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Kerzel, Dirk; Burra, Nicolas

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# Capture by context elements, not attentional suppression of distractors, explains the $P_D$ with small search displays

Dirk Kerzel & Nicolas Burra
Faculté de Psychologie et des Sciences de l'Education
Université de Genève

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Address:
Dirk Kerzel
Faculté de Psychologie et des Sciences de l'Éducation
Université de Genève
40 Boulevard du Pont d'Arve, 1205 Genève, Switzerland
Tel: +41 (0) 22 / 37.99.132 / Fax: +41 (0) 22 / 37.99.129
Email: dirk.kerzel@unige.ch

## Abstract

Top-down control of attention allows us to resist attentional capture by salient stimuli that are irrelevant to our current goals. Recently, it was proposed that attentional suppression of salient distractors contributes to top-down control by biasing attention away from the distractor. With small search displays, attentional suppression of salient distractors may even result in reduced reaction times on distractor-present trials. In support of attentional suppression, electrophysiological measures revealed a positivity between 200-300 ms contralateral to the distractor, which has been referred to as distractor positivity ($P_D$). We re-examined distractor benefits with small search displays and found that the positivity to the distractor was followed by a negativity to the distractor. The negativity, referred to as N2pc, is considered an index of attentional selection of the contralateral element. Thus, attentional suppression of the distractor ($P_D$) preceded attentional capture (N2pc) by the distractor, which is at odds with the idea that attentional suppression avoids attentional capture by the distractor. Instead, we suggest that the initial "$P_D$" is not a positivity to the distractor, but rather a negativity (N2pc) to the contralateral context element, suggesting that initially, the context captured attention. Subsequently, the distractor was selected because paradoxically, participants searched all lateral target positions (even when irrelevant) before they examined the vertical positions. Consistent with this idea, search times were shorter for lateral than vertical targets. In sum, the early voltage difference in small search displays is unrelated to distractor suppression, but may reflect capture by the context.

## Keywords

visual search, attentional capture, attentional suppression, $P_D$, N2pc

## Introduction

The debate on bottom-up vs. top-down control of attention has shifted from the question whether salient distractors capture attention to the question under which conditions this occurs (Awh, Belopolsky, & Theeuwes, 2012; Büsel, Voracek, & Ansorge, 2018; Gaspelin & Luck, 2018b; Lamy, Leber, & Egeth, 2012; Liesefeld & Müller, 2019a; Theeuwes, 2018, 2019). Importantly, capture was found to decrease in conditions that promote precise target templates (Folk, Remington, & Johnston, 1992; Lamy, Carmel, Egeth, & Leber, 2006). For instance, Bacon and Egeth (1994) showed that attentional capture by a salient color distractor disappeared when observers were forced to search for the features of a specific shape (feature search) instead of searching for a divergent shape (singleton search). These results suggest that enhancing the representation of the target avoids attentional capture.

Recently, Gaspelin and Luck (2018b) argued for another top-down control mechanisms. The signal suppression hypothesis (Gaspelin & Luck, 2018b; Sawaki & Luck, 2010) claims that salient stimuli capture attention unless they are suppressed by a top-down mechanism. Strong evidence for suppression was provided by the assessment of visual processing at individual stimulus locations. Gaspelin, Leonard, and Luck (2015) found that letter identification in shape-based feature search was worse at the location of the color distractor than at nontarget locations (see Figure 1), demonstrating that distractor suppression may reduce activation at the distractor location below baseline. In the same vein, Gaspelin, Leonard, and Luck (2017) reported that eye and reaching movements went less frequently to the distractor than to nontarget locations.

For small search displays, distractor suppression may effectively eliminate the distractor from the set of searched stimuli, resulting in shorter RTs on distractor-present than distractor-absent trials (Gaspelin et al., 2015). Thus, the distractor decreased RTs, which is in contrast to more common variants of the additional singleton paradigm where a distractor increases RTs because of attentional capture (Theeuwes, 2018, 2019). However, distractor benefits dovetail nicely with research on an event-related potential, the $P_D$. The $P_D$ is a positivity contralateral to the distractor between 200-300 ms at posterior electrodes sites PO7/8 and is assumed to reflect distractor suppression (Hickey, Di Lollo, & McDonald, 2009). In previous studies, the magnitude of the $P_D$ to the distractor was larger on trials with fast responses (Gaspar & McDonald, 2014; Jannati, Gaspar, & McDonald, 2013), suggesting that the $P_D$ reflects a suppressive mechanism that helps bias attention away from the distractor.

Direct evidence for the contribution of distractor suppression to the distractor benefit with small search displays was provided by Gaspelin and Luck (2018a). In their Experiment 1, participants performed feature search on 70% of the trials. On 30% of trials, a letter identification task was run to probe the distribution of attention at individual stimulus locations. Replicating previous work (Gaspelin et al., 2015), probe identification at the distractor location was worse than at nontarget locations. Importantly, there was a $P_D$ to the color distractor, confirming that distractor suppression occurred.

While the electrophysiological results from Gaspelin and Luck (2018a) are consistent with the signal suppression hypothesis, they are inconsistent with a previous study using larger search displays. Barras and Kerzel (2016) presented eight search items and compared singleton and feature search. In singleton search, the target shape was unpredictable, but unique among uniform nontarget shapes, forcing participants to search for a shape that was different from the others. In contrast, the target was predictable, but shown among heterogeneous nontarget shapes in feature search, forcing participants to search for a particular shape. Singleton and feature search were similar to work by Gaspelin and colleagues (Gaspelin et al., 2015, 2017; Gaspelin & Luck, 2018a). Singleton search resulted in a 30 ms-increase of RTs on distractor-present trials and a $P_D$ to the distractor. In contrast, feature search resulted neither in behavioral interference from the distractor nor in a $P_D$ to the distractor. Rather, the amplitude of the N2pc to the target differed between singleton and feature search, suggesting that target enhancement accounted for the resistance to interference.

The goal of the present study was to clarify whether attentional suppression is a viable explanation for distractor benefits in feature search with small set sizes. Recently, Liesefeld and Müller (2019b) proposed that the small set size combined with the heterogenous nontarget shapes in work by Gaspelin and colleagues (Gaspelin et al., 2015, 2017; Gaspelin & Luck, 2018a) represents a strong departure from more common variants of the additional singleton paradigm. In particular, Liesefeld and Müller (2019b) proposed that their choice of set size and nontarget stimuli promoted systematic scanning over guidance by priority. Guidance by priority relies on a spatial map which represents the selection history, top-down relevance and bottom-up saliency of elements in the search array.

Attention is thought to move to stimulus locations in the order of decreasing priority, that is, the stimulus with the highest priority is attended first (Itti & Koch, 2001; Theeuwes, 2010). In contrast, systematic scanning of individual or grouped stimuli ("clump scanning") involves successive shifts of attention across the search display where scan paths are idiosyncratic. For instance, scan paths may be defined by stimulus eccentricity so that stimuli close to the fovea are scanned before peripheral stimuli (Woodman & Luck, 1999). In the search displays by Gaspelin and colleagues, however, the location of the distractor feature may determine the order of scanning by providing a template for rejection (Arita, Carlisle, & Woodman, 2012; Beck, Luck, & Hollingworth, 2018; Tanda & Kawahara, 2019). An important point is that scanning involves systematic shifts of attention, resulting in N2pc and $P_D$ components that may pass for attentional capture or suppression.

Further, we worried that the experimental design in Gaspelin and Luck (2018a) may have affected attentional selectivity. In Gaspelin and Luck's experiments, search and probe trials were mixed. Because participants were asked to report as many letters as possible on probe trials, there was an incentive to distribute attention evenly across all stimulus locations. In contrast, pure search tasks provide no incentive to attend to locations other than the search target. Therefore, we decided to measure electrophysiological correlates of target and distractor processing in pure feature search with small set sizes.

## Experiment 1

Experiment 1 replicated the first experiment in Gaspelin and Luck (2018a), but without the letter probe task (see Figure 1). The size and eccentricity of the stimuli were closely matched. In particular, the stimuli were close to fixation (at about 2° of visual angle) and the stimuli were relatively small (about 1° in diameter). We asked participants to judge the orientation of a line inside the target stimulus (similar to classic work by Theeuwes, 1992), whereas Gaspelin and Luck (2018a) asked participants to judge the location of a dot.

To isolate electrophysiological responses to the target and distractor, we employed the logic proposed by Woodman and Luck (2003) whereby stimuli presented on a vertical line crossing the fixation point do not affect lateralized components. Therefore, presenting the target on the vertical and the distractor on a lateral position (see Figure 1, panel 4) allows for the isolation of the distractor-related $P_D$, which is the main focus of the current investigation. Because stimulus positions were random, three other configurations of interest occurred. When the target was on a lateral position, either without distractor

(Figure 1, panel 1) or with vertical distractor (Figure 1, panel 2), we expected target-related N2pc-components. The N2pc is a more negative voltage at electrodes contralateral to candidate target objects (Eimer, 1996; Luck & Hillyard, 1994), and may indicate the transient enhancement for high-level processing such as identification (Zivony, Allon, Luria, & Lamy, 2018). It occurs at the same electrodes (PO7/8) and in the same time interval (200-300 ms post-stimulus) as the $P_D$. The N2pc is also referred to as posterior contralateral negativity or PCN (Töllner, Müller, & Zehetleitner, 2012; Töllner, Zehetleitner, Krummenacher, & Müller, 2010).

While the N2pc mostly occurs contralateral to candidate target objects, it may also occur contralateral to distractors, indicating that attention was captured by the distractor. The occurrence of the distractor-related N2pc is contingent on the difficulty of the search task. With unlimited presentation times, an N2pc to the distractor was reported, but in these studies, search was difficult because the target was inconspicuous (Barras & Kerzel, 2017) or because target and distractor shape varied unpredictably (Burra & Kerzel, 2013; Hickey, McDonald, & Theeuwes, 2006; Kiss, Grubert, Petersen, & Eimer, 2012). Further, attentional capture by the distractor (i.e., an N2pc) may be followed by attentional suppression of the distractor (i.e., a $P_D$), suggesting that the $P_D$ reflects the termination of the allocation of attention (Sawaki, Geng, & Luck, 2012). We refer to the sequence of distractor-related N2pc followed by a distractor-related $P_D$ as N2pc-$P_D$-switch. A reliable N2pc-$P_D$-switch was reported when target and distractor features were drawn from the same perceptual dimension (e.g., color target with color distractor; Hilimire, Mounts, Parks, & Corballis, 2011; Liesefeld, Liesefeld, Töllner, & Müller, 2017). For same-dimension distractors, initial selection of the distractor may occur because the distractor partially matched the target features. N2pc-$P_D$-switches were also reported for cross-dimensional distractors when presentation times were short (i.e., shape target with color distractor, Feldmann-Wüstefeld, Brandhofer, & Schubö, 2016), but sometimes the N2pc was absent and only a $P_D$ occurred (Kiss et al., 2012). Because we used unlimited presentation times and easy search, we do not expect an N2pc or an N2pc-$P_D$-switch with lateral distractors. Rather, N2pc-components are only expected to lateral targets.

Further, it is unlikely that the opposite distractor condition (Figure 1, panel 3) yields a sequence of two N2pcs where attentional capture by the distractor (a distractor-related N2pc) is followed by selection of the target on the opposite side (a target-related N2pc). The sequence of distractor-related N2pc followed by a target-related N2pc is referred to as N2pc-flip. Initial reports of N2pc-flips with cross-dimensional distractors opposite to the target (Hickey et al., 2006) were found to be unreliable (Jannati et al., 2013; McDonald, Green, Jannati, & Di Lollo, 2013). However, reliable N2pc-flips were observed for distractors drawn from the same dimension as the target (i.e., orientation target and orientation distractor, Liesefeld et al., 2017).

In sum, based on work by Gaspelin and Luck (2018a), we expect a distractor-related $P_D$, but no distractor-related N2pc. The main reasons are that stimulus presentation in our study was unlimited, the target was easy to find and drawn from a dimension different from the distractor. In contrast, lateral targets are expected to result in an N2pc.

## Methods

**Participants**. Sample size was based on Experiment 1 in Gaspelin and Luck (2018a), which had 20 participants. Here, twenty-four first-year psychology students from the University of Geneva participated for class credit. Eleven datasets were retained in the final sample (3 men, age: $M = 20$, $SD = 3$) and 13 were rejected (1 man, age: $M = 19$, $SD = 1$) because of eye movements (see below). The loss of datasets was substantial, but the remaining number was sufficient (i.e., the study was overpowered with 20 subjects). The critical difference between conditions with lateral distractor and lateral target had a Cohen's $d_z$ of about 0.9 in Gaspelin and Luck (2018a). A sample size of 12 would be necessary replicate this effect with a power of .8 at an alpha of .05. The study was approved by the ethics committee of the Faculty of Psychology and Educational Sciences of the University of Geneva and was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki). Informed consent was given before the experiment.

**Apparatus and stimuli.** Stimuli were displayed on a 21-inch CRT monitor with a refresh rate of 85 Hz and a pixel resolution of 1,280 × 1,024 (horizontal × vertical), viewed at a distance of 80 cm. The background was black, and the stimuli were either red or green (16.5 cd/m$^2$, CIE xyY coordinates: $x = 0.628$, $y = 0.338$ for red, and $x = 0.294$, $y = 0.605$ for green). A white fixation cross with a luminance of 87 cd/m$^2$ was presented in the center of the screen. The search display consisted of a circle, a square, a diamond, and a hexagon. All shapes were filled, similar to Gaspelin and Luck (2018a). The shapes were presented at an eccentricity of 2° of visual angle (center-to-center) on the vertical and horizontal midlines. The circle had a diameter of 1.4° and the dimensions of the remaining shapes (square, diamond, and hexagon) were adjusted to have an equal area. The mean number of lit pixels per shape was 4,306 (*SD* = 14 pixels or 0.3%, range from 4290 to 4324 pixel). A vertical or horizontal black line of 0.7° length was presented in the center of each shape. Stroke width was 0.06°. The Psychtoolbox (Brainard, 1997; Kleiner, Brainard, & Pelli, 2007) was used to run the experiment.

**Electrophysiological recording and initial data processing.** An actiCHamp amplifier (Brain Products, Gilching, Germany) with active Ag/AgCl electrodes was used. Data was recorded using the PyCorder software by Brain Products. In the filter settings of the PyCorder software, we deactivated cutoffs and the notchfilter. Continuous EEG was sampled at 1000 Hz from 26 scalp electrodes and six additional electrodes placed at the outer canthi of each eye, above and below the right eye, and on each earlobe. Cz served as online reference and AFz as ground site. The data were analyzed using ERPLAB (Lopez-Calderon & Luck, 2014), an extension of EEGLAB (Delorme & Makeig, 2004). Raw EEG was re-referenced to the average earlobes and filtered between 0.1 and 30 Hz with a bandpass second-order Butterworth filter (roll-off 12db/octave, command "pop_basicfilter" in ERP-lab). The filter settings matched those in Gaspelin and Luck (2018a). The difference between left and right eye electrode constituted the HEOG channel, and the difference between upper and lower eye electrode constituted the VEOG channel. The EEG was segmented into 500 ms epochs extending from 100 ms before to 400 ms after stimulus onset. The first 100 ms served as baseline.

**Procedure.** Participants were asked to search for a specific shape (e.g., a circle) and to report the line orientation inside the shape. To indicate line orientation, participants pressed the left or right arrow key on a standard keyboard with their right hand. Left and right responses were equiprobable and the key-to-response mapping was initially counterbalanced across participants. Participants were asked to maintain fixation on the central fixation cross, to ignore the colors, and to respond as rapidly as possible while keeping the error rate below 10%. After blocks of 40 trials, mean RT and the error rate were shown for at least 5 secs, forcing participants to take a short break. At the beginning of the experiment, participants practiced the experimental task until they felt comfortable with it. Practice trials were not recorded, but participants completed at least 30 trials.

A trial started with the presentation of the fixation cross for a randomly selected duration between 0.85 and 1.1 sec. Then, the search display appeared. As in Gaspelin and

Luck (2018a), the search display stayed on the screen until a response was registered. Only very few trials had RTs shorter than 350 ms (*M* = 0.09 trials per participant in Experiment 1 and *M* = 3 trials in Experiment 2) so that offset transients caused by the key-press were unlikely to affect ERPs. Choice errors and late trials (RTs > 2 secs) were reported to the participant by visual feedback.

On half of the trials, one non-target shape had a color different from the remaining stimuli (distractor-present trials). On the other half, all four shapes had the same color (distractor-absent trials). The placement of target and distractor was random. To cancel out potential sensory differences, the color (red or green) and target shape (circle or diamond) changed after 480 trials. There were at least ten familiarization trials before data collection resumed. The combination of color and target shape in the first block was initially counterbalanced across participants. A total of 960 trials was run.

## Results

The data from all experiments is available in the open science framework at https://osf.io/ckhgs/?view_only=8ab328c819c34d65b9db77cae1d6fda7

**Exclusion of datasets.** Trials with behavioral errors and RTs slower than 2 secs were excluded from analysis for both behavioral and ERP analysis. Further, individual trials in the ERP analysis were rejected when blinks and vertical eye movements (difference in VEOG channel exceeding ± 50 µV), horizontal eye movements (steps in HEOG channel exceeding ± 16 µV), and muscular or other artifacts (any electrode exceeding ± 80 µV) occurred between 100 ms before to 350 ms after stimulus onset. Thirteen datasets were discarded because more than 25% of the trials were lost, leaving eleven datasets for the final analysis. In the excluded datasets, the mean behavioral error rate was 5% and the mean rate of eye movement errors was 37%, but ERPs were similar to Figure 2.

**Behavior.** Eleven datasets were analyzed. Trials with RTs slower than 2 secs were excluded (less than 1%). Subsequently, data were trimmed for each participant and condition by removing trials with RTs that were more than 2.5 standard deviations above the respective condition mean. This resulted in the exclusion of additional 3% of the trials for the behavioral analysis.

Individual mean RTs of correct responses on distractor-present and -absent trials (480 trials each) were compared by paired t-test. RTs on distractor-present trials were 30 ms shorter than on distractor-absent trials (743 vs. 773 ms), *t*(10) = 3.93, *p* = .003, Cohen's *d* = 1.18. Choice errors did not differ significantly (4% in both conditions), *p* = .446.

**Electrophysiology.** After rejecting trials with electrophysiological artefacts, behavioral errors, or RTs longer than 2 secs, 87% of the trials of interest remained for analysis. The mean number of trials per condition and participant was 210 trials for lateral target + no distractor (range 188-232, out of 240), 140 for lateral distractor + vertical distractor (range 129-153, out of 160), 71 for lateral target + opposite distractor (range 64-77, out of 80), and 139 for vertical target + lateral distractor (range 125-159, out of 160). The 240 trials with vertical targets + no distractor and the 80 trials with vertical target + opposite distractor were not analyzed because they did not result in lateralized ERP-components. The ipsi- and contralateral potentials at electrodes PO7/8 are shown in the upper panels of Figure 2 and the respective difference waves (obtained by subtracting ipsi- from contralateral activity) are shown in the lower left panel of Figure 2.

Inspection of Figure 2 (bottom left panel) shows a biphasic response in the vertical target + lateral distractor condition from about 170 to 350 ms. As this condition is the focus of the current study, we selected the analysis intervals accordingly. A 50-ms analysis window was placed on the positive-going peak, which occurred in the early range of the N2pc, at 209 ms. Another 50-ms analysis window was placed on the negative-going peak, which occurred in the late range of the N2pc, at 284 ms. The positive- and negative-going peaks correspond to the $P_D$ and N2pc, respectively. Peaks were determined after smoothing the grand-average difference waves by a 50 ms sliding average.

**Early N2pc interval.** We tested whether average voltage differences in the 50 ms interval centered on 209 ms were significantly different from zero. By one sample t-test, the positivity to lateral distractors with vertical targets was significant (0.75 µV), *t*(10) = 3.59, *p* = .005, Cohen's $d_z$ = 1.08, consistent with the occurrence of a $P_D$ as in Gaspelin and Luck (2018a). To assure that the time window was indeed the N2pc interval, we also tested the negativities to lateral targets for significance. The critical *p* value was adjusted to control the false-discovery-rate (Benjamini & Hochberg, 1995). One-sample t-tests showed that the negativities to lateral targets without distractor, with vertical distractor, and with opposite distractor were significantly different from zero, *t*s(10) > 2.9, *p*s < .014, Cohen's $d_z$ > 0.9, suggesting that the analysis interval corresponded to the early part of the N2pc time window.

**Late N2pc interval.** We tested whether the average voltage difference in the 50 ms interval centered on 284 ms was significantly different from zero. Importantly, there was a significant N2pc in the vertical target + lateral distractor condition (-1.19 µV), *t*(10) = 4.47, *p* = .001, Cohen's $d_z$ = 1.35, indicating that the early positivity ($P_D$) to the distractor was followed by a late negativity (N2pc). Separate one-sample t-tests against zero confirmed that the late N2pc-components to lateral targets were significantly different from zero in all conditions, *t*s(10) > 3.3, *p*s < .008, Cohen's $d_z$ > 0.99, suggesting that the analysis interval corresponded indeed to the late part of the N2pc time window.

**HEOG.** HEOGs were calculated as the difference between contra- and ipsilateral electrodes, similar to the N2pc, and are plotted in Figure 2, lower right panel. We tested weather the early $P_D$ and late N2pc to the distractor were accompanied by changes in the HEOG, but neither difference was significantly different from zero, *p*s > .38. Similarly, there were no significant differences to lateral targets. However, the lower right panel in Figure 2 shows that there was a tendency to look toward the lateral target after about 350 ms.

## Discussion

We re-examined distractor processing in feature search with small search displays. Behaviorally, we replicated the shorter RTs on distractor-present than distractor-absent trials. However, our electrophysiological results are not compatible with the idea that attentional suppression of the distractor caused the behavioral benefit. We replicated a contralateral positivity to the distractor in the early N2pc interval, but the early positivity was followed by a contralateral negativity to the distractor. As the polar opposite of the N2pc-$P_D$-switch (e.g., Feldmann-Wüstefeld et al., 2016; Hilimire et al., 2011; Liesefeld et al., 2017), we observed that the $P_D$ turned into an N2pc. If we assume that the early positivity and late negativity correspond to distractor-related $P_D$ and N2pc components, respectively, we must conclude that attentional suppression was followed by attentional capture. According to the signal suppression hypothesis (Gaspelin & Luck, 2018b; Sawaki & Luck, 2010), the role of attentional suppression is to prevent the involuntary capture of attention by salient elements. Consequently, the observed sequence of attentional suppression followed by attentional capture is incompatible with the signal suppression hypothesis. Beyond signal suppression, the $P_D$-N2pc-switch seems paradoxical. Why would participants attend to the distractor after they suppressed it? It is easier to find a functional explanation for the N2pc-$P_D$-switch, where attentional capture by the distractor is followed by attentional suppression (Feldmann-Wüstefeld & Schubö, 2013; Hickey et al., 2006; Hilimire et al., 2011; Liesefeld et al., 2017) to terminate the erroneous shift of attention (Sawaki et al., 2012). In the present case, it is not clear what could be achieved by first suppressing and then attending to the distractor. However, the results are consistent with the idea of spatial scanning strategies (Liesefeld & Müller, 2019b). Possibly, participants scanned the sparse display starting opposite to the salient element. Thus, the salient element may provide a template for rejection (Arita et al., 2012; Beck et al., 2018).

Our results deviate from those of Gaspelin and Luck (2018a) who found a distractor-related positivity, but no negativity in their Experiment 1. We attribute the discrepancy to differences in the distribution of attention between a pure search task, where there was no benefit of spreading attention, and mixed tasks, where it was beneficial to also attend to non-target locations. Spreading attention across non-target locations optimizes performance on the letter identification task where all stimuli in the array were probed. While our results deviate from Experiment 1 in Gaspelin and Luck (2018a), results from their Experiment 3 are very similar to ours. In their Experiment 3, Gaspelin and Luck (2018a) presented a color singleton on each trial. In separate blocks of trials, the color singleton was either target or distractor. When the color singleton was a distractor, the same sequence of early $P_D$ followed by a late N2pc was observed (see Figure 9C in Gaspelin & Luck, 2018a). Despite the statistical significance of the late N2pc, it was not discussed by Gaspelin and Luck (2018a). Possibly, the lack of distractor-absent trials in their Experiment 3 prevented firm conclusions.

## Experiment 2

Before we attempt to find an explanation for the paradoxical $P_D$-N2pc-switch in Experiment 1, several methodological issues need to be addressed. First, the orientation-discrimination task in Experiment 1 was different from the localization task in Gaspelin and Luck (2018a). In Experiment 2, we therefore employed Gaspelin and Luck's localization task to avoid spurious effects of seemingly small methodological details. Second, there was a large number of excluded datasets in Experiment 1. Out of 24 participants, 13 were unable to maintain fixation during the search task, resulting in many discarded trials. Possibly, the small eccentricity of the stimuli and the unlimited presentation time made it difficult to refrain from looking at the stimuli. In Gaspelin and Luck (2018a), only few datasets were removed, and we suspect that their participants had some experience with psychophysical tasks. In contrast, the first-year students in our experiments were novices. Therefore, we decided to screen participants for their ability to maintain fixation. It should be mentioned that the ERPs in the excluded datasets showed the same $P_D$-N2pc-switch as in Figure 2. Third, target shape and color were counterbalanced within each participant in our study, whereas target shape and color were counterbalanced across participants in Gaspelin and Luck (2018a). While interference from color distractors is typically absent in feature search mode (Bacon & Egeth, 1994), it has been demonstrated that interference re-emerges for about eight trials following a change of the distractor color (Vatterott, Mozer, & Vecera, 2018; Vatterott & Vecera, 2012). Because we had at least ten familiarization trials after target and distractor colors were swapped, it is unlikely that our results were contaminated by the change of distractor color. Nonetheless, we checked whether the results after the color swap differed from those before the color swap.

## Methods

**Stimuli and task.** The stimuli were the same as in Experiment 1 with the exception that the line inside each shape was replaced by a 0.08°-wide square at 0.5° to the left or right of the center of the shape. The task of the participant was to indicate the relative dot position in the target shape by clicking on the corresponding left or right mouse button.

**Participant screening.** We screened 46 students for their ability to maintain eye fixation during the visual search task in a screening session that preceded the main experimental session. An EyeLink1000 desk-mounted eye tracker (SR Research Ltd., Ottawa, ON, Canada) was used. After practice and calibration of the eye tracker, participants performed two sets of 120 trials. A saccade error was signaled to the participant if a saccade occurred during the 600 ms following the onset of the search display. The standard EyeLink saccade criteria for cognitive research were used (30°/s velocity and $8000°/sec^2$ acceleration). We used the overall error rate in the second block of trials to decide whether the participant was invited to a second session with EEG recording. The selection criterion was 25% errors, but three exceptions occurred. One participant with 24% errors and one with 22% were not motivated to come back, whereas another with 27% errors was highly motivated and was therefore invited back. Out of 46 students, 26 were selected for the EEG experiment (7 men, age: *M* = 19.5, *SD* = 2.2) and 20 were rejected (5 men, age: *M* = 19.9, *SD* = 1.6). The mean error rates in the second block of trials were 14% (*SD* = 7%) and 41% (*SD* = 11%) for the selected and rejected participants, respectively.

## Results

**Exclusion of EEG datasets.** One dataset was discarded because more than 25% of the data were lost after artifact rejection. Two datasets were lost because an earlobe electrode got loose during the experiment and one recording session was interrupted for technical reasons. Thus, 22 out of 26 datasets were available for analysis.

**Behavior.** Trials with slow responses (less than 1%) and outliers (3%) were excluded from analysis. Individual mean RTs of the distractor-present and -absent trials were compared by paired t-test. RTs on distractor-present trials were 11 ms shorter than on distractor-absent trials (587 vs. 597 ms), $t(21) = 3.96$, $p = .001$, Cohen's $d = 0.84$. Choice errors did not differ significantly between distractor-present and -absent trials (2% in both conditions), $p = .422$.

**Electrophysiology.** Data processing was as in Experiment 1. After rejecting trials with electrophysiological artefacts, behavioral errors, or RTs longer than 2 secs, 92% of the trials remained for analysis. The mean number of trials per condition was 223 trials (range 198-236) for lateral target + no distractor, 147 (range 126-157) for lateral distractor + vertical distractor, 74 (range 62-80) for lateral target + opposite distractor, and 147 (range 126-158) for vertical target + lateral distractor. The time intervals for analysis were centered on 211 ms for the early N2pc and on 294 for the late N2pc. These times are close to those in Experiment 1 (209 and 284 ms, respectively). The mean event-related potentials are presented in Figure 3.

**Early N2pc interval.** We tested whether average voltage differences in the 50 ms interval centered on 211 ms were significantly different from zero. A one-sample t-tests against zero showed that there was a positivity to lateral distractors with vertical targets (1.07 µV), $t(21) = 6.53$, $p < .001$, Cohen's $d_z = 1.39$, consistent with the occurrence of a $P_D$. Further one-sample t-tests against zero showed that all target-related negativities were significantly different from zero, $ts(21) > 4.54$, $ps < .001$, Cohen's $d_z > 0.97$, confirming that the analysis interval corresponded to the early N2pc.

**Late N2pc interval.** We tested whether average voltage differences in the 50 ms interval centered on 294 ms were significantly different from zero. Critically, a one-sample t-tests against zero confirmed that the N2pc-component was significant for lateral distractors with vertical targets (-0.81 µV), $t(21) = 5.39$, $p < .001$, Cohen's $d_z = 1.15$. Further, the N2pc-components to lateral targets were significant in the absence of a distractor (-0.99 µV) and with a vertical distractor (-0.88 µV), $ts(21) > 4.68$, $ps < .001$, Cohen's $d_z > 1$, suggesting that the analysis interval corresponded indeed to the late N2pc. However, the N2pc to lateral targets with opposite distractor (0.02 µV), $p = .904$, was not significant, which may be explained by the earlier onset and offset of the N2pc in this condition.

**HEOG.** HEOGs are plotted in Figure 3, lower right panel. We conducted one-sample t-tests against zero for the early and late N2pc interval, but did not find significant differences, *p*s > .173, suggesting that effects at electrodes PO7/8 were not contaminated by eye movements.

**Effects of color swap.** We split the data into the block preceding and following the color swap. Each block had 480 trials. First, we checked whether the reduction of RTs in the presence of a distractor changed from the first to the second block by means of a 2 (distractor: present, absent) x 2 (block: first, second) ANOVA. There were no effects involving block. In particular, the interaction of distractor presence and block was not significant, $p = .728$, suggesting that the effect of distractor presence was unchanged after the color swap. Second, we checked for effects of block in the most important ERP results. Neither the early $P_D$, nor the late N2pc to the lateral distractor differed between the first and the second block, *p*s > .434. Further, the early $P_D$ and the late N2pc to the lateral distractor were significantly different from zero in both blocks, *t*s(21) > 3.69, *p*s < .002, Cohen's $d_z > 0.78$. Thus, there was no evidence to suggest that changing the target shape and color had an effect. Rather, our results are consistent with prior studies showing that increased distractor interference after changes of the distractor color subsides after a few trials (Vatterott et al., 2018; Vatterott & Vecera, 2012). Similar results were obtained in a re-analysis of Experiment 1.

## Discussion

Experiment 2 features methodological improvements and a larger sample compared to Experiment 1. We used the same localization task as Gaspelin and Luck (2018a) and screened participants for their ability to maintain fixation. As a result, participants providing data were trained on the task, which possibly accounts for the shorter overall RTs in Experiment 2 (592 ms) compared to Experiment 1 (758 ms), but differences between the orientation and localization task may also contribute.

Importantly, we were able to replicate the electrophysiological results from Experiment 1. After a $P_D$ to the distractor occurring at 211 ms post-stimulus, we observed an

N2pc to the distractor at 294 ms. The $P_D$-N2pc-switch had similar temporal characteristics as in Experiment 1 and was unaffected by the color swap occurring after half of the trials.

The paradoxical $P_D$-N2pc-switch is hard to reconcile with the signal-suppression hypothesis because attentional suppression (as indexed by a distractor-related $P_D$) is assumed to prevent attentional selection of the distractor (as indexed by a distractor-related N2pc). However, we observed a distractor-related $P_D$ that was followed by a distractor-related N2pc. Because the current results differ from those observed with larger search displays (Barras & Kerzel, 2016), an account of the $P_D$-N2pc-switch is limited to small search displays with heterogeneous shapes. Liesefeld and Müller (2019b) predicted that this type of search display may result in spatial scanning strategies as opposed to guidance by priority. Possibly, scanning started opposite to the distractor before the distractor itself was scanned.

In general, it is unlikely that a waterproof explanation of the $P_D$-N2pc-switch can be given. $P_D$ and N2pc occur with opposite polarity at the same electrodes in the same time interval. Therefore, a data-driven justification for labelling the voltage difference one way or the other is missing. Following Gaspelin and Luck's (2018a) lead, we labelled the early positivity "distractor-related $P_D$", but it could also be a "context-related N2pc". That is, the positivity to the distractor may in fact be a negativity to the nontarget element opposite to the distractor, suggesting that the context captured attention.

What could be gained by turning the interpretation of the early voltage difference around? From the perspective of ideal search behavior, it would be best to use the distractor to guide attention towards potentially response-relevant context elements, as proposed in research on templates for rejection (Arita et al., 2012; Beck et al., 2018; Tanda & Kawahara, 2019). In the lateral distractor condition, this behavior would result in an N2pc to the context element opposite to the distractor.

Thus, we suggest that there were two N2pc-components in the lateral distractor condition, the first to the context element opposite to the distractor and the second to the distractor itself. The second N2pc is certainly a deviation from optimality, as it makes no sense to select the distractor. Therefore, the flip of the lateralized component remains paradoxical. However, the flip may derive from a particular search strategy in this paradigm. We suggest that participants had a tendency to search lateral before vertical positions. When there was a distractor on a lateral position, search started on the opposite side, as visible in a context-related N2pc (formerly distractor-related $P_D$). Because of the tendency to search both lateral positions first, the distractor was attended, as visible in a distractor-related N2pc, even though there was no reason to do so.

To provide solid evidence for this account, it would be necessary to measure the N2pc on single trials in the condition with only a vertical target. In each trial, the N2pc is expected to flip from left to right or the other way around. Unfortunately, the N2pc represents the mean across many trials and searches starting on the left and right will cancel out. Therefore, event-related potentials cannot provide a test of the proposed account. However, there is a simple behavioral prediction. If there was a tendency to attend to lateral positions first, then RTs for lateral targets should be shorter than for vertical targets. In contrast, the original account where a distractor-related $P_D$ is followed by distractor-related N2pc does not make this prediction because both the $P_D$ and the N2pc are related to a single response-irrelevant position.

## Re-Analysis of behavioral data

We re-analyzed effects of spatial configuration on RTs in more detail. The paradoxical succession of two N2pc components predicts faster search times for targets on lateral than vertical positions. In the previous analyses of RTs, we opposed distractor-present and distractor-absent trials. Here, we separated trials according to the spatial configuration of target and distractor. We separated lateral (left and right) from vertical (top and bottom) target positions.  Additionally, we considered the relative distractor position. If present, the distractor was either adjacent or opposite to the target. It should be noted that lateralized ERPs could not be analyzed for two of the conditions presented here. Notably, there were no lateralized elements in the vertical target + no distractor condition and in the vertical target + opposite distractor condition. These conditions are shown in gray in Figure 4. Because the task was different in Experiment 1 and the sample size was small, data from Experiment 1 is reported, but the main analysis concerns Experiment 2.

### Results

Mean RTs as a function of target and distractor configuration are shown in Figure 4. Data from Experiments 1 and 2 are shown in the upper and lower panels, respectively.

**Experiment 1.** There were less than 1% late trials and 5% outliers. We subjected mean individual RTs to a 2 (target position: lateral, vertical) x 3 (relative distractor position: absent, adjacent, opposite) repeated-measures ANOVA. RTs tended to be shorter for lateral than for vertical targets (difference of 26 ms, 728 vs. 754 ms), $F(1, 10) = 4.68$, $p = .056$, $\eta_p^2 =$

.319. RTs without a distractor (760 ms) were longer than RTs with a distractor adjacent (734 ms) or opposite (729 ms) to the target, $F(2, 20) = 8.34$, $p = .002$, $\eta_p^2 = .455$. The interaction was not significant, $p = .131$. Running the same ANOVA on choice errors did not yield any significant effects, *p*s > .214. The mean percentage of choice errors was 4%.

**Experiment 2.** There were less than 1% late trials and 4% outliers. RTs were shorter with lateral than vertical targets (difference of 24 ms, 574 vs. 598 ms), $F(1, 21) = 34.26$, $p < .001$, $\eta_p^2 = .62$, which is consistent with our hypothesis that lateral locations were searched before vertical locations. The main effect of relative distractor position, $F(2, 42) = 9.54$, $p < .001$, $\eta_p^2 = .312$, and the two-way interaction, $F(2, 42) = 4.95$, $p = .012$, $\eta_p^2 = .191$, were significant, showing that the effect of relative distractor position differed between lateral and vertical targets. For lateral targets, RTs did not differ between adjacent and opposite distractors (blue vs. pink bar in Figure 4, 570 vs. 572 ms), $p = .397$. In contrast, for vertical targets, RTs were shorter when the distractor was adjacent than when it was opposite (green vs. right gray bar in Figure 4, 586 vs. 604 ms), $t(21) = 3.35$, $p = .003$, Cohen's $d = 0.71$.

More t-tests involving the condition with lateral distractor and vertical target were carried out because previous work implicitly assumed that RTs in the presence of a distractor are generally shorter, but effects of specific spatial configurations were not evaluated. In particular, Gaspelin and Luck (2018a) suggested that the $P_D$ to the lateral distractor with vertical target explained why RTs were shorter on distractor-present trials. In fact, RTs in this condition were not different from the condition with lateral target only (green vs. red bar in Figure 4, 586 vs. 579 ms), $p = .216$. An RT advantage only emerged when it was compared to the condition with vertical target only (green vs. left gray bar, 586 vs. 603 ms), $t(21) = 4.24$, $p < .001$, Cohen's $d = 0.9$. For vertical targets, however, RTs with opposite distractor were not different from RTs with vertical target only (right vs. left gray bar, 604 vs. 603 ms), $p = .953$, suggesting that the presence of a distractor did not always result in shorter RTs, even when only one target position (vertical) was considered.

Running the same ANOVA as above on choice errors did not yield any significant effects, *p*s > .165. The mean percentage of choice errors was 2%.

## Discussion

The most important result of the reanalysis is that search times for lateral targets were shorter than for vertical targets. We had conjectured that the flip of the voltage difference with lateral distractor + vertical target represents a sequence of two N2pccomponents. The initial N2pc occurs to the lateral context element, the second to the distractor, suggesting that the lateral positions are searched exhaustively even if this does not represent optimal search behavior. If lateral positions are searched before vertical positions, RTs are expected to be shorter for lateral than vertical targets. Data from both Experiment 1 and 2 confirm this assumption and lend some credibility to our explanation.

## Experiment 3

We argued that search behavior with small search displays (Gaspelin & Luck, 2018a) differs from the search behavior with larger set sizes (Barras & Kerzel, 2016). In particular, we suggested that search of horizontal positions precedes search of vertical positions. According to Liesefeld and Müller (2019b), idiosyncratic scanning strategies are promoted by small and heterogeneous displays where the target is inconspicuous (see also Liesefeld, Liesefeld, & Müller, 2019). In contrast, displays where the target stands out are likely to be guided by the priority map. Experiment 3 tested the role of target saliency by using the same displays, but with a different target assignment. Participants were asked to search for the salient color singleton instead of the inconspicuous shape. We expect idiosyncratic scanning to disappear. Second, we sought to rule out contributions of stimulus-response congruency. Participants performed left or right mouse clicks in response to the left or right position of the dot inside the target shape. The congruency between the relative dot position and the response was the same irrespective of the position of the target shape. However, the congruency between the position of the target shape and the response differed between lateral and vertical positons. The lateral position of the target shape may interfere with the response when incongruent or facilitate the response when congruent (Ansorge, 2003; Simon, 1969; Zhang, Zhou, di Pellegrino, & Ladavas, 2007). In contrast, the vertical target position does not overlap with the response and is therefore unlikely to result in interference or facilitation. Possibly, the existence of stimulus-response congruency for lateral positions contributed to the difference between lateral and vertical target positions in Experiment 2. If so, we expect faster RTs with lateral than vertical target even for a different search task. Otherwise, we may conclude that stimulus-response correspondence played no role in our findings.

### Methods

Fifteen students participated (no men, age: *M* = 19.9, *SD* = 1.4). The stimuli were as in Experiment 2, with the exception that there was a color singleton on each trial. Participants were asked to perform the localization task on the dot inside the color singleton. Each shape (circle, square, diamond, and hexagon) was equally likely to be the color singleton. Eye fixation was checked for 400 ms after stimulus onset. Participants worked through 8 blocks of 60 trials. Performance feedback was given after each block and calibration was checked every other block.

### Results

Mean RTs are shown in Figure 5. There were less than 1% late trials and 9% fixation errors or blinks. A one-way (target position: left, right, top, bottom), repeated-measures ANOVA showed a significant main effect, $F(3, 42) = 8.7$, $p < .001$, $\eta_p^2 = .383$. RTs were about 20 ms longer when the target was on the left (552 ms) compared to when it was on the right, top, or bottom (529 ms, 530 ms, and 535 ms, respectively). A follow-up ANOVA on the latter three positions showed no effect, $p = .791$, suggesting that only the left position differed from the remaining positions. Running the same analysis on choice errors also yielded a significant main effect of position, $F(3, 42) = 12.86$, $p < .001$, $\eta_p^2 = .479$, showing that more errors occurred for positions on the left (3%) and right (2%) than for positions above (1%) and below (1%). A follow-up test showed that more errors occurred on left and right target positions when the relative dot position inside the target was incompatible with the target position relative to fixation (4% vs. 1%), $t(15) = 4.32$, $p = .001$, Cohen's $d_z = 1.12$. However, choice errors were rare and no corresponding effects were present in RTs.

### Discussion

We examined effects of target position in color-based singleton search. Contrary to shape-based feature search in Experiments 1 and 2, we found no advantage of lateral positions over vertical positions. Rather, we observed that search times for targets on the left were longer, which is consistent with previous work on shape-based singleton search with larger search displays (i.e., eight items in Carlei & Kerzel, 2018). With respect to the assumption that lateral stimuli are searched before vertical stimuli, we conclude that it may be limited to the specific task and stimuli used in Experiments 1 and 2. Also, there is no reason to believe that stimulus-response compatibility contributed to the difference between lateral and vertical target positions in Experiments 1 and 2 because the same mapping of stimulus to response was used in the present experiment, yet no difference between lateral and vertical target positions was observed in RTs.

## General Discussion

We investigated whether the distractor benefit in feature search with small search displays was the result of attentional suppression as claimed by Gaspelin and Luck (2018a). In feature search with a larger set size, neither a $P_D$ nor an N2pc to the distractor was observed (Barras & Kerzel, 2016). Rather, changes in the N2pc to the target suggested that target enhancement, and not distractor suppression, prevented capture by salient distractors. To reconcile the divergent findings, we re-examined shape-based feature search with small set size. Compared to Gaspelin and Luck (2018a), our experiments present two improvements. First, compared to their Experiment 1, we did not interleave a search and a letter identification task, so that our experiments isolate typical search behavior, whereas mixing tasks may lead to biases in the distribution of attention. Second, compared to their Experiment 3, we presented both distractor-present and -absent trials. Besides replicating the early distractor-related "$P_D$", we also found a late distractor-related N2pc. The latter finding was also reported in Experiment 3 of Gaspelin and Luck (2018a, see Figure 9C), but was not discussed, probably because the distractor-absent condition was missing. The distractor-related "$P_D$" and the following distractor-related N2pc were observed in two experiments with slightly different tasks (i.e., orientation discrimination in Experiment 1 and dot localization in Experiment 2).

The most important conclusion from our findings is that the early positive deflection is unlikely to reflect distractor suppression. According to the distractor-suppression hypothesis (Gaspelin & Luck, 2018b; Sawaki & Luck, 2010), distractor suppression serves to prevent attentional capture by salient elements. However, the sequence of distractor-related $P_D$ and distractor-related N2pc would suggest that suppression of the distractor preceded attentional capture by the distractor, which is incompatible with the distractor-suppression hypothesis. With respect to the original question, it seems unlikely that distractor benefits with small search displays (Gaspelin & Luck, 2018a) result from distractor suppression. Thus, it is not necessary to assume that distractor suppression occurred with small set sizes (Gaspelin & Luck, 2018a) whereas target enhancement occurred with large set sizes (Barras & Kerzel, 2016). Rather, distractor suppression does not seem to be involved in either case, pointing to target enhancement (Bacon & Egeth, 1994; Barras & Kerzel, 2016; Folk et al., 1992) as the reason for resistance to interference in feature search.

### Ambiguity of the $P_D$

While the distractor-suppression hypothesis is unlikely to account for the present results, there is a lot of uncertainty regarding an alternative account. The biggest problem is that there is no data-driven way to distinguish a $P_D$ to the distractor from an N2pc to the context element on the opposite side. We nonetheless explored the hypothesis that the early distractor-related "$P_D$" was in fact an early context-related N2pc. We did not diverge from the original interpretation of the late negativity, which we still believe to be an N2pc to the distractor. We suggest that the paradoxical succession of two N2pc-components was caused by participants' search strategy. In particular, we suggest that participants searched the lateral positions before the vertical positions. When there was a lateral distractor, search started opposite to the distractor, but nevertheless visited the distractor location. This strategy is clearly not optimal, but may arise from the small and heterogeneous search display (Liesefeld & Müller, 2019b). While event-related potentials cannot provide evidence for our conjecture, we found that search times for lateral targets were shorter than for vertical targets, consistent with the idea that lateral positions are searched first. The precedence of lateral positions may be specific to shape-based feature search with small search displays, as we did not replicate the results in a different search task using the same displays (Experiment 3). Further, it may be conjectured that the early and late deflections arise from the averaging of trials that either show an early $P_D$ or a late N2pc. To test this conjecture, we performed a median split by RT and reanalyzed the event-related potentials. Previous research showed that the $P_D$ is associated with faster search times, suggesting that the $P_D$ occurs on trials with successful distractor rejection (Gaspar & McDonald, 2014; Jannati et al., 2013). However, we found no significant effects of search time, making it unlikely that the averaging of trials with either successful ($P_D$) or failed (N2pc) distractor rejection caused the pattern of results.

### How robust is evidence for suppression of salient elements?

While we admit that it is difficult to provide solid evidence for the hypothesis that the positivity contralateral to a distractor was in fact a negativity to the opposite context element, one may wonder whether the evidence for distractor suppression is any better. As the $P_D$ arises in the same time window and at the same electrodes as the N2pc, no data-driven distinction between distractor suppression and context capture is possible. However, the positivity contralateral to the distractor was universally interpreted as a $P_D$. For instance, distractor-related positivities were interpreted as $P_D$ in a variety of tasks such as segmentation or detection tasks (Feldmann-Wüstefeld et al., 2016; Feldmann-Wüstefeld & Schubö, 2013; Feldmann-Wustefeld & Vogel, 2019), compound search tasks (Barras & Kerzel, 2017; Burra & Kerzel, 2013; Gaspar & McDonald, 2014; Jannati et al., 2013; Kiss et al., 2012) or same-different tasks (Kerzel, Barras, & Grubert, 2018). In all these studies, however, there was a context element opposite to the distractor to assure balanced sensory processing. Therefore, it seems entirely possible that the positivity to the distractor was an N2pc to the context opposite the distractor. Under this assumption, observers started to search the context instead of suppressing the distractor, which represents a reasonable search strategy because the target was never at the distractor location.

However, there are two strong arguments against our interpretation. Notably, the $P_D$ has been observed without nontarget elements on the opposite side (Hickey et al., 2009) and the $P_D$ has been observed in the absence of distractors (Wang, van Driel, Ort, & Theeuwes, 2019). In the study by Hickey et al. (2009), there was no stimulus opposite to the distractor. That is, the distractor was the only lateralized element when the target was on the vertical midline. Asymmetries in early sensory components of the EEG were avoided by making the distractor color isoluminant to the background. One may propose that the absence of a stimulus opposite to the distractor made it unlikely that the side opposite to the distractor was attended. However, there is evidence that gaps in a search array involuntarily capture attention (Kiss & Eimer, 2011). Therefore, it cannot be excluded that attention was directed at an empty region of space. Further, Wang et al. (2019) showed that a $P_D$ occurred to inconspicuous nontargets at a location where the distractor occurred with a high probability. In line with the reduced behavioral interference to distractors at a high-probability location (Allenmark, Zhang, Liesefeld, Shi, & Müller, 2019; Wang & Theeuwes, 2018a, 2018b), the $P_D$ to nontarget locations may indicate that there was anticipatory suppression of the high-probability distractor location (see also van Moorselaar & Slagter, 2019). However, we would like to argue that it is also possible that attention was shifted opposite to the high-probability distractor location. In both cases, a $P_D$ to the high-probability location would result. While we do not suggest that all instances of distractor-elicited "$P_D$" components are instances of context-elicited N2pc components, we think that this hypothesis has been neglected in the past literature. More research is needed to disentangle the two processes.

**Evidence from the contingent capture paradigm**

The hypothesis that the "$P_D$" to the distractor was in fact an N2pc to the context element receives more direct support from a related study using the modified spatial cueing paradigm by Folk et al. (1992). In Posner-type cueing paradigms (Posner & Cohen, 1984), it was observed that RTs are shorter when a peripheral cue preceded the target at the same location. Folk and Remington (1998) clarified that cueing benefits are restricted to situations where the features of the cue match the features of the target. For instance, a red cue will result in cueing benefits with a matching red target, but not with a non-matching green target. While RTs with non-matching cues are often equal at cued and uncued positions (Folk & Remington, 1998), there are situations where non-matching cues result in longer RTs at cued than at uncued locations ("same location costs" Carmel & Lamy, 2014; Kerzel, 2019; Schoeberl, Ditye, & Ansorge, 2018). In one series of experiments, Schönhammer, Grubert, Kerzel, and Becker (2016) inverted the colors of the cue and target displays. That is, the cue was in the color of the context elements surrounding the target, whereas the context elements surrounding the cue were in the color of the target. Therefore, the color of the cue context matched the target, whereas the cue was non-matching. A same-location cost was observed for the cue, which was accompanied by a "$P_D$" to the cue, pointing to suppression of the cue as a possible origin of the same-location costs. However, we wondered whether the cue-related "$P_D$" was in fact a context-related N2pc. Effects of cue- and context-related processing are confounded because the lateral cue always appeared opposite to the context. To disentangle cue suppression (i.e., a cue-related $P_D$) from context capture (i.e., a context-related N2pc), Schönhammer, Becker, and Kerzel (submitted) introduced a neutral element in the cue display. To isolate cue- and context-related processing, a neutral element was placed on the opposite side. We observed an N2pc to the context, but no $P_D$ to the cue, suggesting that the context captured attention, but the cue was not suppressed. These results are consistent with the proposed capture of attention by the context. However, it may not be possible to adapt the idea of a neutral element to the present paradigm. In the modified cueing paradigm, characteristics of the cue display may be changed without changing the main search task, because the cue and search displays are temporally separated. In the present paradigm, introducing a neutral stimulus (e.g., a gray item) would change the search task considerably because the color distractor would no longer be the only element with a different color.

## Summary

To sum up, the present study investigated whether distractor suppression occurred in shape-based feature search with small display size. Previously, the occurrence of a positivity contralateral to a color distractor, the $P_D$, was taken as evidence in favor of this hypothesis. We re-examined this situation with a number of methodological improvements. Importantly, we found a sequence of event-related potentials that is incompatible with the idea of distractor suppression. The "$P_D$" to the distractor was followed by an N2pc to the distractor, which is at odds with the idea that distractor suppression prevents attentional capture by the distractor. We suggest that the paradoxical flip of the contralateral voltage difference was due to a search strategy that is idiosyncratic to the task and display type. Participants searched lateral items before vertical items, which reduced search times for lateral compared to vertical targets. When there was a lateral distractor, search started opposite to the distractor, as visible in an early context-related N2pc, and continued at the distractor location, as visible in a late distractor-related N2pc. Thus, we suggest that the early "$P_D$" was in fact a context-related N2pc. While more evidence is needed to confirm our interpretation, it provides a reasonable alternative to distractor suppression theory, which fails to account for the data.

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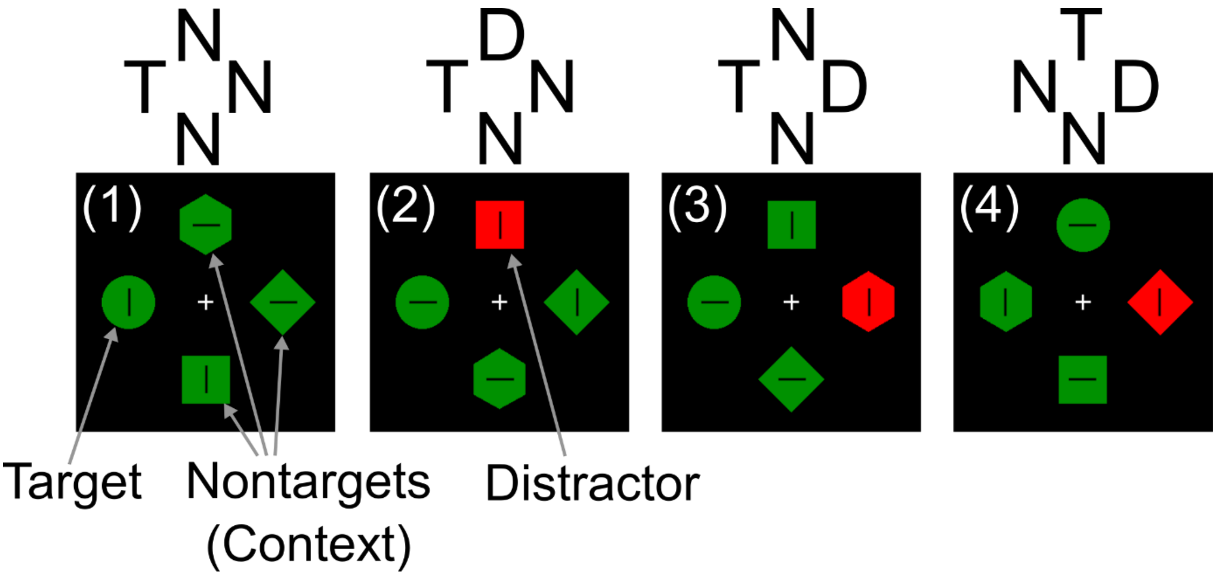

**Figure 1.** Illustration of experimental stimuli and conditions of interest. In the example, the circle was the target and the square, hexagon, and diamond were nontargets. Nontargets are also referred to as context elements. In the experiment, the target shape changed after blocks of trials between circle and diamond. The distractor was the stimulus with a different color. In the example, it was the red stimulus, but in the experiment, the colors were swapped after 480 trials. The conditions of interest for the analysis of event-related potentials are shown from left to right. The schematics in the top row will be used to refer to these conditions in the following graphs. (1) In the lateral target + no distractor condition, the target was on the left or right and the distractor was absent. (2) In the lateral target + vertical distractor condition, the target was on the left or right and the target was on the vertical midline. (3) In the lateral target + opposite distractor condition, the target was on the left or right and the distractor was opposite. (4) In the vertical target + lateral distractor condition, the distractor was shown on the left or right while the target was on the vertical midline.

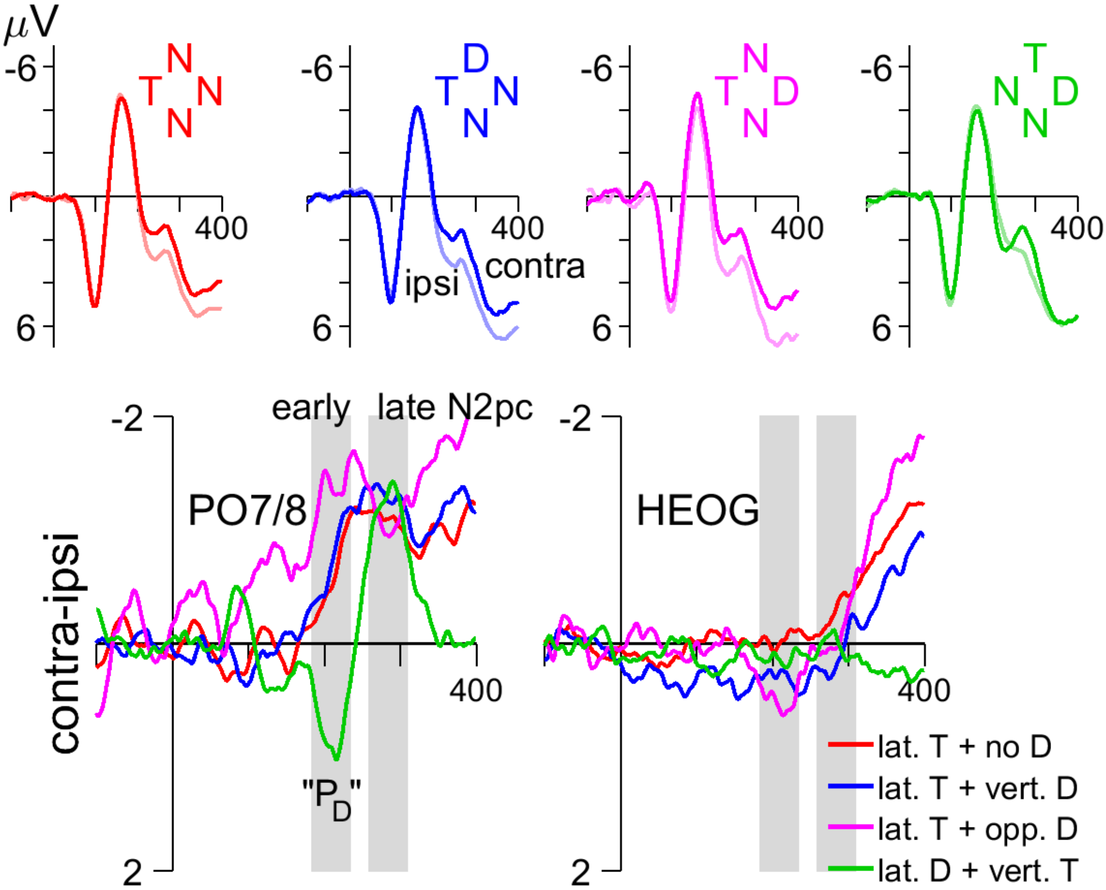

**Figure 2.** Electrophysiological results from Experiment 1. The upper panels show the event-related potentials to lateral distractors and targets at ipsi- and contralateral electrodes PO7/8. The lower left panel shows the difference waves between contra- and ipsilateral electrodes. The shaded areas indicate the 50 ms averaging intervals corresponding to the early and late N2pc. The lower right panel shows the HEOG difference waves where a negative deflection indicates an eye movement toward the lateral stimulus. Epochs extended from -100 to 350 ms post-stimulus in the analysis reported in the text, but the graphs show the data until 400 ms.

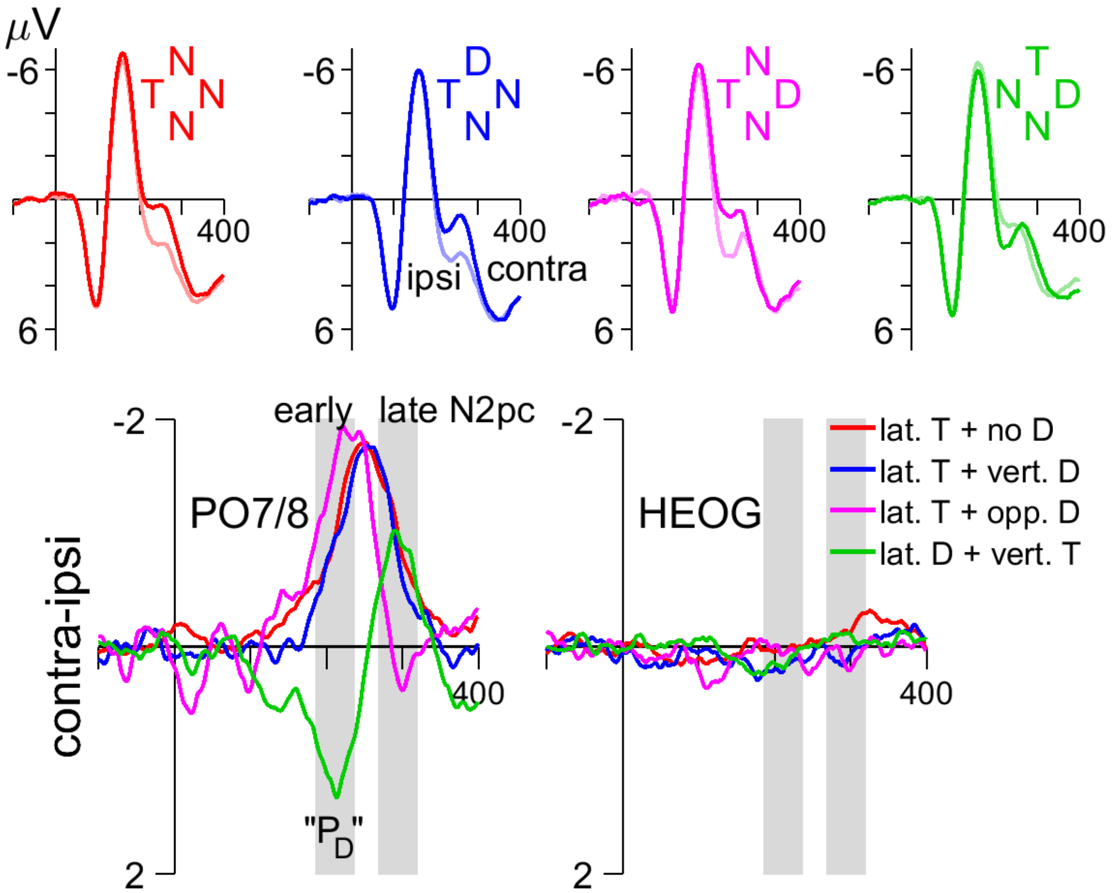

**Figure 3.** Electrophysiological results from Experiment 2. Conventions are as in Figure 2.

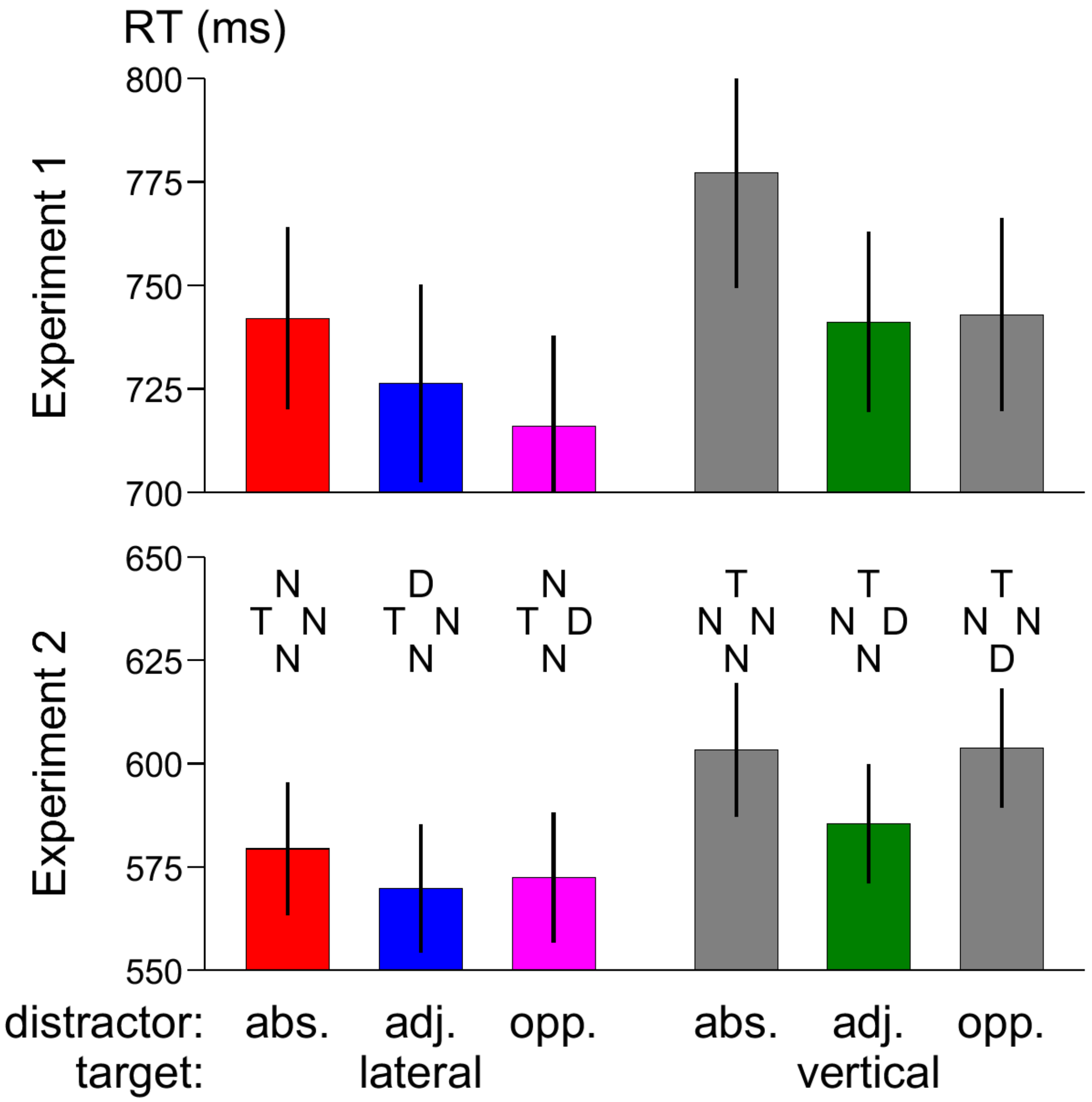

**Figure 4.** Behavioral results from Experiments 1 and 2. Reaction times (RTs, in ms) are shown on the y-axis and the spatial configuration of target and distractor on the x-axis. The target was lateral or vertical, while the distractor was absent, adjacent, or opposite to the target. The configurations with lateral target or distractor are shown in the same colors as in the analyses of ERPs. The configurations without lateral element are shown in gray. Error bars show the between-subjects standard error of the mean.

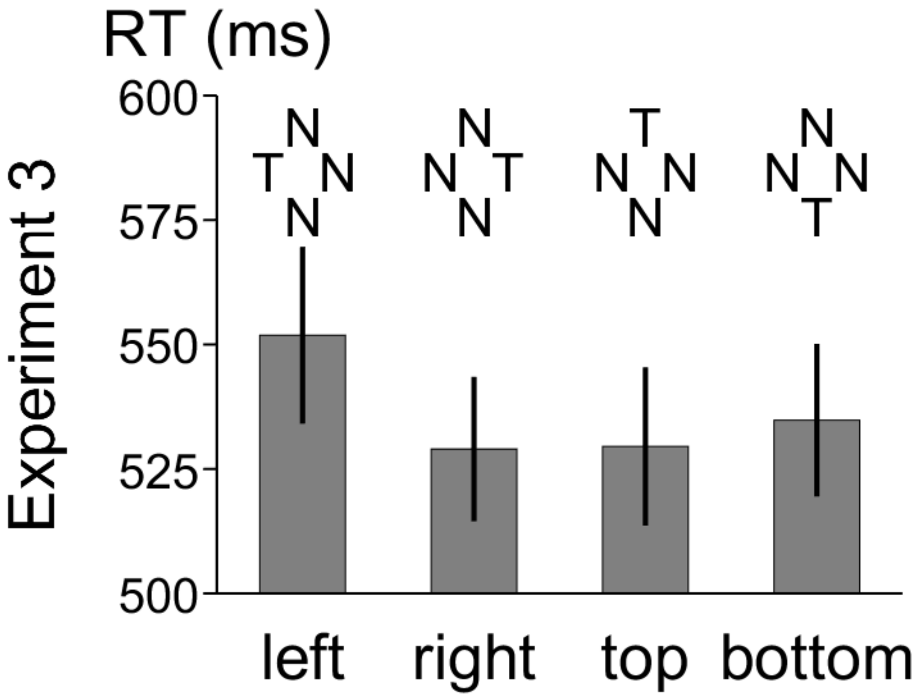

**Figure 5.** Results from Experiment 3. Reaction time (RTs, in ms) are shown on the y-axis and the position of the target on the x-axis. In this experiment, the target was the stimulus with a different color while stimulus shape was irrelevant.