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Tracking target and distractor processing in fixed-feature visual search: Evidence from human electrophysiology

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Abstract

Salient distractors delay visual search for less salient targets in additional-singleton tasks, even when the features of the stimuli are fixed across trials. According to the salience-driven selection hypothesis, this delay is due to an initial attentional deployment to the distractor. Recent event-related potential (ERP) studies found no evidence for salience-driven selection in fixed-feature search, but the methods employed were not optimized to isolate distractor ERP components such as the N2pc and distractor positivity (P_D; indices of selection and suppression, respectively). Here, we isolated target and distractor ERPs in two fixed-feature search experiments. Participants searched for a shape singleton in the presence of a more-salient color singleton (Experiment 1) or for a color singleton in the presence of a less-salient shape singleton (Experiment 2). The salient distractor did not elicit an N2pc, but it did elicit a P_D on fast-response trials. Furthermore, distractors had no effect on the timing of the target N2pc. These results indicate that (i) the distractor was prevented from engaging the attentional mechanism associated with N2pc; (ii) the distractor did not interrupt the deployment of attention to the target; (iii) competition for attention can be resolved by suppressing locations of irrelevant items on a salience-based priority map.

Key words: attention capture, visual search, N2pc, P_D, Ppc
The number of objects falling within our field of view typically exceeds our brain’s perceptual capacity. Observers can deal with this surplus of information by attending to a specific region of the visual field to selectively process stimuli appearing there (Desimone & Duncan, 1995; LaBerge, 1995). At any moment, two complementary control processes interact to determine which location is to be attended next: (1) goal-driven control processes that bias attentional selection toward objects of interest; (2) stimulus-driven control processes that bias selection toward physically salient items. Two main perspectives have emerged regarding the role of each process in attentional selection. According to one perspective, attention is deployed initially to the most salient item, regardless of its task relevance (Theeuwes, 1991, 1992, 1994, 2010). According to the other perspective, such salience-driven attention capture can be prevented when an observer knows what to look for, so that attention can be deployed directly to a relevant, but less salient, stimulus (Anderson & Folk, 2010; Bacon & Egeth, 1994; Folk & Remington, 1998, 2006; Folk, Remington, & Johnston, 1992; Folk, Remington, & Wright, 1994; Müller, Reimann, & Krummenacher, 2003; Wolfe, 1994; Wolfe, Butcher, Lee, & Hyle, 2003).

Evidence for goal-driven control of attention has been obtained from a modified spatial cueing paradigm in which a display containing a spatially nonpredictive singleton precedes a target search display (Folk & Remington, 1998, 1999; Folk et al., 1992, 1994). In this paradigm, the distractor singleton appears to capture attention only when the defining features of the two singletons match (e.g., both are colour singletons; Folk et al., 1992). In contrast, evidence for stimulus-driven control has been obtained from the additional-singleton paradigm, in which observers search covertly for a target singleton while trying to ignore a distractor singleton in the same display (Theeuwes, 1991, 1992, 1994). The distractor singleton is typically chosen to pop out more than the target singleton, so that the distractor’s bottom-up salience and the observer’s
top-down goal are in opposition and will thus compete for attentional selection. In this case, the presence of the distractor delays search for the target. For example, Theeuwes (1991) reported that a salient colour-singleton distractor delayed search for a shape-singleton target by 120–150 ms when the features of the target and the distractor swapped randomly across trials. Under these mixed-feature conditions, participants know that the target will be the unique shape, but they do not know what shape or colour it will be on any given trial. The delay is reduced considerably when the features of the stimuli are fixed across trials. For example, Theeuwes (1992) reported that a salient colour-singleton distractor delayed search for a shape-singleton target by 20–25 ms in a fixed-feature variant of the additional-singleton paradigm.

Salience-driven selection

The results obtained from the additional-singleton paradigm gave rise to the salience-driven selection hypothesis, according to which the initial visual selection is determined entirely by stimulus salience (i.e., local contrast; for a recent review, see Theeuwes, 2010). In the context of this hypothesis, selection is defined as the transfer of information from an early, “preattentive” stage of processing to a subsequent “attentive” stage of processing. It is assumed that basic visual features are processed in parallel and that stimulus salience is computed during the preattentive stage. After these preattentive analyses, sensory information stemming from the location with the highest computed salience is transferred to the attentive stage with no intervening top-down control. By this account, attention is deployed automatically to the location of the most salient item (i.e., it is captured). In the context of the additional-singleton paradigm, if the attended item is identified as the target, the observer processes the orientation of the line inside the shape and makes a response accordingly. If the item is identified as a distractor, attention is disengaged and re-deployed to the location of the next most salient item, i.e., the target.
This processing sequence has been hypothesized to take place in fixed-feature as well as mixed-feature search tasks. Why then does the presence of a salient distractor cause much greater interference in mixed-feature search than in fixed-feature search? According to Theeuwes (2010), an item in fixed-feature search can be identified rapidly because there is no uncertainty stemming from stimulus variability. Thus, in this case, attention can be disengaged from the distractor location quickly, resulting in little RT interference. In mixed-feature search, however, it takes considerably longer to identify the item as target or distractor because the features change across trials and the target and distractor can actually swap. Accordingly, it takes more time to disengage attention from the distractor location in mixed-feature search, resulting in greater RT interference. In other words, there is greater interference in fixed-feature search not because distractors cause more capture, but because it takes additional time to decide whether the initially selected item is a target or a distractor.

**ERP indices of selection in visual search**

Researchers have used event-related potentials (ERPs) to study the neurophysiological correlates of attentional selection. Given the lateralized organization of the visual system, most ERP studies of visual search have focused on *event-related lateralizations* (ERLs), which are isolated by comparing ERP waveforms recorded contralateral and ipsilateral to the location of stimuli of interest.

**The N2pc**

Most ERP studies of attention capture have focused on an ERP component known to reflect the selection of items in visual search. This component – known as the posterior contralateral N2 (N2pc) – is apparent in the ERPs recorded over the lateral occipital scalp, 175–300 ms after the onset of a search display containing a task-relevant singleton. During that time interval, the ERP...
to the search display is more negative contralateral to the (presumably attended) singleton than ipsilateral to that item.

Figure 1 illustrates the stage at which the N2pc likely occurs in an additional-singleton search task. After the preattentive stage, the location of the most salient item is selected (spatial selection). An additional stage of attentional selection is then required to resolve ambiguities in neural responses associated with different objects in the display (Desimone & Duncan, 1995; Luck, Girelli, McDermott & Ford, 1997). The N2pc is believed to be associated with such processes, which we call filtering (cf. Luck & Hillyard, 1994b; Luck, Girelli, McDermott & Ford, 1997). This sequence is consistent with recent evidence that the N2pc is associated with the processing of objects, but not empty locations, in the search display (Woodman, Arita, & Luck, 2009). Once the object features are resolved, the item can be identified as the target or distractor. If the attended item is identified as a distractor, the attended location is inhibited to enable a shift of attention to a new location (e.g., that of the next most salient item on the saliency map). If the attended item is identified as the target, further processing is done to discriminate the orientation of the line inside the target shape and then execute the appropriate manual response.

Beyond the N2pc

Several additional ERL components have been associated with visual search. As noted above, distractors sometimes elicit a contralateral positivity called the P_D in the N2pc time range. This P_D can be isolated using displays containing a lateral distractor and a midline target (Hickey et al., 2009). In this case, attending to the midline target will not result in any lateralized ERP (Woodman & Luck, 2003), thereby making it possible to attribute the observed ERL components
to the distractor. The $P_D$ is not typically observed in the reverse display configuration – that is, when the target is lateralized and the distractor is on the midline – suggesting that it reflects selective processing of the distractor (Hickey et al., 2009; see also Hilimire, Mounts, Parks, & Corbalis, 2011). Hickey et al. proposed that the $P_D$ reflects suppression of an irrelevant, but potentially distracting, stimulus. Similar proposals have been made about distractor positivities that follow the N2pc time range (Hilimire et al., 2011; McDonald, Green, Jannati, & Di Lollo, in press).

Early contralateral positivities preceding the N2pc have also been reported in several search studies. These positivities have been associated with low-level sensory processes (Luck & Hillyard, 1994a), preattentive identification of salient featural discontinuities (Fortier-Gauthier, Moffat, Dell’Acqua, McDonald, & Jolicœur, 2012), or suppression of an “attend-to-me” signal (Sawaki & Luck, 2010). One early positivity appears to be related to the stimulus-driven $P1$ (75–125 ms), which is sometimes larger contralateral to the location of a singleton than ipsilateral to it. This lateralized $P1$ has been attributed to low-level sensory processes (Luck & Hillyard, 1994a).

A similar contralateral positivity has been labeled the $Ppc$ (Positivity, posterior contralateral; Fortier-Gauthier et al., 2012; Leblanc, Prime, & Jolicœur, 2008). The $Ppc$ is typically found over the lateral occipital scalp, in the N1 time interval (140–190 ms). Like the contralateral $P1$, the $Ppc$ is elicited by both target and nontarget singletons, especially in fixed-feature search tasks. Therefore, it also seems to be tied to low-level sensory processes. However, the $Ppc$ can be elicited by a centrally presented stimulus used to cue recollection of a multi-item display presented 1400 ms earlier (Fortier-Gauthier et al., 2012). In this case, the $Ppc$ is found contralateral to a lateral singleton in the previous display, regardless of whether that singleton is
to be recalled or ignored. This finding suggests that the Ppc does not reflect low-level sensory processes, per se.

Later contralateral positivities have been reported recently. One of these positivities has been labeled the Ptc (Positivity, temporal contralateral; Hilimire, Mounts, Parks, & Corballis, 2009, 2010), which is typically found over the lateral temporal scalp, in the post-N2pc time range (290–340 ms). The amplitude of the Ptc has been reported to vary with the separation between target and distractor but not with the separation between two targets. Based on these results, the Ptc has been attributed to individuation of a target subsequent to its identification (Hilimire et al., 2010). However, recent work indicated that distractors, but not targets, elicit the Ptc (Hilimire, Mounts, Parks, & Corballis, 2011). This suggests that, like the PD, the Ptc might reflect resolution of perceptual competition by distractor suppression. Interestingly, Sawaki, Geng, and Luck (2012) described a late (i.e., post-N2pc) positivity contralateral to task-relevant targets. Sawaki et al. interpreted this target positivity (or PT) as a suppression-based termination of target processing.

Lastly, a late negativity called the SPCN (sustained posterior contralateral negativity) has been observed about 400 ms after stimulus onset (Jolicœur, Brisson, & Robitaille, 2008). The SPCN is hypothesized to occur after the attentional-filtering stage and to reflect the active maintenance of information in visual short-term memory (VSTM; Corriveau et al., in press; Jolicœur et al., 2008; Luria, Sessa, Gotler, Jolicœur, & Dell'Acqua, 2010; Vogel & Machizawa, 2004). In compound-search tasks, this active maintenance might be associated with the identification of the relevant stimulus features (e.g., orientation of the line inside the target shape; Mazza, Turatto, Umiltà, & Eimer, 2007).
**ERP evidence for attention capture**

Hickey, McDonald, and Theeuwes (2006) recorded ERPs in a mixed-feature variant of the additional-singleton paradigm. Participants searched for a target shape singleton that was often accompanied by a salient-but-irrelevant colour singleton. Two main results were taken as strong evidence for attention capture. First, when the target was positioned on the vertical midline (so as not to elicit lateralized ERPs), a lateral distractor was found to elicit the N2pc. This demonstrated that attention was deployed directly to the distractor, at least on a portion of trials. Second, when the two singletons were presented on opposite sides of fixation, the ERP recorded over the lateral occipital scalp was initially more negative contralateral to the distractor and subsequently became more negative contralateral to the target. Hickey et al. regarded this N2pc “flip” as evidence that observers attended to the salient distractor before attending to the target.

Although the distractor N2pc showed that attention was deployed to the salient distractor, the evidence for the salience-driven selection hypothesis remains equivocal for two reasons. First, the original ERP evidence for salience-driven selection is not as conclusive as it was once believed. A follow-up study revealed that the N2pc flip reported by Hickey et al. was due to noise in the ERPs and that the distractor elicited a P_D on fast-response trials (McDonald et al., in press). Such findings indicate that salience-driven selection was prevented by distractor suppression on about half of the trials.

Second, as noted earlier, the distractor interference obtained in the mixed-feature search task cannot be ascribed to capture alone because it reflects some combination of attention capture and increased attentional dwell time. In fact, according to Theeuwes (2010), the bulk of the distractor interference may reflect the time required to determine whether the attended stimulus is the target or a distractor (i.e., the dwell time). Moreover, in mixed-feature search, participants
might attend to the distractor only when that stimulus served as the target on the previous trial (cf. Pinto, Olivers, & Theeuwes, 2005). This can occur because the target and distractor features are swapped randomly across trials in Theeuwes' (1991) original mixed-feature task.

Whereas the distractor interference effects obtained in the mixed-feature task may reflect increased attentional dwell time, the interference effects obtained in the fixed-feature task are believed to reflect capture only (because there is very little attentional dwell time; Theeuwes, 2010). Thus, it is necessary to investigate the ERP correlates of attention capture in the fixed-feature variant of the additional-singleton paradigm. This has been done in a few recent studies (Schübo, 2009; Wykowska & Schübo, 2010, 2011). In a study by Schübo (2009), singletons were never presented on the vertical meridian, and thus it was not possible to isolate a distractor N2pc. Instead, Schübo examined how the presence of the distractor affected the target N2pc and looked for an N2pc flip when target and distractor were on opposite sides of fixation. Two main results emerged from this study. First, no N2pc flip was in evidence; when target and distractor were on opposite sides, the N2pc was seen contralateral to the (less-salient) target only. Second, the target N2pc was smaller when a contralateral distractor was present than when the distractor was absent. Based on these findings, Schübo concluded that attention was deployed initially to the distractor on some trials, but not reliably enough to produce an N2pc flip.

Wykowska and Schübo (2010, 2011) reached different conclusions in studies that combined fixed-feature visual search with a subsequent probe task. Participants responded first to the probe and then indicated whether the search target was present in the preceding search display. A target N2pc but no distractor N2pc was in evidence, suggesting that attention was deployed only to the target. Importantly, however, the target N2pc occurred later when the distractor was on the opposite side than when it was on the same side of fixation. Wykowska and
Schübo suggested this delay might reflect a nonspatial filtering cost (cf. Folk & Remington, 1998). Theeuwes (2010), on the other hand, suggested the delay might be due to a shift of attention to the distractor followed by a rapid disengagement of attention.

In summary, the ERP evidence for the salience-driven selection hypothesis is equivocal. Although salient distractors sometimes elicit N2pc in mixed-feature search tasks (Hickey et al., 2006; McDonald et al., in press), they do not appear to elicit N2pc in fixed-feature search tasks (Schübo, 2009; Wykowska and Schübo; 2010, 2011). However, the extant ERP studies of fixed-feature search were designed to test for an N2pc flip, not to isolate a distractor N2pc by placing the target on the vertical meridian. The lack of N2pc flip does not rule out the salience-driven selection hypothesis, however. Indeed, we now know that while salient distractors elicit an N2pc in mixed-feature tasks, there is no N2pc flip when target and distractor are on opposite sides (McDonald et al., in press). Moreover, it is unclear whether the subtle distractor-interference effects on target N2pc that have been reported reflect salience-driven capture (Schübo, 2009; Theeuwes, 2010), nonspatial filtering costs (Wykowska & Schübo, 2010, 2011), or some other process.

The present study

The present study was designed to investigate selective processing of target and distractor singletons in fixed-feature variants of the additional-singleton paradigm. Unlike prior fixed-feature ERP studies, we isolated target and distractor ERLs using displays containing one lateral singleton and one midline singleton. Rather than focusing exclusively on the N2pc, we used the isolated ERLs to track target and distractor processing through successive stages (see Fig. 1).

The present study consisted of two fixed-feature search experiments. In Experiment 1, the target was a shape singleton and the distractor was a more-salient color singleton. In Experiment
2, the same search displays were used, but the singletons designated as target and distractor were reversed (colour-singleton target, shape-singleton distractor). Presenting the identical search displays in the two experiments while reversing the roles of the two singletons would enable us to directly study the effect of salience on the attentional processing in visual search. We hypothesized that if salience alone determines which of the two singletons is attended first, we would observe the interference only when the distractor was more salient than the target. This is because when the target was the most salient item, it would always be attended first and its processing could proceed without delay. On the other hand, if the presence of a less-salient distractor caused interference as well, it would argue against the role of salience in generating distractor interference.

Experiment 1

Methods

The Research Ethics Board at Simon Fraser University approved the experimental protocol used in this study.

Participants. Forty neurologically typical volunteers from Simon Fraser University participated in this experiment after giving informed consent. The participants were either paid for their participation or received course credit. Data from three participants were excluded from analyses because of excessive blinks or eye movements. Each of the remaining 37 participants (27 women, age 19.6 ± 1.4 years, mean ± SD, 4 left-handed) reported normal or corrected-to-normal visual acuity and had normal color vision.

Apparatus. The experiment was conducted in a dimly lit, sound attenuated and electrically shielded chamber that contained a 19-in. CRT monitor with the screen resolution set to 800 × 600 pixels. Participants sat in an adjustable chair and viewed the monitor from a distance of 60
A Windows-based computer running Presentation (Neurobehavioral Systems Inc., Albany, CA, USA) controlled stimulus presentation and registered the participants' button presses. A second Windows-based computer running custom software (Acquire) controlled EEG acquisition. The acquisition computer housed a 64-channel A-to-D board (PCI 6071e, National Instruments, Austin, TX, USA) that was connected to an EEG amplifier system with high input impedance (SA Instrumentation, San Diego, CA, USA). Tin electrodes mounted in an elastic cap (Electro-cap International, Eaton, OH, USA) were used to record EEG.

**Stimuli and Procedure.** At the beginning of the experimental session, participants were presented with a brightness-matching display that consisted of a filled red rectangle ($2.1° \times 3°$; RGB = 255, 0, 0) and a filled green rectangle (RGB = 0, 160, 0) of the same size, adjacent to each other at the center of the screen. Participants were instructed to match the brightness of the red rectangle to that of the green rectangle. Pressing the left or right mouse button increased or decreased the R-value of the red color by 2 RGB units, respectively. The minimum and maximum brightness allowed for the red rectangle were set at RGB = 51, 0, 0, and RGB = 255, 0, 0. When the two rectangles were perceived to be equally bright, participants pressed the middle mouse button to end the current brightness-matching trial. Four brightness-matching trials were presented to each participant. The initial R-values of the red color in the second and fourth trials were 30 RGB units lower than in their preceding trials, whereas the initial R-value of the red color in the third trial was 30 RGB units higher than in the second trial. At the end of the fourth brightness-matching trial, the final R-values in all four trials were averaged together. This averaged value was used as the R-value of the red color throughout the experiment. The color of the green rectangle used in the brightness-matching procedure was used as the green color in the subsequent visual search task (20.1 cd/m$^2$).
All stimuli were presented on a black background (0.02 cd/m²). Search displays consisted of ten objects presented equidistant (9.2°) from a central fixation point. Two of the objects were presented directly above and below fixation, and the remaining eight objects were spaced equally, resulting in four objects on each side. Each display contained nine unfilled diamonds (4.2° × 4.2°) and one unfilled circle (3.4° diameter). On half of the trials, one of the nine diamonds was red; all of the remaining objects were green. A horizontal or vertical gray line (0.3° × 1.5°) was centered within each object.

Each trial began with a fixation point appearing for 800–1,200 ms, followed by a search display that remained on screen for 100 ms after a response was registered. The participants’ task was to press one of two mouse buttons with their right hand depending on the orientation of the line contained in the green circle (i.e., the target shape singleton). Participants were instructed to respond as quickly as possible while maintaining high accuracy. They were also asked to maintain eye fixation throughout the experiment and were told that eye movements were being monitored. Each experimental block consisted of 36 trials, and each participant completed 42 experimental blocks, for a total of 1,512 experimental trials, after performing at least 36 practice trials.

The target shape singleton appeared at one of the eight lateral positions or one of the two positions on the vertical midline. When present, the red diamond (i.e., the distractor color singleton) also appeared either at a lateral position or a midline position, resulting in the following display configurations: lateral target, midline distractor (11%); midline target; lateral distractor (11%); lateral target, no distractor (33%); lateral target, contralateral distractor (11%); lateral target, ipsilateral distractor (11%); midline target, no distractor (17%); midline target, midline distractor (6%).
**Electrophysiological Recording.** EEG signals were recorded using our standard procedures, including a semi-automated routine for rejection of trials contaminated by blinks or eye movements (for additional details, see Green, Conder, & McDonald, 2008). Eye movements were monitored using bipolar recordings from electrodes positioned lateral to the left and right external canthi (horizontal electro-oculogram, HEOG). Blinks were detected using scalp electrode FP2, positioned over the right eye. Electrode impedances were kept below 10 kΩ. All signals were amplified with a gain of 20,000 and a pass-band of 0.01–100 Hz and were digitized at 500 Hz.

**Data analyses.** Median RTs were computed for distractor-present and distractor-absent trials for each participant, after excluding trials on which participants responded incorrectly, too quickly (RT < 100 ms) or too slowly (RT > 1500 ms). A paired $t$-test was used to assess the difference between the resulting median RTs. This was used to gauge the overall RT interference effect (distractor-present RTs vs. distractor-absent RTs). Median RTs were also computed separately for each of five display configurations of interest. This enabled us to compare RTs to targets with same-hemifield distractors and different-hemifield distractors as an initial means to test the hypothesis that nearby distractors cause more interference than distant distractors (Caputo & Guerra, 1998; Mounts, 2000a, 2000b). A subsequent analysis was performed to assess RTs as a function of target-distractor proximity. For this proximity analysis, RTs to lateral-target displays were re-averaged according to the number of positions between target and distractor. Only trials with lateral distractors were submitted to this analysis. Thus, ipsilateral distractors could be one, two, or three items from the target, and contralateral distractors could be two, three, four, or five items from the target. A paired $t$-test was used to compare RTs associated with an adjacent distractor (ipsilateral, distance 1) and an opposite distractor (contralateral,
distance 5). Follow-up t-tests were used to compare each of these RTs to the RT on corresponding lateral-target, distractor-absent trials.

ERPs and average HEOGs time-locked to the various search-display configurations were computed separately based on artifact-free trials. The averaged waveforms were digitally low-pass filtered using a Gaussian finite impulse function (−3 dB point at 25 Hz) to remove high-frequency noise produced by muscle activity and external electrical sources and were digitally re-referenced to the average of the left and right mastoids. Mean ERP amplitudes within time windows of interest (e.g., centered upon the N2pc) were computed with respect to a 200-ms pre-stimulus interval. This interval was also used to determine the baseline of the ERPs presented in all figures. The average HEOG did not exceed 2 µV for any of the 37 participants, which suggests that on average the eyes were within 0.3° of the fixation point throughout the artifact-free trials (see McDonald & Ward, 1999, for HEOG calibration).

We focused on ERPs elicited by search displays that contained: (i) a lateral target and a midline distractor (TL/D_M); (ii) a lateral distractor and a midline target (T_M/D_L); (iii) a lateral target and no distractor (TL/D_A); (iv) a lateral target and a contralateral distractor (TL/D_C); (v) a lateral target and an ipsilateral distractor (TL/D_I). The first two display configurations, each containing one lateral singleton and one midline singleton, are critical for investigating target and distractor processing in the additional-singleton paradigm because they enable isolation of N2pc to just one of the two singletons (the lateral one; Hickey et al., 2006, 2009; Woodman & Luck, 2003;). The third display configuration enabled us to examine target processing in the absence of a salient distractor, whereas the fourth and fifth display configurations enabled us to investigate the effect of target-distractor separation (same side vs. opposite side). For each participant, the ERP waveforms were collapsed across visual hemifields and recording hemisphere to create
waveforms contralateral and ipsilateral to lateral singletons of interest. The ipsilateral waveforms were then subtracted from the contralateral waveforms, resulting in a **contralateral-ipsilateral difference waveform** for each participant.

Following the main analysis of the all-trials ERPs, we set out to determine whether target and distractor processing differed on fast- and slow-response trials. This RT-based analysis of ERPs was based on the idea that different sequence of processing events may occur on different trials. There are at least two sources of variability that could interfere with the constant and successful application of attentional control: (i) changes in target and distractor locations, and (ii) random intermixing of distractor-present and distractor-absent trials (cf. Müller, Reimann, & Krummenacher, 2003). Based on these sources of variability, it is plausible that suppression of the salient distractor (as indexed by the $P_D$) would lead to faster responses whereas failure to suppress the distractor, or even capture of attention by the distractor (as indexed by an N2pc), would lead to slower responses. It is also plausible that the distractor affected the latency or the amplitude of target N2pc only on slow-response trials, when interference should have been greatest (cf. McDonald et al., in press). In these cases, the all-trials ERPs that reflect the algebraic summation of the waveforms elicited on fast- and slow-response trials would obscure such differences in the processing sequence. We averaged the ERPs separately for fast- and slow-response trials to rule out these possibilities. This RT-based ERP analysis was performed by computing the median RT for each display configuration, separately for each participant. Individual trials with RTs falling below or above the relevant median RT were defined as fast-response and slow-response trials, respectively (cf. McDonald et al., in press).

To examine the effect of target-distractor distance on the selective processing of the target, we also re-averaged the ERPs separately for adjacent-distractor trials, in which distractor was
immediately next to the target, and for opposite-distractor trials, in which the distractor was the farthest item (i.e., five items away) from the target.

ERP amplitudes were computed in specific time windows centered on the peaks observed in the relevant contralateral-ipsilateral difference waveforms, relative to a 200-ms pre-stimulus baseline period. The ERLs were measured at lateral occipital electrodes (PO7 and PO8) in order to track the successive stages of processing for the lateral singleton of interest in each configuration. Except where noted, the mean amplitudes of the Ppc, N2pc, P1, and SPCN were measured in the 120–180 ms, 225–275 ms, 325–375 ms, and 400–800 ms time windows, respectively. Latencies were measured as the time at which the voltage reached 70% of the peak amplitude within the time window of interest. This fractional peak latency was measured in the 75–325 ms interval for the N2pc and in the 400–800 ms interval for the SPCN. Fractional peak latency measures were based on jackknife-average ERPs rather than the individual-subject ERPs, and the results of statistical tests were adjusted accordingly (Ulrich & Miller, 2001).

Results

A total of 23.5% of the trials were discarded due to EEG/EOG artifact (15.4%), incorrect response (5.6%), or excessively fast or slow response (2.5%). Behavioral and ERP analyses were conducted on the remaining trials.

Behavior. Table 1 presents the grand-average median RTs and associated distractor-interference effects (termed delays) for distractor-present and distractor-absent trials as well as for the specific display configurations of interest. To assess the overall distractor-interference effect, we compared the grand-average median RTs for distractor-present and distractor-absent trials (668 ms and 660 ms, respectively). The 8-ms difference was statistically significant, $t$ (36) = 4.46, $p < .001$. The error rates on distractor-present and distractor-absent trials were
statistically indistinguishable (5.6% vs. 5.7%, \( t < 1 \)), indicating that the main distractor-interference effect was not due to a speed-accuracy trade-off. Next, we conducted a repeated-measures analysis of variance (RANOVA) on RTs associated with the four distractor-present display configurations of interest to determine whether the display configuration affected search times. This omnibus analysis revealed a significant main effect of Configuration, \( F(3,108) = 3.26, \text{MSE} = 386.62, p = .024, \eta^2_p = .08 \). A planned pair-wise comparison of RTs associated with the \( T_L/D_I \) and \( T_L/D_C \) configurations revealed that search times were longer when the two singletons were in the same visual hemifield (675 ms) than when they were in opposite hemifields (662 ms), \( t(36) = 3.46, p = .001 \).

Table 2 presents the grand-average median RTs and associated distractor-interference effects (termed delays) for lateral-target displays as a function of target-distractor proximity. For both ipsilateral and contralateral distractors, RTs and delays decreased monotonically as the distance between the two singletons increased. Search times were longer for adjacent-distractor trials (680 ms) than for opposite-distractor trials (665 ms), \( t(36) = 2.93, p = .006 \). The adjacent-distractor RT was significantly longer than the \( T_L/D_{A} \) RT, \( t(36) = 4.43, p < .001 \), but the opposite-distractor RT was indistinguishable from the \( T_L/D_{A} \) RT, \( t < 1 \).

Table 3 presents the grand-average median RTs and associated delays for distractor-present and distractor-absent trials as well as for display configurations of interest, separately for fast-response and slow-response trials. To assess the overall delay on fast-response and slow-response trials, we performed an ANOVA on the median RTs with Response Speed (Fast vs. Slow) and Distractor Presence (Present vs. Absent) as within-subject factors. Besides the main
effect of Response Speed, both the main effect of Distractor Presence, $F(1,36) = 19.06, \text{MSE} = 162.48, p < .001, \eta^2_p = .35$, and the interaction effect, $F(1,36) = 13.56, \text{MSE} = 85.01, p = .001, \eta^2_p = .27$, were statistically significant. This indicated that the delay was larger on slow-response trials. To assess whether the overall delay was significant on fast-response trials only, we compared the median RTs on those trials for distractor-present and distractor-absent displays (585 ms vs. 582 ms). The 3-ms overall delay on fast-response trials was statistically significant, $t(36) = 2.97, p = .005$. The corresponding 15-ms delay on slow-response trials (787 ms vs. 772 ms) was also significant, $t(36) = 4.26, p < .001$.

Next, to determine whether the display configuration influenced the search efficiency in both fast-response and slow-response trials, we conducted RANOVAs on median RTs for the four distractor-present display configurations of interest, separately for fast- and slow-response trials. The omnibus analysis for the fast-response trials revealed a significant main effect of Configuration, $F(3,108) = 6.02, \text{MSE} = 108.06, p = .001, \eta^2_p = .14$. A pair-wise comparison revealed that on fast-response trials the RTs were significantly longer for TL/DI configuration (590 ms) than for TL/DC configuration (583 ms), $t(36) = 3.17, p = .003$. Similarly, the omnibus analysis for the slow-response trials revealed a significant main effect of Configuration, $F(3,108) = 6.33, \text{MSE} = 640.24, p = .001, \eta^2_p = .15$. The subsequent pair-wise comparison revealed that on slow-response trials the RTs were significantly longer for TL/DI configuration (796 ms) than for TL/DC configuration (779 ms), $t(36) = 2.41, p = .02$.

**Electrophysiology.** Figures 2, 3, and 4 display the ERP results from Experiment 1. Figure 2 shows the grand-averaged ERPs recorded contralateral and ipsilateral to the target (or distractor, when the target was on the vertical meridian; see panel b) for the five display
configurations of interest. Figure 3 displays ERPs averaged separately for fast-response and slow-response trials. Figure 4 displays contralateral-ipsilateral difference waveforms – which help to visualize the ERL componentry – for the all-trials analysis, median-split analysis, as well as the proximity analysis. All of these ERPs were recorded over the occipital scalp (electrodes PO78).

-------- Insert Figures 2, 3, and 4 about here --------

**N2pc and Pd.** We first examined the ERPs and ERLs elicited by the five displays of interest, averaged across all trials (all-trials ERPs). All display configurations containing a lateral target elicited an N2pc: TL/DM, $F(1,36) = 43.93$, MSE = .41, $p < .001$, $\eta^2_p = .55$; TL/DA, $F(1,36) = 32.30$, MSE = .56, $p < .001$, $\eta^2_p = .47$; TL/DC, $F(1,36) = 31.43$, MSE = .62, $p < .001$, $\eta^2_p = .47$; TL/DI, $F(1,36) = 21.54$, MSE = .57, $p < .001$, $\eta^2_p = .29$. In sharp contrast, no N2pc was in evidence for displays containing a lateral distractor and midline target (TM/DL), $F < 1$. Based on the sequence of processing events outlined in Figure 1, these results suggest that attentional filtering processes were centered upon the location of the target but not upon the location of the distractor.

Next, we tested whether the presence or relative location of the distractor modulated the amplitude or latency of the target N2pc. To this end, separate RANOVAs were performed on the N2pc mean amplitude and fractional peak latency for the four display configurations containing a lateral target (TL/DM, TL/DA, TL/DC, and TL/DI). There was no significant difference in the N2pc amplitudes (-0.99 $\mu$V, -1.00 $\mu$V, -1.03 $\mu$V, and -0.86 $\mu$V, respectively), $F(3,108) = 1.01$, MSE = .22, $p = .39$, $\eta^2_p = .03$, or fractional peak latencies (215 ms, 224 ms, 223 ms, and 222 ms, respectively), $F < 1$. These results indicate that the distractor did not interfere with attentional filtering at the location of the target.
We then examined the ERPs separately for fast- and slow-response trials. No distractor N2pc was found on slow-response trials ($T_M/D_L$: 0.59 $\mu$V contralateral vs. 0.54 $\mu$V ipsilateral to the distractor), $F < 1$. To determine whether the distractor interfered with target processing, we analyzed the amplitude and latency of the target N2pc across the four lateral-target display conditions ($T_L/D_M$, $T_L/D_A$, $T_L/D_C$, $T_L/D_I$). There was no significant difference in the N2pc amplitudes (-0.86 $\mu$V, -0.93 $\mu$V, -1.00 $\mu$V, -0.71 $\mu$V, respectively), $F (3, 108) = 1.26$, MSE = .45, $p = .29$, $\eta^2_p = .03$, or fractional peak latencies, (216 ms, 228 ms, 232 ms, 237 ms, respectively), $F < 1$, across these display configurations on slow-response trials.

Similar analyses of the fast-response trials revealed no distractor N2pc (contralateral = 0.74 $\mu$V, ipsilateral = 0.60 $\mu$V; Fig. 3c), $F < 1$. Furthermore, there was no target N2pc amplitude difference (-1.29 $\mu$V, -1.34 $\mu$V, -1.39 $\mu$V, -1.33 $\mu$V), $F < 1$, and no target N2pc latency difference (219 ms, 224 ms, 213 ms, 219 ms), $F < 1$, across the lateral-target display configurations. Visual inspection of the ERPs elicited by the $T_M/D_L$ display suggested that the distractor elicited a PD in that configuration. This was confirmed by post-hoc statistical analysis of the ERP amplitudes in the 250–300 ms interval, in which the ERP was significantly more positive contralateral to the distractor (1.32 $\mu$V) than ipsilateral to it (0.97 $\mu$V), $F (1,36) = 5.30$, MSE = .43, $p = .027$, $\eta^2_p = .13$. On slow-response trials, however, there was no significant difference between contralateral and ipsilateral ERPs in that interval (1.11 $\mu$V vs. 0.98 $\mu$V, respectively), $F < 1$. These results indicate the distractor in the $T_M/D_L$ display elicited a PD on fast- but not on slow-response trials.

To test whether the target N2pc differed across fast- and slow-response trials, we performed separate ANOVAs on the amplitude and latency of the N2pc elicited by the $T_L/D_M$ display. The target N2pc was larger on fast-response trials than on slow-response trials (-1.41 $\mu$V
vs. -0.89 µV, respectively; see Fig. 3a, 3b, and Fig 4b), $F(1, 36) = 6.78$, MSE = .75, $p = .01$, $\eta^2_p = .16$, but the target N2pc latency was similar across the two trial subsets (219 ms vs. 216 ms, respectively), $F < 1$. Similarly, the target N2pc elicited by the $T_L/D_A$ display was larger on fast-response trials than on slow-response trials (-1.03 µV vs. -0.74 µV, respectively), $F(1, 36) = 7.36$, MSE = .22, $p = .01$, $\eta^2_p = .17$. These latter results indicate that the difference in the amplitude of the target N2pc between fast- and slow-response trials was not due to distractor interference.

Following the analyses of the N2pc waves elicited by the display configurations of interest, we examined the effect of target-distractor proximity on the target N2pc more directly by comparing the mean amplitudes and fractional peak latencies of the target N2pc waves obtained on adjacent-distractor trials and opposite-distractor trials. This analysis was based on the idea that comparing the extreme cases of ipsilateral-distractor and contralateral-distractor configurations (adjacent-distractor and opposite-distractor trials, respectively) would maximize the power to detect any amplitude or latency differences between the target N2pc waves in the two conditions. Neither the mean amplitude of the target N2pc (-0.93 µV vs. -1.0 µV, respectively) nor its fractional peak latency (218 ms vs. 210 ms, respectively) differed statistically between the two conditions, $F$s < 1. These findings dovetail nicely with the results of the main all-trials and median-split analyses. Figure 4c illustrates the ERLs to lateral-target displays when the distractor was 1, 2, 3, 4, or 5 items away from the target.

$P_{pc}$. The ERLs illustrated in Figure 4 contain large deflections prior to the onset of the N2pc. The polarity of the deflection within the 120–180 ms interval was contingent upon the configuration of the display. As in the N2pc amplitude analysis, the amplitude of the Ppc was computed with reference to the lateral target, except when the target was on the midline (in
which case it was computed with reference to the lateral distractor). Thus, when the two singletons were on opposite sides of fixation, ‘contralateral’ and ‘ipsilateral’ were defined with respect to the target position rather than the distractor position. The Ppc was -0.46 µV in this TL/D_C configuration, whereas it was 0.38 µV in the TL/D_I configuration. These opposite-polarity peaks could be interpreted in terms of a negative ERL contralateral to the target or a positive ERL contralateral to the distractor. Critically, the Ppc elicited by the three other display configurations rule out the first interpretation. Small, nonsignificant contralateral-ipsilateral differences were observed for the TL/D_M and TL/D_A displays, whereas a 0.41 µV positive-going Ppc was seen for the T_M/D_L display. Statistical tests revealed that the Ppc was significantly positive for the T_M/D_L and T_L/D_I displays, ps < .001, was significantly negative for the T_L/D_C display, p < .001), and was nonsignificant for the T_L/D_M display, F (1,36) = 3.27, MSE = .09, p = .08, η_p^2 = .08, and T_L/D_A display, F (1,36) = 1.80, MSE = .07, p = .19, η_p^2 = .05. To test whether the absolute amplitude of the Ppc varied as a function of the relative location of the distractor, we compared the Ppc amplitude in the TL/D_C condition (-0.46 µV) with the reversed polarity of the Ppc amplitude in the TL/D_I condition (-0.38 µV). There was no significant difference in the Ppc amplitudes (t < 1). These findings provide conclusive evidence that the Ppc was a positive ERL contralateral to the distractor singleton and that its absolute amplitude did not vary with the relative location of the distractor.

To determine whether the Ppc co-varied with search performance, we compared the amplitudes of the Ppc peaks elicited on fast- and slow-response trials. We focused exclusively on the T_M/D_L display in order to be confident that the ERL under investigation was tied to the lateral distractor (and not to a lateral target). The mean amplitude of the Ppc in the 120–180 ms was not
significantly different between fast- and slow-response trials (.50 μV vs. .38 μV, respectively), $F < 1$. This indicates that the Ppc was not related to the efficiency of search or target processing.

$P_T$. Most display configurations containing a lateral target seemed to elicit a contralateral positivity in the 300–400 ms time range (Figure 4). This positivity, which we call the $P_T$, was statistically significant for $T_L/D_A$ display, $F (1,36) = 13.13$, MSE = .67, $p = .001$, $\eta_p^2 = .28$, and for $T_L/D_t$ display, $F (1,36) = 5.75$, MSE = .46, $p = .02$, $\eta_p^2 = .14$, whereas it did not reach significance for $T_L/D_M$ display, $F (1,36) = 2.38$, MSE = .60, $p = .13$, $\eta_p^2 = .06$ or for $T_L/D_C$ display, $F (1,36) = 3.39$, MSE = .73, $p = .07$, $\eta_p^2 = .09$. For $T_M/D_L$ display, the contralateral and ipsilateral waveforms were indistinguishable in this interval, $F < 1$.

To test whether the presence or relative location of the distractor modulated the amplitude of the $P_T$, we performed a RANOVA on the $P_T$ mean amplitude for the four display configurations containing a lateral target ($T_L/D_M$, $T_L/D_A$, $T_L/D_C$, and $T_L/D_t$). There was a significant difference in the $P_T$ amplitude (0.28 μV, 0.69 μV, 0.36 μV, and 0.38 μV, respectively), $F (3,108) = 3.08$, MSE = .39, $p = .03$, $\eta_p^2 = .08$. This result suggested that the $P_T$ was larger for the $T_L/D_A$ display than for the other lateral-target configurations that also contained the distractor. To test whether the relative location of the distractor affected the $P_T$ amplitude, we performed a RANOVA on the $P_T$ mean amplitude for the three display configurations containing a lateral target and the distractor ($T_L/D_M$, $T_L/D_C$, and $T_L/D_t$). There was no significant difference in the $P_T$ amplitudes, $F < 1$. We also examined the effect of target-distractor proximity on the $P_T$ by comparing the mean amplitudes of the $P_T$ obtained on adjacent-distractor and opposite-distractor trials (0.29 μV and 0.54 μV, respectively). There was no significant difference in the $P_T$ amplitude between the two conditions, $F < 1$. Considered together, these results indicate that the $P_T$ amplitude was reduced by the presence of the
distractor, but it was not affected by the relative location of the distractor or target-distractor proximity.

To test whether the P_T differed across fast- and slow-response trials, we performed separate ANOVAs on the amplitude of the P_T elicited by T_L/D_A and T_L/D_M displays. The amplitudes of P_T elicited by the T_L/D_A display on fast-response and slow-response trials were comparable (0.76 $\mu$V and 0.63 $\mu$V, respectively), $F(1, 36) = 1.18$, MSE = .30, $p = .28$, $\eta^2_p = .03$. Similarly, the P_T elicited by the T_L/D_M display did not significantly differ between fast- and slow-response trials (0.37 $\mu$V and 0.19 $\mu$V, respectively), $F < 1$. These results indicate that there was no relationship between the P_T amplitude and the efficiency of the search.

SPCN. The ERPs once again became more negative contralateral than ipsilateral to the target in the SPCN time interval. The SPCN was in evidence for each display containing a lateral target, $p_s < .001$, but it was absent for the T_M/D_L display, $F < 1$. The absence of the SPCN for the T_M/D_L display supports the conclusion that the SPCN reflects selective processing of the target.

To test whether the presence or relative location of the distractor influenced the amplitude or latency of the target SPCN, we performed separate RANOVAs on the SPCN mean amplitude and fractional peak latency for the four display configurations containing a lateral target (T_L/D_M, T_L/D_A, T_L/D_C, and T_L/D_I). There was no significant difference in the SPCN amplitudes (-0.55 $\mu$V, -0.50 $\mu$V, -0.54 $\mu$V, and -0.42 $\mu$V, respectively), $F < 1$, or latencies (634 ms, 681 ms, 613 ms, and 706 ms, respectively), $F(3, 108) = 1.19$, $p = .32$.

To test whether the SPCN differed across fast- and slow-response trials, we compared the amplitude and latency of the SPCN elicited by the T_L/D_M display. The target SPCN was smaller on fast-response trials than on slow-response trials (-0.47 $\mu$V vs. -0.68 $\mu$V, respectively; see Fig.
3a and 3b), $t(36) = 2.11, p = .042$, but the difference in the latency of target SPCN between the two trial subsets (700 ms vs. 662 ms, respectively) was not significant, $t < 1$.

**Discussion**

As in prior studies using the fixed-feature variant of the additional-singleton paradigm, a salient color singleton resulted in a small, but significant, delay in the search for a known shape singleton. Such RT interference has been attributed to two different mechanisms: salience-driven capture of attention (Theeuwes, 1992, 2010) and nonspatial perceptual filtering (Folk & Remington, 1998). The results of our RT proximity analyses appear to be at odds with nonspatial filtering. Whereas nonspatial filtering should be independent of the spatial relationship between target and distractor, we found RTs to be longest when the target was near the distractor.

Previously, researchers have attributed increased RT interference on adjacent-distractor trials to an inhibitory region surrounding the attended distractor (Caputo & Guerra, 1998; Hickey & Theeuwes, 2011; Mounts, 2000a, 2000b). The general idea is that if attention were captured by the salient distractor and an inhibitory surround were established around the attended distractor location, it would take more time to re-deploy attention to a (nearby) target located within the inhibited surround than to a more distant target falling outside of the inhibitory surround. Although this is possible in theory, there are two immediate shortcomings of the inhibited-surround interpretation that need to be addressed before concluding that attention was deployed to the distractor in the present experiment. First, if the distractor captured attention, some RT interference should have been evident on distant-distractor trials, relative to no-distractor trials. As outlined in the Introduction, the salience-driven selection hypothesis holds that attention is deployed to the distractor, then rapidly disengaged from that location and re-deployed to the target. Clearly, this hypothesized sequence of processing events would take more time than
deploying attention directly to the target whether or not the target falls in an inhibitory surround. This was not the case in Experiment 1: Distant distractors did not delay search for the target.

Second, it is possible to account for the observed RT proximity effects without assuming attention was deployed to the distractor location. For example, referring back to Figure 1, the target location may have been selected initially, but more time may have been required for the subsequent filtering operation when the distractor was nearby than when it was more distant. It is also possible that the nearby distractors mainly influenced decision or motoric stages of processing rather than early spatial selection and perceptual filtering operations. Given the absence of RT interference on distant-distractor trials, these alternative accounts are more plausible than the inhibitory-surround account.

The ERP results help to evaluate these possibilities and to track target and distractor processing more precisely. Five important ERP results emerged from Experiment 1. First, the salient distractor never elicited N2pc, even on slow-response trials. This indicates that the selective filtering operation did not take place at the location of the salient distractor. Second, unlike Hilimire et al.’s (2009, 2010) studies, the amplitude of target N2pc was not reduced with increased target-distractor proximity. More generally, neither the presence nor the relative location of the distractor affected the amplitude or latency of the target N2pc. This pattern of results indicates that the distractor did not interfere with the initial target selection. Third, the distractor elicited a P10 on fast- but not slow-response trials, indicating that observers were able to actively suppress the salient distractor on fast-response trials. This finding, in combination with the finding that the distractor-interference effect was smaller on fast-response trials, indicates that distractor suppression may increase the efficiency of fixed-feature search.
The fourth key ERP effect was seen prior to the onset of the N2pc. Specifically a positive-going ERL was seen contralateral to the distractor singleton – but not the target singleton – in the 120–180 ms interval. At present, the functional significance of this Ppc is unclear. Referring back to Figure 1, the Ppc may have been associated with lateral asymmetries in sensory processing (Luck & Hillyard, 1994a), stimulus salience (Fortier-Gauthier et al., in press), distractor suppression (Sawaki & Luck, 2010), or even fleeting salience-driven spatial selection that had no effect on search performance or target selection (Theeuwes, 2010). We consider each of these options in Experiment 2.

The fifth and final ERP effect to be highlighted was seen in the post-N2pc time range. Specifically, a positivity was elicited contralateral to the target – but not to the distractor – in the 320–370 ms interval. One possible explanation for this P_T is that, similar to the Ptc (Hilimire et al., 2009, 2010), it indexes the resolution of conflict between the target and the distractor by individuating and isolating the target after its identification. Three aspects of the present results argue against this possibility. First, unlike the Ptc reported by Hilimire et al. (2010), the P_T did not vary as a function of the separation between target and distractor or the relative location of the distractor. Second, if the positivity reflected a competition-biasing or conflict resolution between the two singletons, the amplitude of the positivity should presumably correlate with search efficiency, and, therefore, should have differed between fast- and slow-response trials. Third, whereas the Ptc is seen contralateral to distractors but not targets (Hilimire et al., 2011), the P_T was seen contralateral to the target but not the distractor. A more-plausible functional role for this P_T is that it indexes the termination of target processing via suppression (Sawaki et al., 2012).
Experiment 2

Experiment 2 was identical to Experiment 1 except the roles of the two singletons were reversed: the color singleton was the target and the less-salient shape singleton was the distractor. In this case, the salience-driven selection hypothesis would predict no capture-related interference because the target – not the distractor – was the most salient item in the display. Thus, Experiment 2 served as a useful benchmark for Experiment 1.

Method

Participants. 22 participants were drawn from the same population as Experiment 1. None had participated in Experiment 1. Data from 2 participants were excluded from analyses because of excessive blinks or eye movements. Each of the remaining 20 participants (10 women, age 20.1 ± 2.1 years, mean ± SD, all right-handed) reported normal or corrected-to-normal visual acuity and had normal color vision.

Apparatus, Stimuli and Procedure. These were the same as in Experiment 1 except the following. On every trial, one of the stimuli was an unfilled red diamond, which appeared at one of the eight lateral positions or one of the two positions on the vertical midline. On 50% of trials, this color-singleton target was the only unique object in the display. On the remaining 50% of trials, an unfilled green circle (1.7° radius; a shape-singleton distractor) also appeared either at a lateral position or a midline position.

Electrophysiological Recording and Data analyses. The EEG was recorded and processed as in Experiment 1, except for the following changes. A median-split analysis was not performed because salience-driven capture was not expected on any subset of trials. The mean amplitudes of the Ppc and N2pc were measured in the 100–160 ms and 200–250 ms time windows, respectively. Fractional peak latency of the N2pc was measured in the 100–300 ms time window.
Results

A total of 31.7% of the trials were discarded due to EEG/EOG artifact (19.4%), incorrect response (9.6%), or excessively fast or slow response (2.7%). Behavioral and ERP analyses were conducted on the remaining trials.

**Behavior.** Table 1 presents the grand-average median RTs for distractor-present and distractor-absent trials as well as for the specific display configurations of interest. To assess the overall distractor-interference effect, we compared the grand-average median RTs for distractor-present and distractor-absent trials (584 ms and 576 ms, respectively). The 8-ms difference was statistically significant, \( t(19) = 3.73, p = .001 \). The error rates on distractor-present and distractor-absent trials were statistically indistinguishable (9.7% vs. 9.5%, respectively, \( t < 1 \)), indicating that the main distractor-interference effect was not due to a speed-accuracy trade-off.

To compare the RTs between the two experiments, we conducted an ANOVA with Experiment (1 vs. 2) as a between-subjects factor and Distractor Presence (Present vs. Absent) as a within-subject factor. The main effect of Experiment was significant, \( F(1,55) = 15.93, \text{MSE} = 11366.68, p < .001, \eta^2_p = .23 \), with shorter RTs in Experiment 2 than in Experiment 1. The main effect of Distractor Presence was also significant, \( F(1,55) = 29.74, \text{MSE} = 52.56, p < .001, \eta^2_p = .35 \), with shorter RTs on distractor-absent trials. Critically, the interaction was not significant, \( F < 1 \), thereby confirming that the overall distractor interference effect was indistinguishable across the two experiments.

Next, to determine whether the display configuration affected target search times, we conducted a RANOVA on RTs associated with the four distractor-present display configurations of interest. This omnibus analysis revealed a significant main effect of Configuration, \( F(3,57) = 12.15, \text{MSE} = 108.62, p < .001, \eta^2_p = .39 \). A planned pair-wise comparison of RTs associated
with the TL/DI and TL/DC configurations revealed that search times were indistinguishable when
the two singletons were in the same visual hemifield (587 ms) and when they were in opposite
hemifields (587 ms), $t < 1$. Similarly, both TL/DI and TL/DC RTs were indistinguishable from
TL/DA RT (581 ms), $ts < 1$. Since the overall distractor interference effect was 8 ms, the non-
significance of this 6-ms difference could be either due to a lack of power or due to a genuine
absence of an effect. It should be noted that the robust overall distractor interference effect was
based on a comparison between all distractor-present trials and distractor-absent trials (not
limited to lateral-target configurations).

Table 2 presents the grand-average median RTs and associated delays for lateral-target
displays as a function of target-distractor proximity. In contrast to Experiment 1, the RTs and
interference effects for either ipsilateral or contralateral distractors did not fall off monotonically
with increasing target-distractor distance. Search times were not significantly longer for
adjacent-distractor trials (591 ms) than for opposite-distractor trials (589 ms), $t < 1$. Similarly,
both adjacent-distractor and opposite-distractor RTs were indistinguishable from TL/DA RT, $ts < 1$.

**Electrophysiology.** Figures 5 and 6 display the ERP results from Experiment 2. Figure 5
shows the grand-averaged ERPs recorded contralateral and ipsilateral to the target (or distractor,
when the target was on the vertical meridian; see panel b) for the five display configurations of
interest. Figure 6 displays contralateral-ipsilateral difference waveforms – which help to
visualize the ERL componentry – for the all-trials analysis, as well as the proximity analysis. All
of these ERPs were recorded over the occipital scalp (electrodes PO78).

------------ Insert Figures 5 and 6 about here ----------
**N2pc and Pp.** All display configurations containing a lateral target elicited an N2pc:

- TL/DA, $F(1,19) = 34.45, \text{MSE} = 1.47, p < .001, \eta^2_p = .65$; TL/DM, $F(1,19) = 26.99, \text{MSE} = 2.31, p < .001, \eta^2_p = .59$; TL/DC, $F(1,19) = 31.04, \text{MSE} = 2.0, p < .001, \eta^2_p = .62$; TL/DI, $F(1,19) = 20.38, \text{MSE} = 1.82, p < .001, \eta^2_p = .52$. In contrast, no N2pc was in evidence for displays containing a lateral distractor and midline target (TM/DL). For this configuration, a significant Pp was observed: the mean ERP amplitude in the 200–250 ms interval was significantly more positive contralateral to the distractor (1.21 µV) than ipsilateral to it (.75 µV), $F(1,19) = 15.26, \text{MSE} = .14, p = .001, \eta^2_p = .45$.

Next, separate RANOVAs were performed on the N2pc mean amplitude and fractional peak latency for the four display configurations containing a lateral target (TL/DM, TL/DA, TL/DC, and TL/DI) to determine whether the presence or relative location of the distractor modulated the target N2pc. The analysis revealed a significant difference in the N2pc amplitudes (-2.50 µV, -2.25 µV, -2.50 µV, and -1.93 µV, respectively), $F(3,57) = 5.71, \text{MSE} = .25, p = .002, \eta^2_p = .23$. A subsequent pair-wise comparison confirmed that the N2pc was significantly larger for the TL/DC than for the TL/DI display configuration, $t(19) = 3.47, p = .003$. In contrast, there was no significant difference between fractional peak latencies of the N2pc for these configurations (196 ms, 196 ms, 197 ms, and 200 ms, respectively), $F < 1$.

Whereas the target N2pc was larger for TL/DC displays than for TL/DI displays, the follow-up proximity analysis revealed no such difference: opposite-distractor and adjacent-distractor trials were indistinguishable in terms of both the mean amplitude of the target N2pc (-2.31 µV vs. -2.04 µV, respectively) and its fractional peak latency (197 ms vs. 202 ms, respectively), $F < 1$. Figure 6b illustrates the ERLs to lateral-target displays when the distractor was 1, 2, 3, 4, or 5 items away from the target.
We compared the target N2pc observed in Experiment 2 to that observed in Experiment 1 to determine whether relative stimulus salience influences the timing or magnitude of selective target processing in fixed-feature search. We focused on one display configuration – TL/D_M – for this between-experiment comparison, and we randomly selected 20 of the 37 participants from Experiment 1 in order to have equal sample sizes in the two groups. The N2pc was found to occur 28 ms earlier in Experiment 2 (196 ms) than in Experiment 1 (224 ms), $F(1,39) = 6.70, p = .01$. Given this latency difference, mean amplitudes of the target N2pc waves were computed in different 50-ms intervals: 225–275 ms in Experiment 1 and 200–250 ms in Experiment 2. The N2pc was found to be 1.53 $\mu$V larger in Experiment 2 (-2.50 $\mu$V) than in Experiment 1 (-0.97 $\mu$V), $F(1,39) = 8.74, p = .005$. In other words, the target N2pc was both earlier and larger when the target was the most salient item in the search display (Experiment 2) than when the distractor was the most salient item (Experiment 1).

**Ppc.** The Ppc was in evidence only for lateral-target displays. It was significantly positive for the T_L/D_M configuration, $t(19) = 4.74, p < .001$, the T_L/D_A configuration, $t(19) = 3.31, p = .004$, and the T_L/D_I configuration, $t(19) = 3.06, p = .006$. A positive Ppc was marginally significant for the T_L/D_C configuration, $t(19) = 1.74, p = .098$. Critically, there was no Ppc for the T_M/D_L configuration, $t(19) = 1.48, p = .16$.

A between-experiment analysis revealed that the amplitude of the Ppc elicited by the T_L/D_M display in Experiment 2 (0.51 $\mu$V) was no different than the amplitude of the Ppc elicited by the T_M/D_L display in Experiment 1 (0.35 $\mu$V), $F(1,39) = 1.29, MSE = .21, p = .26, \eta^2_p = .03$.

Visual inspection of the ERLs in Figure 6 indicated that the T_M/D_L display elicited an early, positive ERL contralateral to the irrelevant shape singleton, which peaked at approximately 100 ms. This was confirmed by statistical analysis: In the 90–110-ms interval, the mean amplitudes at
contralateral occipital and ipsilateral occipital electrodes were 2.99 µV and 2.55 µV, respectively. This 0.44-µV difference was found to be statistically significant, $F(1,19) = 16.41$, MSE = .12, $p < .001$, $\eta^2_p = .46$.

$P_T$. There was no target positivity in evidence in the post-N2pc time range. This might be due to an absence of a $P_T$ or due to large N2pc and SPCN waves obscuring a temporally overlapping $P_T$.

$SPCN$. The SPCN was in evidence for each display containing a lateral target, $ps < .001$, but it was absent for the $T_M/D_L$ display, $t(19) = 1.27$, $p = .22$. A between-experiment analysis revealed that the amplitude of SPCN elicited by the $T_L/D_M$ display in Experiment 2 (-0.96 µV) was not significantly different from that in Experiment 1 (-0.55 µV), $F(1,55) = 2.81$, MSE = .78, $p = .10$, $\eta^2_p = .05$.

Discussion

The design of Experiment 2 was nearly identical to that of Experiment 1 except the roles of target and distractor singletons were reversed. Whereas participants searched for a shape singleton in the presence of a more salient, but irrelevant, color singleton in Experiment 1, they searched for a color singleton in the presence of an irrelevant shape singleton in Experiment 2. From the salience-driven selection perspective, less distractor interference should have occurred in Experiment 2 than in Experiment 1 because the target was the most salient item in the display. This was not the case, however: the magnitude of the distractor-interference effect observed in Experiment 2 was on par with that observed in Experiment 1 (8 ms in each). The parity does not imply, however, that the distractor captured attention in Experiment 2. This option can be ruled out on the grounds that the distractor was less salient than the target. A plausible alternative –
that the distractor failed to capture attention in Experiment 1 as well as in Experiment 2 – is evaluated in the General Discussion.

A noticeable aspect of the behavioral results in Experiment 2 was the absence of systematic relationship between RTs and the relative location of the two singletons, as well as target-distractor proximity, that was observed in Experiment 1. Based on these behavioral results, one could argue that distractor interference observed in Experiment 2 was due to nonspatial filtering costs (Folk & Remington, 1998, 2006). By this account, observers did not deploy attention to the distractor location; rather, there was a delay while observers decided which of the two locations should be attended. We note, however, that this nominally nonspatial account allows for considerable spatial processing during the pre-attentive stage. Firstly, the visual system would likely have information about the spatial locations of the two singletons. In terms of the processing steps outlined in Figure 1, this could involve the registration of both singletons on the saliency map. Additionally, the decision to orient attention to the target might, in theory, involve enhancement of the target’s location or the suppression of the distractor’s location. The results obtained in Experiment 2 are in line with this latter possibility. Namely, the distractor in Experiment 2 elicited a $P_D$ – a lateralized ERP component believed to reflect attentional suppression of irrelevant, but potentially distracting, stimuli (Hickey et al., 2009; McDonald et al., in press).

One of the main goals of Experiment 2 was to shed light on the Ppc, which was elicited by the color-singleton distractor in Experiment 1. In that experiment, the Ppc bore similarity to the $P_D$: it was a positive-going ERL elicited by an irrelevant, but potentially distracting, stimulus. Although the $P_D$ typically occurs in the N2pc interval (Hickey et al., 2009; present study) or shortly thereafter (Hilimire et al., 2011; Kiss, Grubert, Petersen, & Eimer, 2012; McDonald et
Sawaki and Luck (2010) reported to find an early, pre-N2pc P_D to a salient-but-irrelevant colour singleton. Sawaki and Luck surmised that (i) the early onset of their P_D was due to the high salience of the distractor in their study, and (ii) the P_D reflected suppression of a salience-driven *attend-to-me* signal. Accordingly, we considered the hypothesis that the Ppc in Experiment 1 was an early P_D that prevented the distractor from capturing attention. The results of Experiment 2 disconfirmed this hypothesis. Specifically, a Ppc was elicited not by the irrelevant shape singleton but by the task-relevant color singleton in Experiment 2. The fact that the salient color singleton elicited a Ppc in both experiments, whether it was the distractor or the target, rules out the possibility that the Ppc reflects suppression that prevents selection of the eliciting stimulus. The pattern of results is consistent with the remaining alternatives outlined in the Discussion of Experiment 1: The Ppc may be associated with lateral asymmetries in sensory processing (Luck & Hillyard, 1994a), stimulus salience (Fortier-Gauthier et al., in press), or even fleeting salience-driven spatial selection that had no effect on search performance or target selection (Theeuwes, 2010).

Finally, in Experiment 2, the target N2pc was larger when the distractor was in the contralateral hemifield (T_l/D_C configuration) than when it was in the ipsilateral hemifield (T_l/D_l configuration). Although this result was unexpected from the salience-driven capture perspective (since the distractor was not expected to capture attention), it is in line with our prior speculation about the summation of opposite-polarity N2pc sub-components (Hickey et al., 2009). Using a different fixed-feature search paradigm, Hickey et al. found a negative ERL (which was termed the *target negativity, N_T*) contralateral to a target stimulus and a positive ERL (the P_D) contralateral to the same stimulus when it was irrelevant to the task. As in the current experiment, the N_T and P_D were observed when one of two stimuli was positioned laterally and
the other was positioned on the vertical meridian (i.e., TL/DM and TM/DL configurations). Hickey et al. speculated that when target and distractor singletons are placed on opposite sides of fixation, the NT and PD would sum linearly to produce the conventional N2pc. Here, we note a corollary of this argument: When target and distractor are placed on the same side of fixation, the NT and PD should again sum linearly (via volume conduction from the brain generators to the scalp), this time acting in opposition. According to this line of reasoning, the N2pc measured contralateral to the target should be smaller when the target and distractor are on the same side of fixation (TL/DI) than when they are on opposite sides (TL/DC). This is precisely what we found in Experiment 2.

**General Discussion**

The issue of whether salient singletons capture attention automatically has remained unresolved. According to the salience-driven selection hypothesis, the location of the most salient item in the display is detected preattentively, after which attention is deployed automatically to that location. By this account, the presence of a salient distractor delays search for a less-salient target because attention is deployed initially to the distractor location and then to the target location only after the distractor has been identified and dismissed (Theeuwes, 2010). By another account, however, the presence of a salient distractor delays search because the system must first determine to which of the two singletons attention should be deployed before deploying attention directly to the target location (i.e., nonspatial filtering costs; Folk & Remington, 1998, 2006).

The present study was designed to examine the ERP evidence for the salience-driven selection hypothesis using a fixed-feature search task. Critically, we used search displays with one lateral singleton and one midline singleton to isolate the target and distractor ERLs. One of
our main questions was whether a salient distractor would elicit the N2pc because that
component has been linked to attentional selection. Such a finding, in association with salience-
driven RT interference, would provide clear evidence for the salience-driven selection
hypothesis. This was not the case, however. In Experiment 1, the salient-but-irrelevant colour
singleton did not elicit an N2pc, even on slow-response trials. Based on this result, we conclude
that attentional filtering did not occur at the distractor location. This conclusion is not based
solely on a null result, i.e., the absence of a distractor N2pc, but rather on a clear pattern of ERP
results. Specifically, when search displays contained a target singleton and a distractor singleton,
it was the target – not the distractor – that elicited the N2pc. In other words, when the salient
distractor was pitted against a less-salient target, observers attended to the target rather than the
distractor.

One important finding in Experiment 1 was the presence of PD on fast-response trials, but
not on slow-response trials. This is consistent with the hypothesis that distractor suppression led
to more efficient search but could not be implemented on all trials. Since the features of target
and distractor do not vary in a fixed-feature search, one could ask what underlies this trial-to-trial
variability. One factor may have been the intermittent and unpredictable presence of the
distractor. According to Müller, Reimann, and Krummenacher, (2003), participants are better
able to deal with potentially distracting stimuli when those stimuli occur regularly. By this
account, participants in Experiment 1 may have been better able to suppress the distractor when
the distractor was present on the preceding trial(s). A second potential factor may have been the
random fluctuation of top-down control settings. Consistent with this option, Leber (2008)
reported a negative correlation between the strength of the pre-trial fMRI signal in middle frontal
gyrus (MFG) and the magnitude of distractor interference. Such trial-by-trial fluctuations in the
strength of top-down control can also occur in fixed-feature search, although perhaps to a less extent compared to mixed-feature search. Namely, on trials with high pretrial MFG activity, it might have been more likely to observe a $P_D$ and small distractor interference, whereas on trials with low pretrial MFG activity, it might have been more likely to observe no $P_D$ and large distractor interference.

Recently, there has been debate about whether the absence of an N2pc to a salient distractor rules out salience-driven attention capture. According to Theeuwes (2010) attention can be deployed to the distractor location and then re-deployed to the target location without eliciting a distractor N2pc. This *fleeting-capture* account is based on the view that the N2pc does not reflect the initial selection of an object but rather some enduring attentional process that follows. According to Eimer and Kiss (2010), however, the absence of a distractor N2pc would indicate that attention was never deployed to the distractor location. This claim is based on the view that the N2pc does reflect initial object selection. Our own view of N2pc shares attributes with both of these contrasting views. Like Theeuwes, we leave open the possibility for an initial spatial selection prior to the attentional process that gives rise to the N2pc (see Fig. 1). However, like Eimer and Kiss, we consider the N2pc to reflect an early stage of object selection – namely, the initial selection of an object via an ambiguity-resolution process that we labeled *filtering* in Figure 1 (cf. Hickey et al., 2009; Hopf et al., 2002; Luck et al., 1997; Luck & Hillyard, 1994b).

Although we agree with Theeuwes (2010) that spatial selection may precede the attentional process that gives rise to the N2pc, we do not consider fleeting capture to be plausible at this point. The crux of the matter is whether an attended item can be identified and dismissed without eliciting an N2pc. The fleeting-capture account is contingent on the assumption that it can. In contrast, we contend that in visual search (i) identification is possible only after attentional
filtering has resolved the neural ambiguities arising from the presence of multiple, dissimilar items (cf. LaBerge & Brown, 1989); (ii) attentional filtering gives rise to N2pc. Based on these premises, we conclude that identification of one item appearing among other dissimilar items is possible only after the N2pc has occurred (see Fig. 1). Thus, in Experiment 1, if participants had attended and identified the salient distractor before re-deploying attention to the target, we should have observed a distractor N2pc.

In addition to these theoretical considerations, three empirical results obtained in the current study also argue against fleeting capture by the salient distractor. First, in Experiment 1, the distractor not only failed to elicit the N2pc but also elicited a PD on fast-response trials. On the grounds that the PD reflects attentional suppression (Hickey et al., 2009), this indicates that on fast-response trials, observers suppressed the location of the distractor to prevent that item from capturing attention (see also Sawaki & Luck, 2010). One might assume alternatively that observers would need to select and identify the distractor in order to suppress it. Such a processing sequence would likely entail an N2pc (signifying object selection) prior to the PD (signifying suppression). In fact, a similar sequence of target-elicited ERLs has been reported (Sawaki, et al., 2012): the target N2pc associated with selection was followed by a PT, which was interpreted as termination of target processing via suppression. The finding that the salient distractor in Experiment 1 elicited a PD but no preceding N2pc indicates that the suppression was applied on the basis of the preattentive analysis alone. Specifically, in Experiment 1, the preattentive stage of processing would culminate in the construction of a salience map on which the distractor location is determined to have the highest salience (without identifying the features at that location). The visual system could selectively suppress the location of the most salient
item on the map in order to prevent selection and identification of the item at that location. This would enable selection of the less salient target without first selecting the distractor.

Second, if the salient distractor captured attention, even briefly, the RT-interference effect should have been larger in Experiment 1 than in Experiment 2. This was not the case: the overall interference effects were equal in the two experiments. Whereas the interference effect appeared to be smaller than that reported by Theeuwes (1992), it was on par with interference effects observed in recent fixed-feature search tasks (e.g., Schübo, 2009; Töllner, Müller, & Zehetleitner, 2012). Third, neither the presence nor the relative location of the salient distractor affected the target N2pc in any way (Experiment 1). Because it is unlikely that attention was deployed to the distractor location, disengaged, and then re-deployed to the target location without affecting the latency or amplitude of the target N2pc, this pattern of results is inconsistent with the fleeting-capture variant of the salience-driven selection hypothesis.

Although there was no clear evidence for salience-driven selection in the present study, stimulus salience was found to influence ERPs in two ways. First, the target N2pc was earlier (and larger) when participants searched for the color singleton (Experiment 2) rather than the shape singleton (Experiment 1). This latency effect was in evidence even on distractor-absent trials, indicating that the effect was driven by target salience, not distractor salience. A similar, albeit larger, difference was observed for mean RTs, which were shorter in Experiment 2 than in Experiment 1. Thus, the N2pc latency effect is in line with the existing behavioral evidence that increasing target salience (e.g., by increasing target-distractor dissimilarity) leads to faster search (Duncan & Humphreys, 1989; Nagy & Sanchez, 1990; for review, see Wolfe & Horowitz, 2004).
Second, the salient color singleton elicited a Ppc in both experiments – that is, when it was a distractor (Experiment 1) or the target (Experiment 2). The latter finding rules out the possibility that the Ppc reflects suppression of an attend-to-me signal (Sawaki & Luck, 2010) (insert footnote 1). It is possible that the Ppc reflects the initial spatial selection of the salient color singleton. As noted above, however, the presence of the distractor in Experiment 1 had no influence on the target N2pc. Thus, if the Ppc reflected the initial spatial selection of the colour singleton, such selection had no impact on target processing in Experiment 1. The Ppc might alternatively be linked to laterally imbalanced sensory activity (Luck & Hillyard, 1994a) or representation of the most salient item in a salience map (Fortier-Gauthier et al., 2012).

On the basis of the present results, we propose the sequence of hypothetical processing steps illustrated in Figure 7 takes place in the fixed-feature variant of the additional singleton search task. As was noted in the context of the salience-driven selection hypothesis (see Fig 1), the entire visual display is processed in parallel at the earliest preattentive stage. This culminates in a salience map on which the locations of both singletons are represented. We have placed this process in an intermediate stage rather than the earliest stage of preattentive processing on the evidence that the visual system monitors a limited number of high-priority locations for purposes of assigning priority for attentional selection (e.g., Yantis & Johnson, 1990). Whereas the salience-driven selection hypothesis asserts that information at the location of the most salient item is passed to the attentive stage automatically, we propose that the visual system can selectively use the contents of the salience map in two different ways. One way is analogous to the conventional notion of selection, which we now call selection for identification. Additionally, the visual system can suppress the locations of salient items so that those items do not gain access to the selection-for-identification pathway. We propose that when the distractor singleton
is more salient than the target, the location of the most salient item is suppressed to enable more efficient selection of the target. This suppression, indexed by the $P_D$, takes effort and is applied at the earliest stage possible (ideally by the time filtering begins at the target location).

-------- Insert Figure 7 about here --------

The framework outlined above is similar to the signal suppression hypothesis of controlled attention capture, which was introduced by Sawaki and Luck (2010) to account for what appeared to be a $P_D$ (but occurred in the Ppc time range) contralateral to a salient-but-irrelevant colour singleton. According to Sawaki and Luck, the most salient item generates an “attend-to-me” signal that can be suppressed when the features of the eliciting item do not match the current attentional control settings. In the context of our own salient-signal suppression view, this “attend-to-me” signal is likely associated with activation on the salience map. Here, we emphasize that multiple items are represented on the salience map and that each of these items – not just the most salient item – generate “attend-to-me” signals.
References


Eimer, M., & Kiss, M. (2010). The top-down control of visual selection and how it is linked to the N2pc component. *Acta psychologica*, 135, 100–102.


*Perception & Psychophysics, 61*, 727–739.


contingent on attentional control settings. *Journal of Experimental Psychology: Human 
Perception and Performance, 18*, 1030–1044.

Folk, C. L., Remington, R. W., & Wright, J. H. (1994). The structure of attentional control: 
Contingent attentional capture by apparent motion, abrupt onset, and colour. *Journal of 

Contralateral cortical organisation of information in visual short-term memory: Evidence 
from lateralized brain activity during retrieval. *Neuropsychologia, 50*, 1748–1758.


Hickey, C., & Di Lollo, V., & McDonald, J. J. (2009). Electrophysiological indices of target and 


*Attention, Perception & Psychophysics, 73*, 2053–2064.


targets across dimensions: Stimulus and expectancy-driven effects in dimensional
weighing. *Journal of Experimental Psychology: Human Perception and Performance, 29,*
1021–1035.


Pinto, Y., Olivers, C. N. L., & Theeuwes, J. (2005). Target uncertainty does not lead to more
distraction by singletons: Intertrial priming does. *Perception & Psychophysics, 67,* 1354 –
1361.

Sawaki, R., Geng, J. J., & Luck, S. J. (2012). A common neural mechanism for preventing and

Sawaki, R. & Luck, S. J. (2010). Capture versus suppression of attention by salient singletons:
Electrophysiological evidence for an automatic attend-to-me signal. *Attention, Perception &
Psychophysics, 72,* 1455–1470.

Schübo, A. (2009). Salience detection and attentional capture. *Psychological Research-
Psychologische Forschung, 73,* 233–243.

184–193.

51,* 599–606.

429–440.


Footnote

1. One might also wonder whether the early contralateral positivity reported by Sawaki and Luck (2010) was a Ppc rather than a suppression-related P_D, because it was also observed in the pre-N2pc time interval. A definitive test would be to conduct a version of Sawaki and Luck’s task in which participants search for the color singleton. If the early contralateral positivity were to occur prior to an N2pc – as it did in the present study – it would be most likely related to an attend-to-me signal rather than the suppression of such a signal.
Acknowledgments

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Table 1. Grand averages across participants of median response times (in milliseconds) for all distractor-present and distractor-absent trials and for the display configurations of interest in Experiments 1 and 2.

<table>
<thead>
<tr>
<th>Trial type / Display configuration</th>
<th>Experiment 1</th>
<th></th>
<th>Experiment 2</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT (SEM)</td>
<td>Delay</td>
<td>RT (SEM)</td>
<td>Delay</td>
</tr>
<tr>
<td>Distractor present</td>
<td>668 (13)</td>
<td>8</td>
<td>584 (13)</td>
<td>8</td>
</tr>
<tr>
<td>Distractor absent</td>
<td>660 (14)</td>
<td>–</td>
<td>576 (13)</td>
<td>–</td>
</tr>
<tr>
<td>Lateral target, midline distractor</td>
<td>670 (15)</td>
<td>11</td>
<td>591 (14)</td>
<td>10</td>
</tr>
<tr>
<td>Midline target, lateral distractor</td>
<td>666 (14)</td>
<td>7</td>
<td>573 (13)</td>
<td>-8</td>
</tr>
<tr>
<td>Lateral target, no distractor</td>
<td>659 (13)</td>
<td>–</td>
<td>581 (14)</td>
<td>–</td>
</tr>
<tr>
<td>Lateral target, contralateral distractor</td>
<td>662 (13)</td>
<td>3</td>
<td>587 (13)</td>
<td>6</td>
</tr>
<tr>
<td>Lateral target, ipsilateral distractor</td>
<td>675 (14)</td>
<td>16</td>
<td>587 (13)</td>
<td>6</td>
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</tbody>
</table>

Note: Delay on distractor-present trials is measured in relation to the distractor-absent trials. For other display configurations, delay is measured in relation to the lateral target, no distractor configuration.
Table 2. Grand averages across participants of median response times (in milliseconds) for the display configurations and target-distractor proximities of interest for Experiments 1 and 2.

<table>
<thead>
<tr>
<th>Configuration</th>
<th>Experiment 1</th>
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<th>Experiment 2</th>
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<tbody>
<tr>
<td></td>
<td>RT</td>
<td>Delay</td>
<td>RT</td>
<td>Delay</td>
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<tr>
<td>Ipsilateral Distractor</td>
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<td></td>
</tr>
<tr>
<td>1 (adjacent)</td>
<td>680</td>
<td>21</td>
<td>591</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>675</td>
<td>16</td>
<td>586</td>
<td>5</td>
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<td>3</td>
<td>668</td>
<td>9</td>
<td>595</td>
<td>14</td>
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<tr>
<td>Contralateral Distractor</td>
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<tr>
<td>2</td>
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<td>4</td>
</tr>
<tr>
<td>4</td>
<td>662</td>
<td>3</td>
<td>581</td>
<td>0</td>
</tr>
<tr>
<td>5 (opposite)</td>
<td>655</td>
<td>-4</td>
<td>589</td>
<td>8</td>
</tr>
</tbody>
</table>

Note: Delay is measured in relation to the lateral target, no distractor configuration (659 ms in Experiment 1; 581 ms in Experiment 2)
Table 3. Grand averages across participants of median response times (in milliseconds) on fast-response and slow-response trials for all distractor-present and distractor-absent displays and for the search-display configurations of interest in Experiment 1.

<table>
<thead>
<tr>
<th>Trial type / Display configuration</th>
<th>Fast responses</th>
<th>Slow responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>RT (SEM)</td>
<td>Delay</td>
</tr>
<tr>
<td>Distractor present</td>
<td>585 (11)</td>
<td>3</td>
</tr>
<tr>
<td>Distractor absent</td>
<td>582 (11)</td>
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<tr>
<td>Lateral target, midline distractor</td>
<td>588 (12)</td>
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<tr>
<td>Midline target, lateral distractor</td>
<td>584 (11)</td>
<td>3</td>
</tr>
<tr>
<td>Lateral target, no distractor</td>
<td>581 (11)</td>
<td>–</td>
</tr>
<tr>
<td>Lateral target, contralateral distractor</td>
<td>583 (11)</td>
<td>2</td>
</tr>
<tr>
<td>Lateral target, ipsilateral distractor</td>
<td>590 (12)</td>
<td>9</td>
</tr>
</tbody>
</table>

Note: Delay on distractor-present trials is measured in relation to the distractor-absent trials. For other display configurations, delay is measured in relation to the lateral target, no distractor configuration.
**Figure Captions**

*Figure 1.* Hypothetical sequence of processes in additional-singleton search, based on the salience-driven selection account. Here, selection is considered to take place when information at one location is transferred from the preattentive stage to the attentive stage for further processing (cf. Theeuwes, 2010). Four lateralized ERP components have been associated with specific processing stages (see text for details).

*Figure 2.* All-trials ERPs recorded at occipital electrodes (PO7, PO8) in Experiment 1. Panels a–c show the ERPs elicited by displays containing only one lateral singleton, whereas panels d and e show the ERPs elicited by displays containing two lateral singletons, either on opposite sides (d) or the same side (e). The target singleton was a green circle among green diamonds. The distractor singleton (dashed diamond) was a red diamond. TL/DM = lateral target, midline distractor; TM/DL = midline target, lateral distractor; TL/DA = lateral target, no distractor; TL/DC = lateral target, contralateral distractor; TL/DI = lateral target, ipsilateral distractor. Negative voltages are plotted up, by convention.

*Figure 3.* ERPs recorded at occipital electrodes (PO7, PO8) in Experiment 1, averaged separately for fast-response and slow-response trials. Individual trials with RTs falling below or above the median RT for each display configuration were defined as fast-response and slow-response trials, respectively.

*Figure 4.* ERLs from Experiment 1. ERLs were computed by subtracting ipsilateral waveforms from corresponding contralateral waveforms. Upward and downward deflections reflect negative and positive voltages contralateral to the eliciting stimulus, respectively. (a) All-trials ERLs from the five display configurations of interest. (b) ERLs for isolation displays
(containing one lateral singleton and one midline singleton), separately for fast-response and slow-response trials. Individual trials with RTs falling below or above the median RT for the relevant display configuration were defined as fast-response and slow-response trials, respectively. 

(c) ERLs to lateral-target displays as a function of the distance between target and distractor. D1 signifies the distractor was one position from the target (i.e., adjacent distractor); D5 signifies the distractor was five positions from the target (i.e., opposite distractor).

*Figure 5.* All-trials ERPs recorded at occipital electrodes (PO7, PO8) in Experiment 2. Panels a–c show the ERPs elicited by displays containing only one lateral singleton, whereas panels d and e show the ERPs elicited by displays containing two lateral singletons, either on opposite sides (d) or the same side (e).

*Figure 6.* ERLs from Experiment 2. (a) All-trials ERLs from the five display configurations of interest. (b) ERLs for isolation displays (containing one lateral singleton and one midline singleton), separately for fast-response and slow-response trials. (c) ERLs to lateral-target displays as a function of the distance between target and distractor.

*Figure 7.* Hypothetical sequence of processes in additional-singleton search, based on our own salient-signal suppression hypothesis. Six laterialized ERP components are associated with specific processing stages (see text for details).
ipsilateral to target
contralateral to target
ipsilateral to lateral singleton
contralateral to lateral singleton
contralateral to target
ipsilateral to target

Figure 2
MEDIAN-SPLIT ERPs

FAST-RESPONSE TRIALS

T/L/D_M

ipsilateral to target

contralateral to target

SLOW-RESPONSE TRIALS

T/M/D_L

ipsilateral to lateral singleton

contralateral to lateral singleton

T/L/D_A

ipsilateral to target

contralateral to target

T/L/D_C

ipsilateral to target

contralateral to target

TL/DM

TM/DL

TL/DA

TL/DC

TL/DI

a. All-trials ERPs

b. Median-split ERPs

c. Proximity analysis

Figure 4

ALL-TRIALS ERPs

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Figure 6