us to examine whether any observed PoP effect in this temporal selection task included both activation and inhibition components, as does the PoP effect typically obtained in spatial selection tasks.

Lamy, Antebi, et al. (2008) used a task similar to Maljkovic and Nakayama's (1994) spatial search task and compared the different repetition conditions created by the use of four possible colors instead of only two. On each trial, two different colors were randomly drawn from the four possible colors and assigned to the target and distractors. This resulted in three different kinds of sequences defined by target variation on successive trials: On any given trial, the target color could be (a) the same as the previous target color (repeated target color), (b) the same as the previous distractor color (switched target color), or (c) different from the previous target and distractor colors (new target color). Similarly, there were three kinds of sequences defined by distractor variation on successive trials: On any given trial, the distractor color could be (a) repeated, (b) switched, or (c) new.

The effect of target-color activation was quantified using two measures (Lamy, Antebi, et al., 2008). Following selection of the target on trial $n - 1$, activation of the target color on trial n was expected to facilitate selection of a target of the same color (repeated vs. new target color) and slow rejection of distractors of that color (switched vs. new distractor color). Thus, activation of the target feature was measured as the advantage on repeated-target-color trials relative to new-target-color trials (target-activation benefit) and also as the cost on switched-distractor-color trials relative to new-distractor-color trials (target-activation cost). Similarly, following rejection of distractors on trial $n - 1$, inhibition of the distractor color on trial n was expected to facilitate rejection of distractors of the same color and slow selection of a target of that color. Thus, inhibition of the distractor feature was measured as the advantage on repeated-distractor-color trials relative to new-distractor-color trials (distractor-inhibition benefit) and also as the cost on switched-target-color trials relative to new-target-color trials (distractor-inhibition cost).

In spatial search for a featural singleton, repetition effects have been reported not only for the target-defining feature, but also for its spatial location. To further investigate the similarity between spatial and temporal PoP, we examined whether repeating the target position in the RSVP sequence—that is, its position in time—would also facilitate search.

Experiment 1

Method

Subjects. Participants were 17 Tel Aviv University undergraduate students who participated in the experiment for course credit. All reported having normal or corrected-to-normal visual acuity and normal color vision.

Apparatus. Displays were generated by an Intel Pentium 4 computer attached to a 17-in. CRT monitor, using a graphics mode with 1024 × 768 resolution. Responses were collected via the computer keyboard. A chin rest was used to set viewing distance at 50 cm from the monitor.

Stimuli and procedure. An example of the stimulus displays is presented in Figure 1a. Each trial began with a fixation display consisting of a gray plus sign (0.2° × 0.2°) in the center of a black background. This display was presented for 500 ms and followed by an RSVP stream that consisted of 12 successively presented colored digits (font size = 20) randomly selected from 1 to 9, with the restriction that no two consecutive digits were the same. The presentation duration of each digit and the interstimulus interval (ISI) between successive digits were 55 ms. Each RSVP stream contained one digit with a unique color, the target, and 11 digits in a different color, the distractors. On each trial, the target and distractor colors were randomly drawn from four possible colors: red, blue, green, and yellow. The target position was randomly selected, but was restricted to the fifth through ninth positions. On each trial, a blank screen followed the RSVP stream for 5 s or until response. Participants were instructed to report whether the target was an odd or an even number by pressing a designated key ("3" with the right hand for an even number or "z" with the left hand for an odd number) as accurately and quickly as possible. A blank screen was presented for 500 ms before the next trial began.

Design. There were three kinds of sequences defined by variation of target color from one trial to the next (repeated, new, and switched) and three kinds of sequences defined by variation of the distractor color from one trial to the next (repeated, new, and switched). The seven possible combinations of these (switched target color combined with repeated distractor color and repeated target color combined with switched distractor color were impossible conditions) resulted from random selection of the target and distractor colors on each trial. The experiment began with 20 practice trials, followed by 560 experimental trials divided into eight blocks.

Results and discussion

Trials with incorrect responses (12% of all trials) or outlying RTs (less than 2.5% of all correct trials) were removed from all RT analyses. The data from 3 participants were discarded because their mean RT (1 subject) or error rate (2 subjects) exceeded the group's mean by more than 2 standard deviations.

Color PoP. The basic PoP effect and its components are depicted in Figure 2 (RT data) and in Tables 1 and 2 (accuracy data). A planned comparison between trials with repeated target and distractor colors and trials with switched target and distractor colors showed that the basic PoP effect previously reported in spatial search tasks (e.g., Maljkovic & Nakayama, 1994) was replicated in the present temporal search task, $t(13) = 11.87$, $p < .005$. There was no significant effect on accuracy, $t < 1$.

Next, we examined the relative contributions of target activation and distractor inhibition in the observed PoP effect. RTs

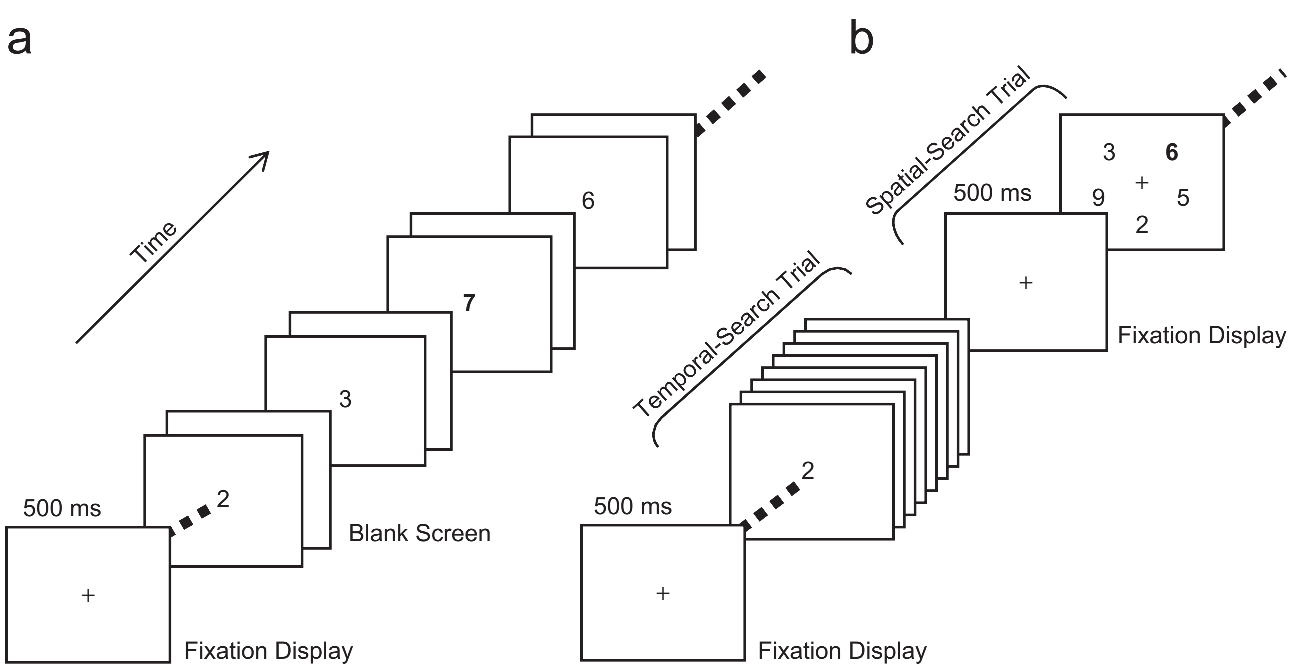

Fig. 1. Illustration of the sequence of events in (a) Experiment 1 and (b) Experiment 2. Experiment 1 used a temporal search task in which the target and 11 distractors were presented in a rapid serial visual presentation stream. In Experiment 2, the temporal search task used in Experiment 1 alternated with a spatial search task in which the target and 4 distractors were arranged around the circumference of an imaginary circle centered at fixation. The stimuli were displayed against a black background, shown here in white. On a given trial, all the distractors were in one color, and the target was in a different color. Possible colors were red, green, blue, and yellow. In the illustration, all digits are shown in black, and the target digit is indicated by boldface.

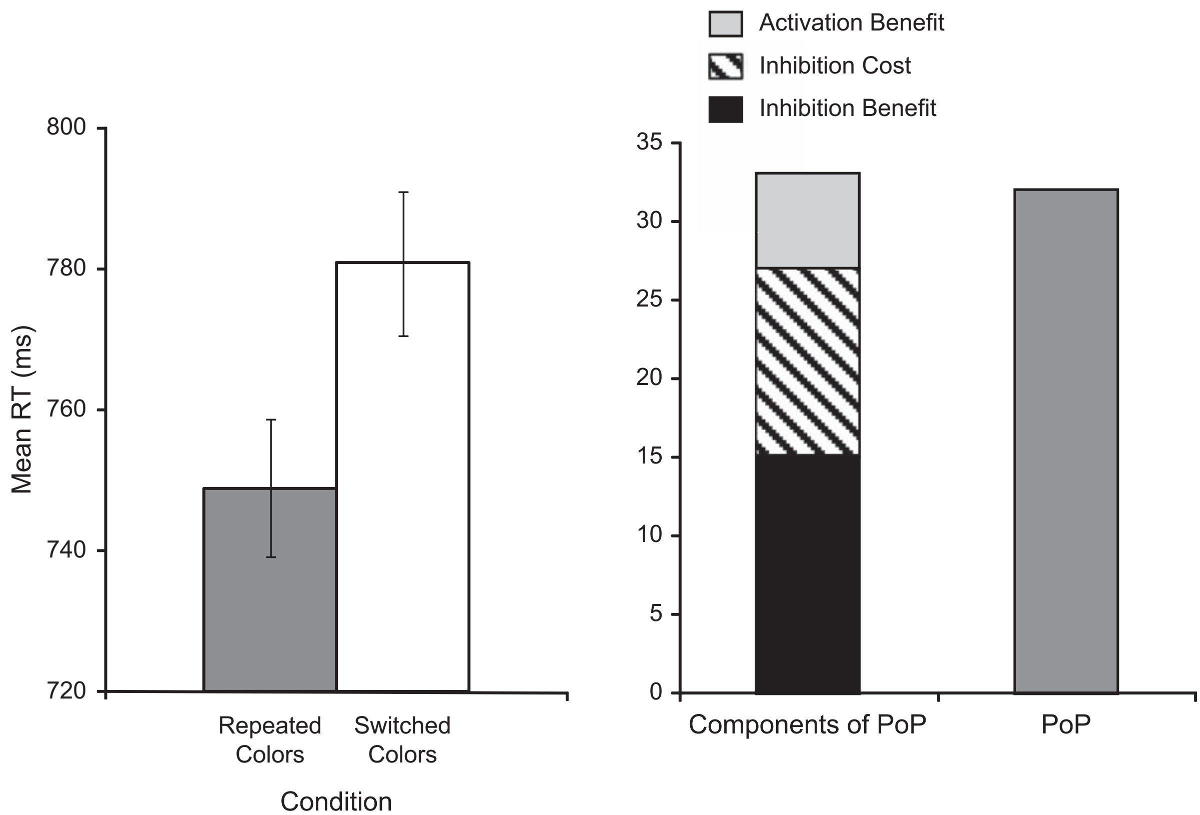

Fig. 2. Color priming of pop-out (PoP) for trials responded to correctly in Experiment 1. The graph on the left shows the basic PoP effect: reaction times (RTs) on trials with repeated target and distractor colors and on trials with switched target and distractor colors. Error bars represent standard errors. The graph on the right compares the basic PoP effect with the sum of the four PoP components (target-activation benefit and cost, distractor-inhibition benefit and cost; note that the activation cost was null).

were analyzed in two separate analyses of variance (ANOVAs), one with target repetition (repeated vs. new) and distractor repetition (repeated vs. new) as factors and the other with target switch (switched vs. new) and distractor switch (switched vs. new) as factors. As the interaction between the two factors was nonsignificant in both analyses, the main effects in the former analysis measured the target-activation benefit and distractor-inhibition benefit and the main effects in the latter analysis measured the target-activation cost and distractor-inhibition cost.[1] Neither of the two measures of target activation yielded a significant effect, $F(1, 13) = 1.65$, $p > .2$, for repeated- versus new-target-color trials and $F < 1$ for switched- versus new-distractor-color trials. The two measures of distractor inhibition yielded significant effects. Participants responded more quickly to repeated-distractor-color trials than to new-distractor-color trials, $F(1, 13) = 5.09$, $p < .05$, and marginally slower to switched-target-color trials than to new-target-color trials, $F(1, 13) = 4.34$, $p < .06$.

Analysis of the accuracy results showed that responses to repeated-distractor-color trials tended to be more accurate than responses to new-distractor-color trials, $t(13) = 3.24$, $p < .09$. No other effect approached significance, all ps > .2.

Temporal-position PoP. A planned comparison showed that RTs were faster when the target occurred in the same temporal position within the RSVP sequence on consecutive trials than

Table 1. Mean Percentage of Errors in Experiments 1 and 2 in the Basic Priming of Pop-Out (PoP) Conditions

Condition	Experiment 1: temporal search	Experiment 2: temporal search	Experiment 2: spatial search
Repeated target color, repeated distractor color	11.0% (1.3%)	8.4% (1.2%)	3.8% (1.2%)
Switched target color, switched distractor color	11.2% (1.5%)	12.4% (1.6%)	3.2% (0.9%)

Note: Standard errors are given in parentheses.

Table 2. Basic Priming of Pop-Out (PoP) Effect and Its Activation and Inhibition Components in Experiments 1 and 2: Percentage Accuracy

Effect	Experiment 1: temporal search	Experiment 2: temporal search	Experiment 2: spatial search
PoP effect	0.2%	4.0%*	–0.6%
Activation benefit	–0.3%	2.4%	–0.2%
Activation cost	–0.4%	–0.4%	0.6%
Inhibition benefit	–0.6%	2.2%	0.8%
Inhibition cost	2.7%	–0.2%	0.1%

*$p < .01$.

when it occurred in different temporal positions, $F(1, 13) = 5.20$, $p < .05$ (Fig. 3a). There were no significant effects of temporal position on accuracy, $F(1, 13) = 1.66$, $p > .2$ (Table 3). We also calculated the distance between the target position within the RSVP stream on the current trial and its position on the previous trial. If, for example, the target had appeared in Position 6 on trial $n - 1$ and in Position 9 on trial n, then the distance was 3. If the target had appeared in the same position within the RSVP stream on successive trials, then the distance was 0. An ANOVA with target distance in time as a within-subjects factor revealed a significant effect on RTs, $F(4, 52) = 6.05$, $p < .0006$. As is clear from Figure 3b, RTs increased as the distance in time between target positions on the current and previous trial increased. That is, the more the temporal position of the target on the current trial differed from the temporal position of the target on the previous trial, the slower search performance was. There were no significant effects of distance in time on accuracy, all *F*s < 1 (Table 4).

The results of Experiment 1 show that PoP occurs in a temporal search task in which the target appears at the same known spatial location on each trial but at a point in time that varies from trial to trial. Separate analyses of the activation and inhibition components showed that only distractor inhibition underlies this effect. In addition, repetition of the target position in time within the RSVP stream speeded search, an effect that parallels the spatial-position PoP effect reported by Maljkovic and Nakayama (1996) in spatial search tasks.

These results indicate that PoP also occurs when the spatial deployment of attention is not required. To the extent that common—not only similar—mechanisms underlie PoP in spatial and in temporal search, these findings suggest that PoP may affect the selection process, irrespective of whether it

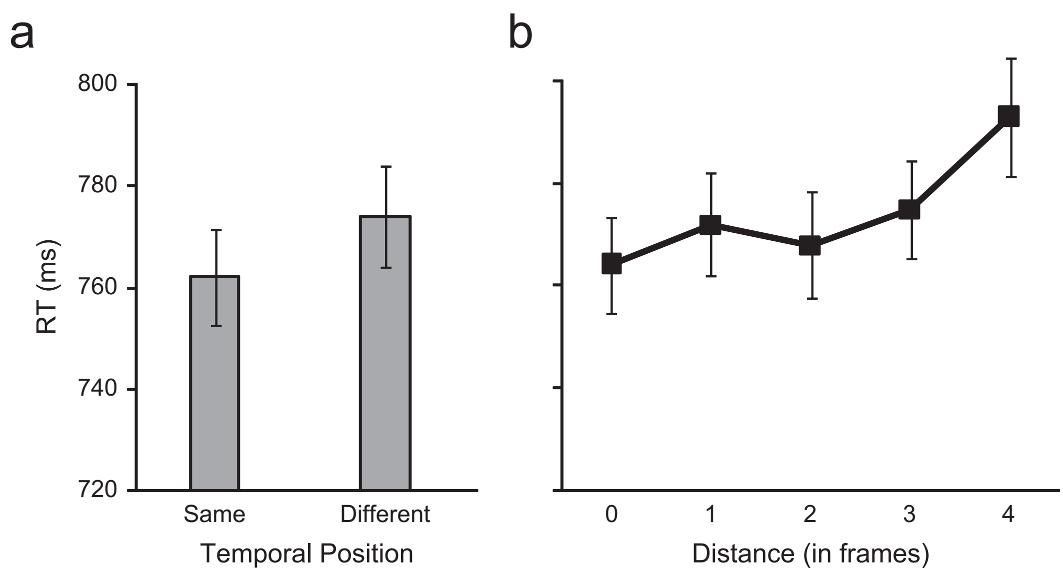

Fig. 3. Effect of temporal position on mean reaction time (RT) for correct responses in Experiment 1. The graph in (a) shows mean RT as a function of whether the target was in the same temporal position as in the previous trial or in a different temporal position. Error bars represent standard errors. The graph in (b) shows mean RT as a function of the distance in temporal position between the target on the current trial and the target on the previous trial. Temporal distance was calculated as the absolute value of the difference between the target's position in the stream on trial *n* and its position on trial $n - 1$.

Table 3. Mean Percentage of Errors in Experiment 1 as a Function of the Target's Position in the Current Stream Relative to Its Position in the Previous Stream

Position of the target in the current stream	Error rate
Same position	11.0% (1.5%)
Different position	12.2% (1.3%)
Temporal priming effect	1.2%

Note: Standard errors are given in parentheses.

occurs in space or in time, rather than the direction of attention in space.

Experiment 2

The objective of Experiment 2 was to directly examine whether the same mechanisms underlie the classical PoP effect observed in previous spatial search tasks and the PoP effect in temporal search demonstrated in Experiment 1. To address this question, we interleaved spatial and temporal search trials within the same experiment, such that a temporal search trial was always followed by a spatial search trial and vice versa. Thus, to use the terminology suggested by Goolsby and Suzuki (2001), encoding of the selected and ignored features on a spatial search trial took place during a temporal search trial, whereas their retrieval occurred during a spatial search trial. The reverse situation prevailed for temporal search trials. The same four colors were used for the targets and distractors in the two tasks. With this procedure, any PoP effect would indicate that attending to a target or ignoring distractors in one task affects search in the other task. Finding such a transfer would suggest that PoP affects the same target and distractor representations in the two tasks, which would lead us to conclude that the same mechanisms are responsible for the PoP effect in temporal search and in spatial search.

Method

Subjects. Participants were 22 Tel Aviv University undergraduate students who participated in the experiment for course credit. All reported having normal or corrected-to-normal visual acuity and normal color vision.

Table 4. Mean Percentage of Errors in Experiment 1 as a Function of the Distance in Temporal Position Between the Current Target and the Previous Target

Distance	Error rate
0	10.9% (0.8%)
1	12.0% (0.7%)
2	12.5% (0.7%)
3	11.8% (0.9%)
4	12.5% (1.3%)

Note: Standard errors are given in parentheses.

Apparatus, stimuli, and procedure. The apparatus was the same as in Experiment 1. An example of the stimulus displays is presented in Figure 1b. The experiment included two tasks: an RSVP task and a spatial search task. The RSVP task was the same as in Experiment 1. The spatial search task was similar to the RSVP task except for the following differences. The search displays consisted of the fixation display with the addition of five colored digits evenly spread around the circumference of an imaginary circle that had a radius of 4° and was centered at fixation. Each display contained one digit with a unique color, the target, and four digits with a different color, the distractors. Target position was randomly selected on each trial.

Design. The tasks alternated from trial to trial. Thus, there were never two consecutive trials of the same task type. The experiment began with 80 practice trials, followed by 660 experimental trials divided into 11 blocks. Participants were allowed a short rest after each block.

Results and discussion

Trials with incorrect responses (5.7% of all trials) or outlying RTs (less than 2.5% of all correct trials) were removed from RT analyses. The data from 3 participants were discarded because their mean RT (1 subject) or error rate (2 subjects) exceeded the group's mean by more than 2 standard deviations.

The PoP effect was analyzed separately for the temporal and spatial search tasks. Thus, a PoP effect in the temporal search task would reflect the effect of selecting the target in a spatial search trial on performance in a temporal search trial, whereas a PoP effect in the spatial search trial would reflect the effect of selecting the target in a temporal search trial on performance in a spatial search trial. The basic PoP effect and its components are depicted in Figure 4 (RT data) and in Tables 1 and 2 (accuracy data).

Temporal search task. Planned comparisons between trials with repeated target and distractor colors and trials with switched target and distractor colors showed a significant PoP effect for RTs, $t(18) = 4.42$, $p < .05$, and for accuracy, $t(18) = 8.94$, $p < .008$. However, further analyses of the activation and inhibition components of the PoP effect yielded only trends in the expected direction. For RTs, none of these approached significance, all Fs < 1, and for accuracy, only the benefit of target-color activation approached significance: Responses to repeated-target-color trials tended to be more accurate than responses to new-target-color trials, $t(18) = 3.44$, $p < .09$ (all other ps > .2).

Spatial search task. Planned comparisons between trials with repeated target and distractor colors and trials with switched target and distractor colors showed a significant PoP

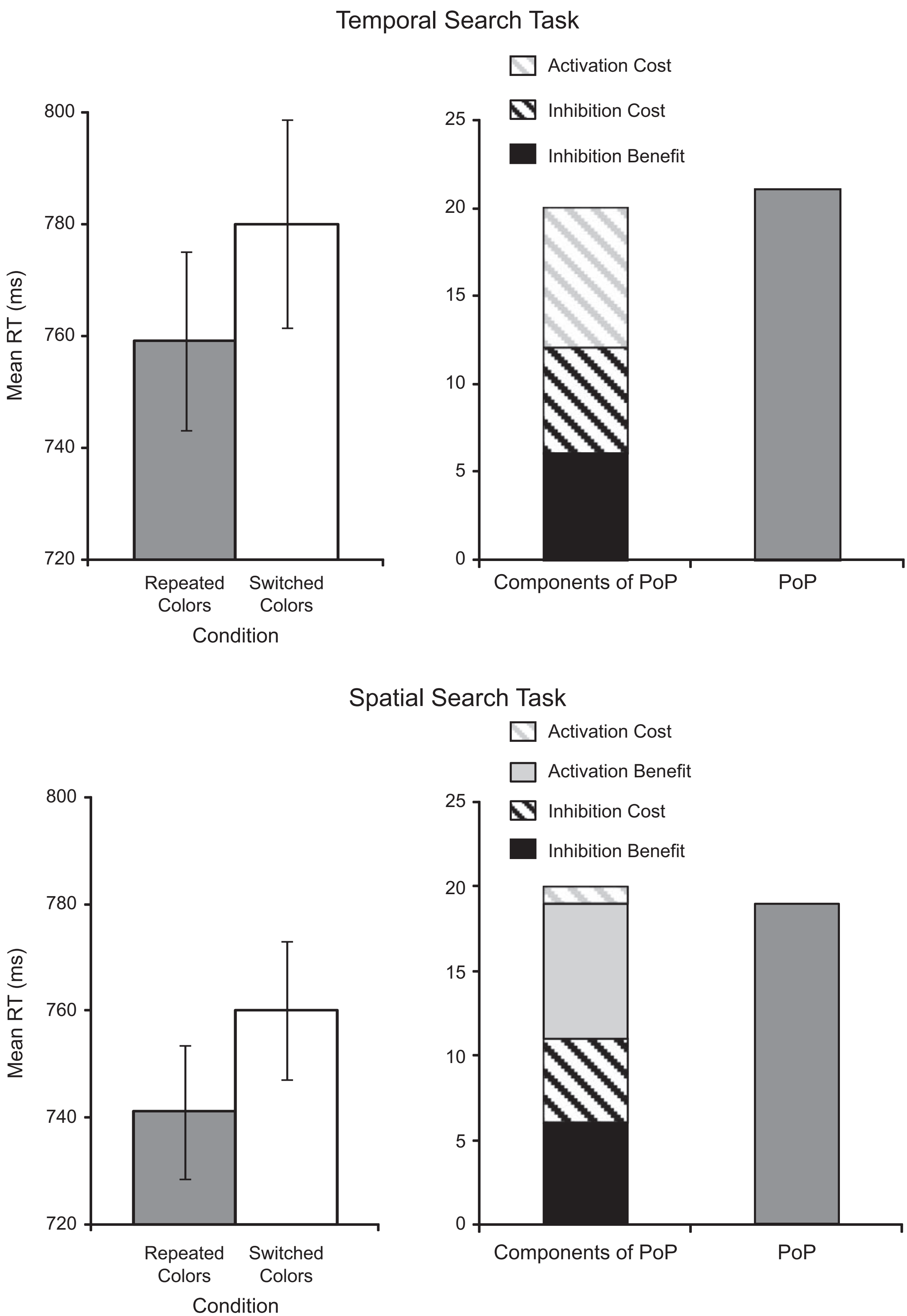

Fig. 4. Color priming of pop-out (PoP) for trials responded to correctly in the temporal search task (upper panel) and spatial search task (lower panel) in Experiment 2. The graphs on the left show the basic PoP effect: reaction times (RTs) on trials with repeated target and distractor colors and on trials with switched target and distractor colors. Error bars represent standard errors. The graphs on the right compare the basic PoP effect with the sum of its components (target-activation benefit and cost, distractor-inhibition benefit and cost).

effect for RTs, $t(18) = 5.51$, $p < .04$, and no PoP effect for accuracy, $F < 1$. Again, however, further analyses of the activation and inhibition components of PoP yielded only numerical trends in the expected direction. None of these approached significance for either RTs or accuracy, all Fs < 1.

Discussion. The decomposition of the PoP effect into its activation and inhibition components did not reveal any significant effects, whether retrieval took place in a temporal search or in a spatial search task. However, it may be noteworthy that, as illustrated in Figures 2 and 4, the sum of the four effects (target-activation benefit and cost plus distractor-inhibition benefit and cost) was very similar in magnitude to the basic PoP effect (repeated-target-color and repeated-distractor-color trials vs. switched-target-color and switched-distractor-color trials), in both the temporal search task and the spatial search task. Specifically, in the temporal search task of Experiment 2, the PoP components summed to 20 ms and the basic PoP effect was 21 ms, and in the spatial search task, these values were 20 ms and 19 ms, respectively.

The results of Experiment 2 revealed a PoP effect in both the temporal and the spatial search tasks: RTs were faster when the target and distractor features were repeated from one task to the next than when these features were switched. This finding suggests that the mechanisms underlying the PoP effect operate on the same representations in temporal and in spatial search tasks.

General Discussion

Our study provides the first demonstration of a PoP effect in a temporal search task. Our results have two main implications. First, by extending the PoP effect from the domain of selection in space to the domain of selection in time, they suggest that the effect occurs whenever there is a need for attentional selection, rather than only when there is spatial uncertainty (i.e., when the search task requires locating the target). Second, by showing that a selection-based effect, PoP, occurs when consecutive trials involve different search types, temporal search and spatial search, our results demonstrate that common mechanisms underlie selection in space and selection in time.

The findings from Experiment 1 suggest that the PoP effect in temporal search may result mainly from distractor-color inhibition (see Lleras, Kawahara, & Levinthal, 2009, for a report of distractor inhibition in an RSVP task, in the context of a different intertrial priming effect, namely, the distractor preview effect, or DPE). However, one should be cautious in interpreting this finding, as it may be tied to specific features of our RSVP task, rather than intrinsic characteristics of selection in the temporal domain. On the one hand, our RSVP task may not have been sensitive enough to measure effects of target-color activation. Indeed, these effects are known to wane over time (e.g., Maljkovic & Nakayama, 1994). Thus, selecting the target on the previous trial may have boosted the target-color representation, but, as the target appeared relatively late during RSVP trials, such target-feature activation may have disappeared by the time the target appeared on the current trial. On the other hand, during an RSVP trial, attention remained focused on the stream of distractors until the target appeared, thus making distractor-feature encoding—and, as a result perhaps, distractor inhibition—particularly potent. In Experiment 2, in which successive trials always involved different search tasks, the overall PoP effect proved to be significant, yet too small to allow assessment of the relative contributions of target activation and distractor inhibition.

Previous research has shown that attention can be focused on a particular location without being engaged at that location (e.g., Folk, Ester, & Troemel, 2009). In an RSVP pop-out search, observers must focus their attention on the stream and withhold attentional engagement until the task-relevant item (in the present case, the odd-colored item) appears. We suggest that in pop-out search, PoP affects the speed of attentional engagement on an object, which also depends on how much this object differs from the items that surround it in time or in space. Consistent with this hypothesis, the findings from brain studies of PoP suggest that both target-activation and distractor-inhibition components of PoP modulate neuronal activity in brain areas associated with coding of attentional saliency or behavioral relevance (e.g., the frontal eye field; Bichot & Schall, 2002). Accordingly, we propose that in both spatial and temporal pop-out search, the level of attentional saliency of a given feature on a particular trial is some weighted average of a value assigned to this feature according to its status on the current trial (negative if it is a distractor and positive if it is the target) and of a value assigned to it in a similar fashion according to its status on the previous trial. Engagement is faster the further apart the weighted average for the target feature is from the weighted average for the distractor feature. Further research should determine whether task demands modulate the relative weights of PoP and current target-distractor discriminability.

Our study is also the first to demonstrate a temporal priming effect. Previous studies have extended the role of top-down expectations from the spatial to the temporal domain, by showing that search performance is improved by informative cues regarding the time interval preceding the presentation of peripheral (Coull & Nobre, 1998) and central (Miniussi, Wilding, Coull, & Nobre, 1999) targets. Here, we have reported intertrial effects pertaining to the target's position in time: Performance is faster the more similar a target's position in the RSVP stream is to the position of the target on the previous trial. Further research is needed to determine whether this temporal priming effect is automatic, as the spatial-location and feature PoP effects are (Maljkovic & Nakayama, 1996), or whether it relies on trial-by-trial expectations formed by a high-level top-down mechanism.

Declaration of Conflicting Interests

The authors declared that they had no conflicts of interests with respect to their authorship and/or the publication of this article.

Note

1. This procedure for calculating the PoP components departed from that of Lamy, Antebi, et al. (2008), as their analyses pertaining to conditions of target-color variation (repeated, new, switched) were conducted across distractor-color conditions, and their analyses pertaining to conditions of distractor-color variation (repeated, new, switched) were conducted across target-color conditions. Indeed, the original procedure resulted in biased sampling of the orthogonal dimension. For instance, in the repeated- vs. new-target-color comparison, which measures the target-activation benefit, the repeated-color-target condition included only repeated- and new-color-distractor trials, whereas the new-color-target condition included switched-color-distractor trials in addition. Thus, activation effects were contaminated by inhibition effects, and vice versa. We thank an anonymous reviewer for this observation. The procedure used in our study removed this confound.

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