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Strategic visual imagery and automatic priming effects in pop-out visual search

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ABSTRACT

Priming of Pop-out (PoP) is defined by faster responses in singleton search when the target repeats across trials than when it switches. In a recent study, it was shown that the PoP effect can be reversed using visual imagery (Cochrane, Nwabuike, Thomson, & Milliken, 2018). The goal of the current study was to pinpoint the procedural constraints necessary to observe the imagery-induced reversal of PoP. Across four experiments the reversal of the PoP effect (i) depended critically on the response-stimulus interval between trials, (ii) was remarkably stable across long experimental sessions, (iii) was observed within trial-pairs when participants engaged in visual imagery, but not between trial-pairs when participants did not, and (iv) appeared to be more robust with self-paced trial-pairs than with a long continuous run of trials. Together, these results offer strong confirmation of the idea that self-generated visual imagery can produce robust reversals of the PoP effect.

1. Introduction

In a typical visual search task the goal is to find a target object among an array of distractor objects. Variations in search efficiency as a function of properties of the visual scene have been studied extensively (Treisman & Gelade, 1980; Duncan & Humphreys, 1989). Visual search is particularly efficient when the target differs from all distractors on a specific feature. These singleton targets appear to 'pop out' from the distractors. Interestingly, the efficiency of pop-out search itself has been shown to vary as a function of whether target and distractors remain the same or alternate across trials. Bravo and Nakayama (1992) observed that when the singleton color of a pop-out target repeated across trials, the target was identified faster than when that target color switched across trials. Maljkovic and Nakayama (1994) found this effect to be incredibly robust, naming it Priming of Pop-out (PoP).

Several theories have been forwarded to account for the PoP effect. One theory assumes that the effect results from passive memory representations of the target that carry-over from one trial to the next (Maljkovic & Nakayama, 1994, 1996, 2000). According to this view, identifying a red singleton target on one trial results in pre-attentive activation that speeds movement of attention and eye gaze to red targets on the subsequent trial. Another theory proposes that the PoP effect is mediated by more complex episodic memory representations (Hillstrom, 2000; Huang, Holcombe, & Pashler, 2004; Thomson & Milliken, 2011, 2012, 2013a). According to this view, faster responses for repeat trials hinge on retrieval of episodic representations for which the stored feature bindings match those needed to perform the current search task. As such, the episodic view assumes that the PoP effect is not due entirely to enhanced attentional processing, but rather reflects a form of improved decision-related processing; observers are faster to respond when the target and distractor colors remain consistent across trials because they are faster at interpreting the odd-colored object as being the target. It has also been proposed that the PoP effect works to resolve stimulus ambiguity (Meeter & Olivers, 2006), as the PoP effect only occurs when the target needs to be disambiguated across trials. Recent studies suggest that the PoP effect may have more than one cause, and may be influenced by more than one of the above putative causes simultaneously

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within a single task (Lamy, Yashar, & Ruderman, 2010; Becker, 2008; Kristjansson & Campana, 2010; Thomson & Milliken, 2013b).

A key constraint on these theories is a set of early findings indicating that the PoP effect is driven predominantly by automatic rather than strategic processes (Maljkovic & Nakayama, 1994). Maljkovic and Nakayama hypothesized that if expectation influences the PoP effect, then participants should respond fastest when the trial structure offers predictive information about an upcoming target. For example, in a pop-out search task with just two colors, one a target color and the other a distractor color, participants ought to respond equally fast when the target and distractor colors switch predictably on all trial transitions (i.e., a 100% switch block) or repeat predictably on all trials (i.e., a 100% repeat block). Furthermore, participants should respond more slowly than both of these conditions when target and distractor colors switch unpredictably on half of all trial transitions (i.e., a 50% switch block). What they found instead was that performance depended on the proportion of repeat targets rather than the predictability of targets within a block. In another experiment, Maljkovic and Nakayama ordered switch and repeat trials in the following predictable pattern: 'red', 'red', 'green', 'green', 'red', 'red', and so forth. In one block of trials, participants were instructed to report subvocally the predictable target color prior to onset of each search display. In a different block of trials, participants were instructed simply to respond to the search display without generating a prediction of the upcoming target color. Importantly, responses were faster for target color repeats than for target color switches in both blocks, and this advantage for repeats over switches did not differ between the two blocks. This result suggests that subvocalization of the upcoming target color had no impact on the PoP effect. From these experiments, Maljkovic and Nakayama (1994) concluded that the PoP effect is not impacted by strategic expectancies.

The broader issue of how strategic processes impact visual search also remains a contentious topic in the literature. Although there is wide agreement that top-down processes play a role in visual search (Wolfe, 1994), and do so even in efficient singleton search tasks (Folk, Remington, & Johnston, 1992), it can be difficult to tease apart top-down processes that are truly strategic from other more automatic processes. For example, Wolfe, Butcher, Lee, and Hyle (2003) showed that singleton search performance was efficient in blocks in which both the target-defining dimension (e.g., orientation, color) and feature (e.g., horizontal/vertical, red/green) varied unpredictably from trial-to-trial – suggesting that bottom-up processes can effectively guide search. At the same time, search performance was substantially faster in pure blocks in which singleton targets stayed the same from trial-to-trial. Wolfe et al. proposed that this difference between mixed and pure block performance could be due to top-down strategy differences between the conditions. However, Wolfe et al. acknowledged that this performance difference could also have been driven by inter-trial influences that produce PoP effects (Maljkovic & Nakayama, 1994), or more broadly 'selection history' effects (Awh, Belopolsky, & Theeuwes, 2012), that may be automatic (implicit) rather than strategic (explicit) in nature. Teasing apart these two influences on singleton search is not a straightforward issue – automatic effects on performance can easily be misattributed to top-down strategies (Awh et al., 2012).

A similar theme is captured by a study reported by Theeuwes and van der Burg (2011). Search displays with two color singletons were presented, one a target singleton and the other a distractor singleton. A cue that preceded the search display indicated which of the two singletons was the target. The key research question was whether top-down processing of the cue that signaled the target singleton would prevent processing of the distractor singleton. Interference from the distractor singleton was measured by manipulating the congruency of line segments inside the target and distractor singletons, and by asking participants to respond to the orientation of the line inside the target singleton. With this method, a null congruency effect indicates perfect selection of the target singleton, whereas faster responses to congruent than incongruent trials indicate capture of attention by the distractor singleton. The results indicated perfect selection only when the target singleton repeated on consecutive trials. In other words, automatic selection history influences that produce inter-trial priming effects were more effective than top-down processing of the cue in guiding selection of the target singleton (see also Theeuwes, 2010a, 2010b). Again, these results highlight the idea that automatic influences on visual search can easily be misattributed to top-down, strategic effects. In light of results such as these, Awh et al. (2012) cautioned that "goal-driven selection effects can be elusive when inter-trial priming effects are eliminated … future efforts to demonstrate goal-driven selection of non-spatial features should focus on isolating putative goal-driven effects from the known consequences of selection history" (p. 438).

In line with the recommendation of Awh et al. (2012), we introduced a new method that teases apart goal-driven strategy effects and automatic selection history effects in a PoP procedure (Cochrane et al., 2018). Visual search trials were presented in pairs, and participants self-initiated the presentation of each pair. The target and distractor colors (red and green, or vice versa) interchanged across trials within a trial pair on switch trials, and remained the same on repeat trials. Participants were to respond to the first trial in each trial pair, and then to imagine a square opposite in color to the first trial target in preparation for the second trial target. This method teases apart top-down visual imagery strategies and automatic selection history effects by placing these two influences on performance in opposition. The key result was that responses were faster for switch trials than for repeat trials; that is, participants identified the target more quickly when the upcoming target color matched the color they were imagining than when it matched the previous target color. Furthermore, we found that not all expectancies reverse the PoP effect. When participants were required to say the opposite color aloud instead of imagining the opposite color a reversal of the PoP effect was not observed. This result implies that strategic expectancies that are visual in nature can influence the PoP effect.

A puzzle that remains is why strategic expectancies have so little influence on the PoP effect in some studies (e.g., Maljkovic & Nakayama, 1994; Theeuwes & van der Burg, 2011), but have a profound influence in other studies (Cochrane et al., 2018). To address this issue in the present study, we examined the visual imagery effect reported by Cochrane et al. (2018) in more detail. The goal was