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Active suppression of salient-but-irrelevant stimuli does not underlie resistance to visual interference

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ABSTRACT

In visual search for a shape target, interference from salient-but-irrelevant color singletons can be resisted in feature search mode, but not in singleton detection mode. In singleton detection mode, we observed a contralateral positivity (P_D) after 260–340 ms, suggesting that the salient distractor was suppressed. Because RTs in singleton detection mode increased when a distractor was present, we conclude that active suppression of distractors takes time. In feature search mode, no increase in RTs and no P_D to the distractor was observed, showing that resistance to interference was not accomplished by suppression. Rather, the smaller N2pc to the target in feature search than in singleton detection mode suggests that enhancement of target features avoided interference. Thus, the strong top-down set in feature search mode eliminated the need to suppress the early attend-to-me signal (corresponding to the Ppc, from 160 to 210 ms) that was generated by salient stimuli independently of search mode.

1. Introduction

In some advertisement campaigns, the advertised product is the only colored object in an otherwise black-and-white picture. The creative minds behind these campaigns followed their intuition that observers' attention would be drawn to the colored stimulus. Research on visual selective attention provides evidence that this strategy may work even against the intentions of the observer. In the additional singleton paradigm (Theeuwes, 1991), participants were asked to search for a shape that was different from the remaining shapes in the display (i.e., a shape singleton). On 50% of the trials, all stimuli had the same color whereas on the other 50% of the trials, one of the nontarget elements had a different color (i.e., a color singleton). The presence of a color singleton increased search times for the shape singleton although color was completely irrelevant for the task. The interpretation by Theeuwes (1991, 2010) was that the color singleton captured attention. According to this view, the initial attentional selection is based on saliency. That is, attention selects the object that stands out most from its visual context.

1.1. Singleton detection and feature search mode

The view that attention is controlled in a bottom-up manner by characteristics of the stimulus was opposed by the view that attentional control is top-down (e.g., Bacon & Egeth, 1994; Folk, Remington, & Johnston, 1992) (for review, see Lamy, Leber, & Egeth, 2012). According to Bacon and Egeth (1994), the distractor effect in the additional singleton paradigm arises because participants did not search for a particular target feature, but for any odd element. While this singleton detection strategy was feasible on distractor absent trials, it led to the erroneous selection of the color singleton on distractor present trials. Correcting for the wrong selection explains the longer RTs. To isolate the singleton detection strategy, Bacon and Egeth (1994) used a singleton shape target that varied unpredictably from trial to trial while the shape of nontarget elements did not change (see Fig. 1). Thus, participants could not focus on any particular shape, but had to search for the odd shape. To isolate search for a particular feature (i.e., feature search mode), they mixed various shapes into the search display so that the shape target was no longer a singleton. As a result, interference from the color distractor disappeared, demonstrating that the top-down set determines whether interference occurs. We refer to the absence of behavioral interference from salient distractors in feature search mode as **resistance to interference**.

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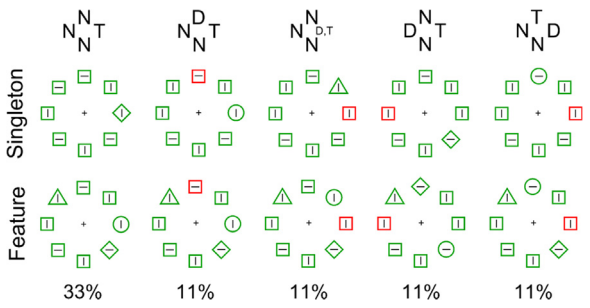

Fig. 1. Examples of experimental stimuli in singleton detection and feature search modes. Insets in row 1 show the schematic target (T), distractor (D), and nontarget (N) positions. In singleton detection mode, participants searched for a randomly changing shape (diamond, circle, or triangle, see row 2) that was a singleton among uniform nontargets. In feature search mode, participants searched for a circle among various nontarget shapes (see row 3). Here, we presented the target and distractor mostly at the top and on the right, but in the experiment, stimulus positions were randomized. The prevalence of each configuration as percentage of the total number of trials is shown at the bottom.

It should be noted that the original additional singleton paradigm allows for both search strategies. Bacon and Egeth (1994) stressed that observers may have used singleton detection because the target was a shape singleton. However, the target shape never changed so that in principle, observers could have used feature search. Whether observers use singleton detection or feature search may depend on previous exposure to singleton detection or feature search. Leber and Egeth (2006) showed that participants who were trained in singleton detection mode (with variable targets and uniform nontargets) showed interference in a subsequent test with the additional singleton paradigm. In contrast, participants who were trained in feature search mode (with fixed target and heterogeneous nontargets) did not show interference in the additional singleton paradigm. Thus, both strategies are available in the additional singleton paradigm (see also Lamy & Egeth, 2003).

1.2. Mixed- and fixed-feature search

Hickey, McDonald, and Theeuwes (2006) were the first to investigate the deployment of attention to salient-but-irrelevant color singletons in the additional singleton paradigm using electrophysiology. They focused on the N2pc, a negative deflection occurring contralateral to the attended stimulus at posterior sites (Eimer, 1996; Luck & Hillyard, 1994). By placing the distractor on a lateral position and the target on the vertical midline above or below central fixation (see Woodman & Luck, 2003), they were able to measure attentional capture by the distractor. Hickey et al. (2006) reported an N2pc to lateral distractors with midline targets, confirming attentional capture by salient stimuli. In their study, target and nontarget shapes were randomly swapped so that participants could not focus on a specific target shape. That is, on one trial, the target may have been a circle among diamonds, but on the subsequent trial, the target may have been a diamond among circles. We refer to this paradigm as the mixed-feature version of the additional singleton paradigm (see Theeuwes, 1991). An overview of the different search tasks is provided in Table 1.

Some studies replicated the N2pc to salient distractors in mixed-feature search (Burra & Kerzel, 2013; Kiss, Grubert, Petersen, & Eimer, 2012), in particular on trials after target and distractor shapes swapped (Hickey, Olivers, Meeter, & Theeuwes, 2011), but others failed to do so (McDonald, Green, Jannati, & Di Lollo, 2013). Instead, McDonald et al. (2013) observed a contralateral deflection of opposite polarity in distractor-present trials with short RTs. The contralateral positivity is referred to as P_D and occurs in the same time range as the N2pc (Burra & Kerzel, 2013; Hickey, Di Lollo, & McDonald, 2009; Kiss et al., 2012) or follows the N2pc (Feldmann-Wüstefeld & Schubö, 2013; Hilimire, Mounts, Parks, & Corballis, 2011; Sawaki & Luck, 2012). The interpretation of the P_D occurring in the N2pc time range was that it reflects the suppression of irrelevant-but-salient stimuli, and the interpretation of the P_D occurring after the N2pc was that it reflects the active termination of a shift of attention.

While there is some disagreement on the presence of the P_D to salient-but-irrelevant stimuli in the mixed-feature version of the additional singleton paradigm (see Theeuwes, 1991), the P_D was more reliably observed in the fixed-feature version (see Theeuwes, 1992) where the target and nontarget shapes do not swap, but are fixed throughout the experiment. Jannati, Gaspar, and McDonald (2013) reported a P_D to the color distractor on trials with short RTs and Burra and Kerzel (2013) reported a P_D for all trials.

Further, a P_D to salient distractors occurred in mixed-feature search when the search display of the additional singleton paradigm was only briefly flashed for 200 ms (Kiss et al., 2012), suggesting that suppression of salient-but-irrelevant stimuli occurred when attentional selection had to occur rapidly (see also Feldmann-Wüstefeld, Uengoer, & Schubö, 2015). In general, divergent results were reported in studies with briefly flashed stimuli and fixed-feature search that did not use geometrical shapes as nontarget elements, but a large array of vertical lines that resemble a visual texture or pattern. Töllner, Müller, and Zehetleitner (2012) and Wykowska and Schubö (2010) reported no lateralized ERP to salient color distractors (but see Feldmann-Wüstefeld & Schubö, 2013), but an increase in the latency of the N2pc to the target when the distractor was present. Because we used geometrical shapes and unlimited viewing time in the present study, we derive our predictions from studies using these parameters.

Overall, the P_D appears to be associated with conditions that favor efficient target selection and rapid suppression of irrelevant stimuli. Most important, the P_D to salient distractors occurred reliably in fixed-feature search where RTs were short and interference from distractors was small, presumably thanks to active suppression of the distractor (Burra & Kerzel, 2013; Jannati et al., 2013; Lamy & Yashar, 2008; Pinto, Olivers, & Theeuwes, 2005). In contrast, an N2pc to salient distractors was only observed in mixed-feature search where RTs were long and interference from distractors was large, most likely due to attentional capture by the distractor (Burra & Kerzel, 2013; Hickey et al., 2006; Hilimire & Corballis, 2014; Kiss et al., 2012).

Table 1
Characterization of the different search tasks and the corresponding behavioral and electrophysiological observations. The shape of the singleton target varied across trials in mixed-feature search and singleton detection mode. The number of possible target shapes across trials is indicated by "# shapes". The nontargets in a given trial could either be the same or there could be other unique elements ("various"). Target and nontargets switched roles randomly in mixed-feature search. See the introduction for more detailed explanations and References.

Title	Target (# shapes)	NonTargets	Roles	Interference	ERP
mixed-feature search	singleton (2)	same	swaps	large	mostly N2pc
fixed-feature search	singleton (1)	same	fixed	intermediate	P_D
singleton detection	singleton (3)	same	fixed	intermediate	P_D
feature search	non-singleton (1)	various	fixed	absent	none