



# The $P_D$ Reflects Selection of Nontarget Locations, Not Distractor Suppression

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## Abstract

■ In visual search tasks, negative features provide information about stimuli that can be excluded from search. It has been shown that these negative features help participants to locate the target, possibly by attentional suppression of stimuli sharing the negative feature. Attentional suppression is assumed to be reflected in an event-related potential, the  $P_D$  component. To provide a further test of these assumptions, we presented the color of the distractor at the start of a trial and asked participants to find the other colored stimulus in the subsequent search display. Consistent with attentional suppression, we

observed a  $P_D$  to a lateral distractor shown with a vertical target. However, the  $P_D$  occurred in this condition only when target and distractor could also be on opposite sides of fixation. The effect of trial context on the  $P_D$  suggests that the  $P_D$  reflects a search strategy whereby participants select stimuli opposite to the distractor when trials with opposite placements occur during the experiment. Therefore, the  $P_D$  to the distractor may in fact be an N2pc to the opposite stimulus, indicating that the distractor is not suppressed, but avoided by redirecting attentional selection to the opposite side. ■

## INTRODUCTION

When searching for objects of interest, it is desirable to avoid distraction by irrelevant stimuli. Classic theories of visual search favored mechanisms whereby a positive processing bias enhances stimuli sharing the target features (Desimone & Duncan, 1995; Wolfe, Cave, & Franzel, 1989). In addition, there may also be a negative processing bias for stimuli with nontarget features (Treisman & Sato, 1990; Duncan & Humphreys, 1989; reviewed by Dent, Allen, Braithwaite, & Humphreys, 2012). Both processing biases may rely on representations of target or nontarget features stored in working memory, which we refer to as positive or negative attentional templates (Wolfe, 2021; Geng, Won, & Carlisle, 2019; Eimer, 2014). Whereas it is clear that positive attentional templates facilitate attentional selection of potential targets (e.g., Grubert, Fahrenfort, Olivers, & Eimer, 2017; Hout & Goldinger, 2015; Chen & Zelinsky, 2006), the way negative attentional templates prevent nontargets from interfering with visual search remains poorly understood.

### Attentional Suppression of Negatively Cued Stimuli

Effects of negative attentional templates on search performance were demonstrated by Woodman and Luck (2007), who showed that search improved when the color of a subset of nontarget stimuli was cued before onset of the search display. Thus, information about which stimuli to avoid can benefit performance. However, it is debated

whether the performance benefit resulted from attentional suppression of nontarget stimuli in the cued nontarget color or some other process.

First, there is behavioral evidence that participants recoded the cued nontarget color into the color of the subset of stimuli containing the target (Beck, Luck, & Hollingworth, 2018; Becker, Hemsteger, & Peltier, 2016; but see Zhang & Carlisle, 2023). However, it may be that attentional suppression of stimuli in the nontarget color only occurs when the search task is difficult enough to make attentional suppression worthwhile (Kerzel & Huynh Cong, 2022b; Zhang, Sahatdjian, & Carlisle, 2022; Conci, Deichsel, Müller, & Töllner, 2019).

Second, there is no conclusive electrophysiological evidence to support attentional suppression of stimuli that have been flagged as nontargets by a preceding cue. Two studies are of interest in this regard and will be described in some detail. Carlisle and Nitka (2019) investigated attentional suppression of color-defined nontargets when participants searched for a shape-defined target in a search array of 12 stimuli. Stimuli on the left were in a color different from stimuli on the right, but stimuli in the same hemifield shared a color. At the start of a trial, a cue indicated either the color of the group of stimuli containing the target (positive cue) or the group of stimuli without the target (negative cue). Thus, positive and negative cues allowed participants to focus on a subgroup of stimuli in the search array. Because each subgroup was lateralized in one hemifield, attentional selection or suppression could be measured by lateralized ERPs. Typically, attentional selection of candidate target stimuli is indexed by

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the N2pc component, which is a more negative voltage contra- than ipsilateral to the candidate target stimulus in the interval from 180 to 300 msec after stimulus onset at posterior electrodes PO7/8 (Eimer, 1996; Luck & Hillyard, 1994). Carlisle and Nitka (2019) found that both positive and negative cues resulted in a contralateral negativity relative to the hemifield containing the target. Although the negativity following a positive cue was most likely an N2pc to the hemifield containing the target, two alternative interpretations are possible for negative cues (see p. 314 in Carlisle & Nitka, 2019). On the one hand, the negativity could be considered as evidence for attentional selection of the subset of stimuli containing the target, consistent with an N2pc. However, the same negativity could also be viewed as a positivity contralateral to the other hemifield, which shared the color of the negative cue. A contralateral positivity in the time range of the N2pc at electrodes PO7/8 has been considered an index of attentional suppression and is referred to as  $P_D$  (Hickey, Di Lollo, & McDonald, 2009). Thus, the lateralized ERP with negative cues could either indicate attentional selection of the subgroup containing the target (i.e., an N2pc) or attentional suppression of the subgroup in the color of the negative cue (i.e., a  $P_D$ ).

To provide less ambiguous support for the attentional suppression of negatively cued stimuli, displays may be used where the target is on the vertical midline and a nontarget on a lateral position. Along these lines, Berggren and Eimer (2021) used displays with four stimuli placed at equal distance from fixation on the vertical and horizontal axes. As in Carlisle and Nitka (2019), participants searched for a shape target and half of the stimuli in the search display were in the target color and the other half in the nontarget color. Berggren and Eimer (2021) found only inconsistent evidence for a  $P_D$  to lateral nontargets in the color of the negative cue, which is surprising because many studies have confirmed robust  $P_D$  components to distractors in a known color (e.g., Abbasi, Henare, Kadel, & Schubö, 2023; Stilwell, Egeth, & Gaspelin, 2022; Drisdelle & Eimer, 2021; Kerzel & Burra, 2020; Gaspelin & Luck, 2018a; Gaspar & McDonald, 2014; Burra & Kerzel, 2013; Feldmann-Wüstefeld & Schubö, 2013; Jannati, Gaspar, & McDonald, 2013). However, these studies investigated attentional suppression of a single salient stimulus (i.e., a distractor), whereas the negatively cued stimuli in Berggren and Eimer (2021) were not salient because there were two stimuli in each color. Thus, it may be that attentional suppression as indexed by the  $P_D$  is limited to the suppression of distractors and does not occur for inconspicuous nontargets (see Gaspelin & Luck, 2018b). However, there is one study reporting a  $P_D$  with equally salient target and distractor stimuli. Donohue, Bartsch, Heinze, Schoenfeld, and Hopf (2018) presented search displays with six stimuli containing four blue nontarget stimuli with one target and one distractor in distinct colors. Although the distractor was not more salient than the target, it elicited a  $P_D$  between 200 and 300 msec, suggesting that

attentional suppression is not limited to distractors more salient than the target.

### Nuisance Variables in the Center of Interest

Thus, many studies found electrophysiological evidence for the attentional suppression of distractors, but the study by Berggren and Eimer (2021) provided little electrophysiological evidence for attentional suppression after negative cues. However, a methodological detail concerning the placement of target and distractor stimuli should be considered. In many studies on the  $P_D$ , three different types of placement were used, whereas Berggren and Eimer (2021) used only two. First, to measure the distractor-elicited  $P_D$ , the distractor was placed on a lateral position and the target on the vertical midline. Second, to measure the target-elicited N2pc, the target was placed on a lateral position and the distractor on the vertical midline. The first and second placements are referred to as adjacent placements. Third, target and distractor were placed on opposite sides, either horizontally or vertically. Opposite placements were absent in Berggren and Eimer (2021), but present in virtually all the other studies that reported a  $P_D$  in the interval of the N2pc with manual responses and search displays of at least four items (e.g., Stilwell et al., 2022; Feldmann-Wüstefeld, Weinberger, & Awh, 2021; Liesefeld, Liesefeld, & Muller, 2021; van Moorselaar, Daneshmand, & Slagter, 2021; van Moorselaar & Slagter, 2019; Wang, van Driel, Ort, & Theeuwes, 2019; Gaspelin & Luck, 2018a; Barras & Kerzel, 2017; Kadel, Feldmann-Wüstefeld, & Schubö, 2017; Liesefeld, Liesefeld, Töllner, & Müller, 2017; Barras & Kerzel, 2016; Feldmann-Wüstefeld, Uengoer, & Schubö, 2015; Burra & Kerzel, 2014; Gaspar & McDonald, 2014; Burra & Kerzel, 2013; Jannati et al., 2013; McDonald, Green, Jannati, & Di Lollo, 2013; Kiss, Grubert, Petersen, & Eimer, 2012). With horizontally opposing stimuli, lateralized components reflect the sum of target- and distractor-elicited components, which makes their interpretation difficult. Therefore, only a few studies interpreted results from opposite target-distractor placement (e.g., Kerzel, Barras, & Grubert, 2018; Liesefeld et al., 2017; Hickey, McDonald, & Theeuwes, 2006). To the best of our knowledge, the only study on distractor suppression with manual responses and search displays of at least four items that did not use opposite placement was performed by Corriveau and colleagues (2012). Interestingly, these authors did not find a  $P_D$  to lateral distractors with vertical targets.

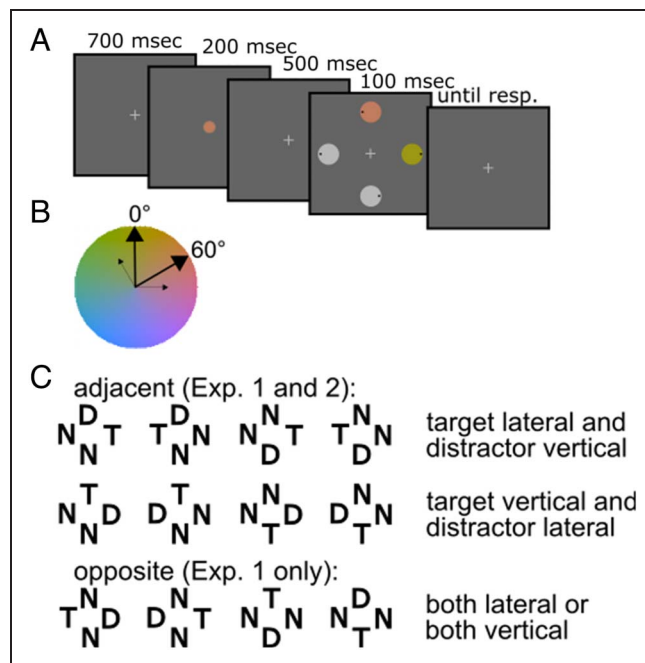
Despite the fact that opposite placements provide little useful data, they may be important to make target and distractor appearance unpredictable. Here, we argue that the predictability of target-distractor placements also affects the way in which the stimuli are searched. If only adjacent placements are used, there is no incentive to search the opposite location once the distractor has been located. If opposite placements are included, however, there is an

incentive to also search the opposite location. This was the case in previous electrophysiological experiments reporting a  $P_D$  with small search displays of four stimuli (Drisdelle & Eimer, 2021; Kerzel & Burra, 2020; Gaspelin & Luck, 2018a), but not in the study by Berggren and Eimer (2021) where the  $P_D$  was mostly absent. Therefore, it may be that including the opposite placement type in the experimental design contributes to the occurrence of the  $P_D$  component. That is, the  $P_D$  may result from search strategies induced by opposite target-distractor placement.

In support of this view, Kerzel and Burra (2020) made the paradoxical observation that a positivity contralateral to the distractor was followed by a negativity. Because the initial positivity was previously interpreted as a  $P_D$  to the distractor, the subsequent negativity would be an N2pc to the distractor. However, it is implausible that the distractor was first suppressed ( $P_D$ ) and then selected (N2pc) if the role of attentional suppression is to prevent attentional capture by the distractor (Gaspelin & Luck, 2018b). Therefore, Kerzel and Burra (2020) suggested that the polarity flip was rather a sequence of two N2pc components. The first indicated attentional selection of the nontarget opposite to the distractor and the second, attentional selection of the distractor itself. While the functional significance of this pattern is also uncertain, it may at least be related to serial search behavior (Liesefeld & Muller, 2020). However, Drisdelle and Eimer (2021) considered the polarity flip not as a sequence of two N2pcs but as a sequence of two  $P_D$  components because it occurred even when the two lateral positions were task irrelevant. That is, the first  $P_D$  was thought to suppress the distractor and the second to suppress the nontarget opposite the distractor. Again, the functional significance is unclear because there was no need to suppress the inconspicuous nontarget once the salient distractor was suppressed. Although a conclusive interpretation of the polarity flip is elusive, the discussion underlines the inherent ambiguity of lateralized ERPs. Because only differences between ipsi- and contralateral activity are considered, a positivity to a stimulus on one side may also be considered a negativity to a stimulus on the other side.

## Experiments 1 and 2

In the following experiments, we tested whether the placement of target and distractor stimuli affected the  $P_D$  to negatively cued stimuli. We chose a paradigm where the color of the distractor was necessary to find the target (see Figure 1A). That is, a color cue at the beginning of the trial informed participants about the color that was not the target and this color changed on every trial to prevent habituation (Won & Geng, 2020; Bonetti & Turatto, 2019; Turatto, Bonetti, Pascucci, & Chelazzi, 2018). As there were only two colored stimuli, we expected participants to suppress the stimulus in the cued color (i.e., the distractor) to locate the target (Forstinger, Gruner, &



**Figure 1.** Illustration of experimental stimuli and conditions. (A) shows the time course of a trial. The trial started with a fixation period of 700 msec. Then, the negative color cue was shown in the center for 200 msec. After a retention interval of 500 msec, participants were asked to find the other color in the search display (100 msec). The task was to indicate the relative location of the dot inside the target. (B) shows the target and distractor color in CIE-lab color space. The target and distractor colors differed by 60° and by at least 30° from the colors on the previous trial. (C) shows the 12 possible target and distractor placements. Target and distractor were either adjacent (Exp. 1 and 2) or opposite (Exp. 1 only). T = target; D = distractor; N = nontarget.

Ansorge, 2022; Kerzel & Huynh Cong, 2022b). Our displays only had four possible stimulus positions, which made it easy to balance the probability for each placement. In experiments with larger set sizes, the probability of vertical placements was often larger than chance to have enough observations in the conditions of interest (e.g., Burra & Kerzel, 2013; Jannati et al., 2013). In Experiment 1, we presented all possible placements of target and distractor (adjacent + opposite), whereas in Experiment 2, we presented only the adjacent placements (see Figure 1C). If attentional suppression, as indexed by the  $P_D$ , was employed to avoid the distractor and thereby locate the target, a  $P_D$  is expected in both experiments. On trials where the  $P_D$  is measured, it should not matter which placements occur on the other trials. If adaptive search strategies contributed to the  $P_D$ , however, then the  $P_D$  should differ as a function of placement type. With opposite placements of target and distractor in Experiment 1, it made sense for observers to search the location opposite the distractor to find the target. That is, on trials where the  $P_D$  is measured, participants may search the location opposite to the distractor because this was a valid strategy on some trials with opposite placement. In Experiment 2, however, opposite placements were absent and there was no incentive to

search the location opposite the distractor because the target would never appear there. In summary, if the  $P_D$  resulted from search strategies related to the placement of target and distractor, it should be present in Experiment 1, but absent in Experiment 2.

In addition to the  $P_D$  between 200 and 300 msec after onset of the search display, we also analyzed an earlier positivity between 100 and 150 msec, which is referred to as Ppc (Corriveau et al., 2012). Whereas some studies found the Ppc to be related to attentional processing (Barras & Kerzel, 2017; Weaver, van Zoest, & Hickey, 2017; Fortier-Gauthier, Moffat, Dell'Acqua, McDonald, & Jolicœur, 2012), other studies suggested that it reflects imbalanced saliency between the left and right hemifield (Kerzel & Huynh Cong, 2022a; Schönhammer, Becker, & Kerzel, 2020; Schönhammer, Grubert, Kerzel, & Becker, 2016; Jannati et al., 2013; Corriveau et al., 2012; Sawaki & Luck, 2010). In support of the latter view, the Ppc was found to be of similar amplitude whether the salient stimulus was the target or distractor (Barras & Kerzel, 2017; Jannati et al., 2013; Corriveau et al., 2012) and it decreased when distractor saliency was lowered by a nearby target stimulus (Kerzel & Huynh Cong, 2022a).

Finally, we also analyzed an interval after 300 msec because a polarity flip similar to previous studies may occur (Drisdelle & Eimer, 2021; Kerzel & Burra, 2020; Gaspelin & Luck, 2018a; see also Liesefeld et al., 2017, 2021). Because the polarity flip occurs less frequently with large display sizes (Stilwell et al., 2022; Tam, Callahan-Flintoft, & Wyble, 2022), our four-stimulus displays maximized the chances of replication. If the expected flip occurs, it is likely to be toward the end or after the  $P_D$  interval.

In summary, our focus is on the  $P_D$  interval from 200 to 300 msec, but earlier and later intervals are also considered to assess diverging interpretations of the Ppc and to check for the presence of a polarity flip.

## METHODS

### Participants

After replacing five data sets in each experiment, there were 18 data sets in Experiment 1 (2 men, age:  $M = 21$  years,  $SD = 4$  years) and 18 in Experiment 2 (3 men, age:  $M = 20$  years,  $SD = 2$  years). The criteria for replacement are detailed below. The 18 participants allowed us to find significant  $P_D$  or Ppc components with an effect size of  $d_z = 0.61$  in a one-sample  $t$  test against zero ( $\alpha = .05$ , power = .8, two-tailed). An independent-samples  $t$  test with two groups of 18 participants would require a minimum  $d_s = 0.96$  ( $\alpha = .05$ , power = .8, two-tailed). 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 each experiment.

### Apparatus

A 22.5-in. LCD monitor was used for the stimulus presentation (100 Hz,  $1920 \times 1200$  pixels, backlight disabled; VIEWPixx Light, VPixx Technologies Inc.). Color calibration was based on measurements with an i1Display Pro (VPixx Edition) colorimeter by X-Rite. Participants responded on a RESPONSEPixx Handheld 5-button response box (VPixx Technologies Inc.) using the left and right keys. The experiment was run using the Psychtoolbox (Kleiner, Brainard, & Pelli, 2007; Brainard, 1997).

### Stimuli

A fixation cross ( $0.5^\circ \times 0.5^\circ$ , linewidth  $0.07^\circ$ ) was shown in the center of the screen unless it was replaced by the color cue. The color cue was a filled disk with a diameter of  $0.5^\circ$ . The search display consisted of four filled disks with a diameter of  $1^\circ$ , which were presented above, below, left, and right of central fixation at an eccentricity of  $2^\circ$ . A black dot with a diameter of  $0.1^\circ$  was shown inside the disk close to its left or right edge. The stimuli were presented against a medium gray background with  $xyY = (0.31\ 0.33\ 24.35)$  and  $Y$  in  $\text{cd/m}^2$ . The color of the disks was selected in CIELAB-space (Fairchild, 2005) on an isoluminant color wheel (luminance of  $48.76\ \text{cd/m}^2$  or  $L^* = 59$ , saturation of 64). The target and distractor colors changed on every trial and were selected as in Kerzel and Huynh Cong (2022b). That is, target and distractor colors were separated by a rotation of  $60^\circ$  on the color wheel. To avoid inter-trial priming, the colors on a given trial differed by at least  $30^\circ$  from the colors on the previous trial (see Figure 1B). Thereby, random color selection was restrained to  $240^\circ$  instead of  $360^\circ$ . For instance, if the colors on the previous trial were  $0^\circ$  for the target and  $60^\circ$  for the distractor, the selection of the target and distractor colors on the subsequent trials would be limited to the range from  $90^\circ$  to  $330^\circ$ . In supplementary analyses, Kerzel and Huynh Cong (2022b) demonstrated that a difference of  $30^\circ$  between subsequent trials produced similar results as a color difference of  $60^\circ$ , suggesting that intertrial priming did not contribute to the results.

### Design

In each search display, there were two colored and two gray disks. The colored disks were the target and distractor, and the gray disks were the nontargets. The main variable of interest was the placement of the colored disks. We distinguished between adjacent and opposite placements (see Figure 1C). In adjacent placements, target and distractor were placed next to each other. For instance, the target could be in the top position and the distractor in the right position or the other way around. There were eight possible adjacent placements. In opposite placements, target and distractor were both placed on the horizontal or vertical axis. For instance, the target could be on the left and the



distractor on the right or the other way around. There were four possible opposite placements. In Experiment 1, all possible placements were shown. The 24 conditions resulting from crossing the 12 possible placements and the two possible responses were shown once in each mini-block. In Experiment 2, only adjacent placements were shown. The 16 conditions resulting from crossing eight placements and two possible responses were shown once in each mini-block. To have an equal number of trials, there were 24 mini-blocks in Experiment 1 and 36 in Experiment 2, which resulted in 576 trials for each experiment.

## Procedure

A trial started with the presentation of the fixation cross for 700 msec, followed by the negative color cue for 200 msec. In the subsequent retention interval of 500 msec, only the fixation cross was shown. Then, the search display was flashed for 100 msec and the fixation cross remained visible until a response was registered. The participants' task was to indicate the relative position of the black dot inside the target disk by pressing the spatially corresponding button on the response box. Because the negative color cue indicated the color of the distractor, participants had to find the other color. Participants were told to respond as rapidly and accurately as possible. They were encouraged to make less than 10% errors. The response window for acceptable responses was 1250 msec after onset of the search display. An immediate error message was presented on the screen if the response occurred outside the response window or if it was wrong. Self-terminated breaks occurred every 48 trials. During the breaks, visual feedback about the percentage of correct responses and the median RT in the last block of trials was displayed for at least 2000 msec. The experiment started with two practice blocks of 48 trials. The colors in the first practice block were as in the experiment, whereas in the second practice block, they were restricted to the bluish range. The bluish colors were harder to discriminate despite equal distances in color space. Presenting only the more difficult colors in the second practice block was meant to prepare participants for variations in the difficulty of the search task.

## Electrophysiological Recording and Initial Data Processing

We recorded electrophysiological signals from active Ag/AgCl electrodes (ActiCap Slim) converted by an ActiCHamp amplifier at 1000 Hz using the BrainVision Recorder software (Version 1.25.0001). The recording software, devices, and conductive gel used to connect the electrodes were produced by Brain Products. We deactivated cutoffs and notchfilters in the filter settings of the BrainVision Recorder software. Twenty-five electrodes were placed on the scalp (Fp1, Fp2, F7, F3, Fz, F4, F8, FC5, FC6, T7, C3, Cz, C4, T8, CP5, CP6, P7, P3, Pz, P4, P8, PO7, PO8, PO9, PO10) and six electrodes on the outer

canthi of each eye, above and below the right eye, and on each earlobe. Cz was the online reference, and AFz was the ground site. The data were analyzed using ERPLAB (Lopez-Calderon & Luck, 2014), an extension of EEGLAB (Delorme & Makeig, 2004). Before analysis, the EEG was rereferenced to the average earlobes and filtered between 0.1 and 30 Hz with a bandpass second-order Butterworth filter (roll-off 12-dB/octave, command *pop\_basicfilter* in ERPLAB). The horizontal electrooculography (HEOG) channel was the difference between left and right eye electrodes, and the vertical electrooculography (VEOG) channel was the difference between upper and lower eye electrodes. The EEG was segmented into 500 msec epochs from 100 msec before to 400 msec after onset of the search display. The first 100 msec served as the baseline.

## RESULTS

### Exclusion of Trials and Data Sets

Trials with opposite placement in Experiment 1 were included to change the search strategy, but confounded target- and distractor-elicited ERPs. Therefore, they were excluded from all analysis. Furthermore, we rejected trials with choice errors or RTs outside the response window of 1250 msec. In the ERP analysis, we additionally rejected trials with blinks or vertical eye movements (difference in the VEOG channel exceeding  $\pm 50 \mu\text{V}$ ), horizontal eye movements (10-msec steps in the HEOG channel exceeding  $\pm 16 \mu\text{V}$ ), and muscular or other artifacts (any electrode exceeding  $\pm 80 \mu\text{V}$ ) between 100 msec before and 400 msec after onset of the search display. Ten data sets were replaced because less than 70% of the trials remained after excluding choice errors, responses outside the response window and electrophysiological artifacts. The most frequent artifacts were eye movements, which may reflect that participants had no prior experience with electrophysiological experiments. The criterion of 70% retained trials is close to the 75% criterion proposed in the literature on the N2pc (Luck, 2014). If the percentage of retained trials is inferior to this criterion, the quality of the data is generally poor and even the retained trials may be contaminated by artifacts. In the conditions of interest, 127–180 out of 192 trials were retained in Experiment 1 ( $M = 154$  trials), and 186–270 out of 288 trials in Experiment 2 ( $M = 239$  trial). In Experiment 2, there was one data set with only 415 instead of 576 trials and another where the HEOG was missing. Because there were few horizontal eye movements (or other artifacts) in these data sets, we decided to keep them. To assess whether the different trial number affected the stability of the individual mean voltages in Experiment 1 compared with Experiment 2, we evaluated the equality of variances in  $t$  tests by Levene's test. However, none of the tests was significant, suggesting that individual mean voltages were equally stable in Experiments 1 and 2.

## Behavior

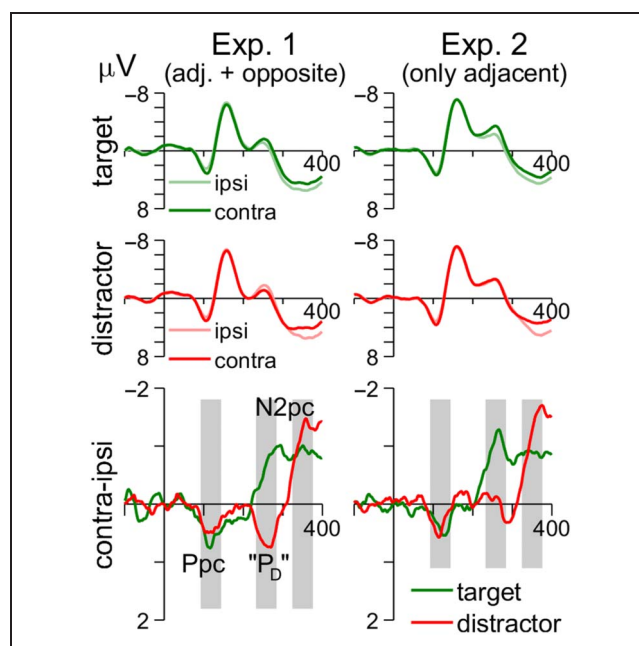
In the analysis of RTs, we excluded choice errors (Experiment 1: 8.3%, Experiment 2: 8.2%), responses outside the response window (1.1%, 0.8%), and trials with RTs longer than 2.5 SDs above the condition mean (2–3%). Kerzel and Burra (2020) observed that RTs to horizontal targets were shorter than to vertical targets, which may arise from the temporal precedence of horizontal over vertical scanning. To evaluate whether a similar scanning strategy was employed here, we evaluated differences between horizontal and vertical targets with adjacent placement. Trials with opposite placement from Experiment 1 were excluded from this analysis. A 2 (Target-Distractor Placement: “adjacent + opposite” = Experiment 1, “only adjacent” = Experiment 2)  $\times$  2 (Target Meridian: horizontal, vertical) mixed ANOVA showed a significant effect of Target Meridian,  $F(1, 34) = 4.97, p = .03, \eta_p^2 = .127$ , which was modulated by Target-Distractor Placement,  $F(1, 34) = 5.58, p = .02, \eta_p^2 = .141$ . The interaction showed that RTs were shorter with horizontal than vertical targets in Experiment 1 (550 vs. 564 msec),  $t(17) = 3.55, p < .01$ , Cohen’s  $d_z = 0.84$ , but not in Experiment 2 (563 vs. 563 msec),  $t(17) = 0.09, p = .93$ , Cohen’s  $d_z = 0.02$ . Running the same ANOVA on percentage of choice errors did not yield any significant effects,  $ps > .83$ . Thus, scanning of horizontal positions took precedence over vertical positions, replicating Kerzel and Burra (2020), but this effect was modulated by target-distractor placement. When only adjacent placements were shown, the difference between horizontal and vertical meridians disappeared, suggesting that it was caused by idiosyncratic scanning strategies (Liesefeld & Muller, 2020), and not by improved perceptual processing on the horizontal compared with the vertical meridian (e.g., Kupers, Benson, Carrasco, & Winawer, 2022; Barbot, Xue, & Carrasco, 2021).

Furthermore, we evaluated whether the distractor was attended by analyzing effects of the congruency between dots inside the target and distractor. If RTs are shorter when the response-defining characteristic inside target and distractor is the same, the distractor is attended despite being irrelevant (Becker, 2007; Theeuwes & Burger, 1998). We conducted a 2 (Target-Distractor Placement: “adjacent + opposite” = Experiment 1, “only adjacent” = Experiment 2)  $\times$  2 (Dot Location in target and distractor: congruent, incongruent) mixed ANOVA on trials with adjacent placement. The ANOVA showed that RTs on congruent trials were shorter than on incongruent trials (535 vs. 575 msec),  $F(1, 34) = 90.01, p < .01, \eta_p^2 = .726$ , suggesting that both the target and the distractor were attended. The interaction of Experiment and Dot Congruency was not significant,  $F(1, 34) = 0.43, p = .52, \eta_p^2 = .012$ , suggesting that the distribution of attention across adjacent positions was similar in Experiments 1 and 2. In addition, the main effect of Experiment was not significant,  $F(1, 34) = 0.11, p = .74, \eta_p^2 = .003$ . To rule out speed-accuracy tradeoff, we conducted the same ANOVA on the

percentage of choice errors. Consistent with RTs, fewer choice errors occurred on congruent than incongruent trials (2.2% vs. 11.1%),  $F(1, 34) = 181.68, p < .01, \eta_p^2 = .842$ , but no other effect approached significance,  $ps > .6$ .

## Electrophysiology

The ipsi- and contralateral potentials at electrodes PO7/8 are shown in the upper rows of Figure 2. We subtracted ipsi- from contralateral activity as a measure of lateralized processing. There were two conditions of interest. Distractor-elicited lateralized components were obtained with a lateral distractor + vertical target, whereas target-elicited components were obtained with a lateral target + vertical distractor. Opposite placements in Experiment 1 were not analyzed. We adapted standard analysis intervals of the Ppc and P<sub>D</sub> components to our data set. The Ppc was mostly observed between 100 and 150 msec poststimulus and the P<sub>D</sub> between 180 and 300 msec. To determine the maximal positive deflections in the respective time intervals, we calculated the 50-msec moving average on the distractor-elicited difference wave in Experiment 1. The positive peak in the Ppc interval was at 118 msec and at 258 msec in the P<sub>D</sub> interval. We based the choice of analysis intervals on Experiment 1 because



**Figure 2.** Electrophysiological results from electrodes PO7/8 in Experiments 1 and 2. Voltages ipsi- and contralateral to the target and distractor are shown in the upper panels, and the respective difference waves are shown in the bottom panels. Target-elicited and distractor-elicited activity is shown in the first and second rows of panels. The third row of panels shows the respective difference waves and the averaging intervals of the distractor-elicited Ppc (94–143 msec), presumed distractor-elicited P<sub>D</sub> (233–283 msec), and late distractor-elicited N2pc (325–375 msec). The target-elicited N2pc was evaluated in the same interval as the presumed distractor-elicited P<sub>D</sub>.

stimulus placements were as in previous research, and therefore, results from Experiment 1 may be considered a baseline. In addition, there was no significant positivity in the interval of the P<sub>D</sub> in Experiment 2, even after extending the interval to 350 msec. The main results did not change when the analysis intervals were selected based on the averaged traces from Experiments 1 and 2.

### Distractor-elicited Ppc

The distractor-elicited voltage difference in the interval from 93 to 143 msec was compared between Experiments 1 and 2. An independent-samples *t* test showed that the Ppc did not differ significantly (0.43 vs. 0.35  $\mu$ V),  $t(34) = 0.46$ ,  $p = .65$ , Cohen's  $d_s = 0.153$ . One-sample *t* tests against zero showed that means were significantly different from zero in both experiments,  $ts(17) > 2.89$ ,  $ps < .01$ , Cohen's  $d_z > 0.68$ .

### Distractor-elicited P<sub>D</sub>

The distractor-elicited voltage difference in the interval from 233 to 283 msec was compared between Experiments 1 and 2. The P<sub>D</sub> was larger to distractors occurring in the context of "adjacent + opposite" placements in Experiment 1 than to distractors occurring in the context of "only adjacent" placements in Experiment 2 (0.62 vs.  $-0.03$   $\mu$ V),  $t(34) = 2.91$ ,  $p < .01$ , Cohen's  $d_s = 0.97$ . By one-sample *t* test, the P<sub>D</sub> was significantly different from zero in Experiment 1,  $t(17) = 3.29$ ,  $p < .01$ , Cohen's  $d_z = 0.78$ , but not in Experiment 2,  $t(17) = 0.25$ ,  $p = .803$ , Cohen's  $d_z = 0.06$ . Because the P<sub>D</sub> was measured with the same stimulus configurations in Experiments 1 and 2 (i.e., target vertical, distractor lateral), it is unlikely that the need for attentional suppression differed. However, the presence of opposite placements in Experiment 1 induced participants to search the location opposite to a distractor, which contributed to the occurrence of the P<sub>D</sub>. We will show in the discussion that the distractor-elicited P<sub>D</sub> should better be considered an N2pc to the nontarget on the opposite side. Furthermore, inspection of Figure 2 may suggest that the P<sub>D</sub> in Experiment 2 occurred about 30 msec later than the P<sub>D</sub> in Experiment 1 because there was a small positive peak at 289 msec in Experiment 2. However, a one-sample *t* test showed no significant positivity in the corresponding interval from 264 to 314 msec (0.16  $\mu$ V),  $t(17) = 1.12$ ,  $p = .28$ ,  $d_z = 0.26$ .

### Late Distractor-elicited N2pc

Inspection of Figure 2 suggests that a polarity flip occurred in Experiment 1. That is, the distractor-elicited P<sub>D</sub> turned into an N2pc. In Experiment 2, there was no P<sub>D</sub>, but a negativity occurred between 300 and 400 msec. In both cases, the negativity between 300 and 400 msec was the first negativity and we therefore consider it a late distractor-elicited N2pc. An independent-samples *t* test showed that the late

distractor-elicited N2pc from 325 to 375 msec did not differ significantly between Experiments 1 and 2 ( $-1.17$  vs.  $-1.20$   $\mu$ V),  $t(34) = 0.09$ ,  $p = .93$ , Cohen's  $d_s = 0.03$ . Two one-sample *t* tests against zero showed that the late N2pc was significantly different from zero in both experiments,  $ts(17) > 5.13$ ,  $ps < .01$ , Cohen's  $d_z > 1.21$ .

### Target-elicited Components

Target-elicited components were calculated for lateral targets with vertical distractors. Although not the focus of the present study, we wanted to rule out differences between Experiments 1 and 2 concerning the deployment of attention to the target. We used the same analysis interval for the target-elicited Ppc and N2pc as for the distractor-elicited Ppc and P<sub>D</sub> (from Experiment 1) because visual inspection showed that these components largely overlapped. This choice appears justified as results obtained with averaged traces were similar. The target-elicited Ppc in the interval from 93 to 143 msec did not differ between Experiments 1 and 2 (0.57 vs. 0.38  $\mu$ V),  $t(34) = 1.03$ ,  $p = .31$ , Cohen's  $d_s = 0.34$ . Both means were significantly different from zero,  $ts(17) > 2.58$ ,  $ps < .01$ , Cohen's  $d_z > 0.84$ . Furthermore, the target-elicited N2pc from 233 to 283 msec did not differ between Experiments 1 and 2 ( $-0.64$  vs.  $-1.01$   $\mu$ V),  $t(34) = 1.14$ ,  $p = .26$ , Cohen's  $d_s = 0.381$ . Both N2pc components were significantly different from zero,  $ts(17) > 2.58$ ,  $ps < .01$ , Cohen's  $d_z > 0.907$ . Thus, the target-elicited components were comparable between Experiments 1 and 2.

Furthermore, we performed comparisons between target-elicited and distractor-elicited components. To decide whether the Ppc was affected by attention, we compared the distractor-elicited to the target-elicited Ppc. The difference was neither significant in Experiment 1 (0.43 vs. 0.57  $\mu$ V) nor in Experiment 2 (0.35 vs. 0.38  $\mu$ V),  $ts(17) < 1.05$ ,  $ps > .31$ , Cohen's  $d_z < 0.57$ , suggesting that the Ppc reflected imbalanced saliency and was unaffected by attention. This result is at odds with the claim that positivities between 100 and 200 msec reflect attentional processing (Gaspelin & Luck, 2018b; Sawaki & Luck, 2010). We also compared the latency of the target-elicited N2pc with the late distractor-elicited N2pc using a Jackknife procedure (Kiesel, Miller, Jolicoeur, & Brisson, 2008) with a fixed threshold of  $-0.5$   $\mu$ V. In Experiment 1, the target-elicited N2pc occurred 101 msec earlier than the distractor-elicited N2pc (225 vs. 326 msec),  $t_{adj.}(17) = 9.46$ ,  $p < .01$ , Cohen's  $d_z = 2.23$ . In Experiment 2, this difference was 71 msec (250 vs. 321 msec),  $t_{adj.}(17) = 7.18$ ,  $p < .01$ , Cohen's  $d_z = 1.69$ .

Note, however, that the target- and distractor-elicited N2pc components overlapped. That is, the target-elicited N2pc remained significant even in the analysis interval of the distractor-elicited N2pc. That is, the target-elicited N2pc from 325 to 375 msec was  $-0.91$   $\mu$ V in Experiment 1 and  $-0.88$   $\mu$ V in Experiment 2,  $ts(17) > 3.04$ ,  $ps < .01$ , Cohen's  $d_z > 0.71$ . The overlap suggests that participants

selected target and distractor stimuli in parallel. However, this conclusion is limited by the fact that target- and distractor-elicited components were measured on different trials to either lateral targets or lateral distractors. Thus, the target stimulus was selected about 100 msec before the distractor stimulus, but both were simultaneously attended toward the end.

## N2 Component

In the upper panels of Figure 2, the N2 in the interval from 228 to 278 msec appears larger in Experiment 2 than 1 ( $-2.26$  vs.  $-0.84$   $\mu\text{V}$ ). However, the difference was not significant,  $t(34) = 0.99$ ,  $p = .33$ , Cohen's  $d = 0.33$ . The reason may be the large variability between participants ( $SD = 4.3$ ).

## HEOG

We analyzed voltages at lateral eye electrodes to rule out potential contamination of ERPs by eye movements occurring after onset of the search display. Because the search display was only presented for 100 msec, it is unlikely that eye movements changed the retinal projections of the stimuli, but one may worry that the propagation of voltage changes from the eyes to posterior electrodes biased the results. To evaluate this possibility, the voltage at the eye electrode ipsilateral to the distractor was subtracted from the voltage at the eye electrode contralateral to the distractor in the Ppc and P<sub>D</sub> intervals. The resulting voltage differences varied between  $-0.77$  and  $0.30$   $\mu\text{V}$ . These voltage differences are too small to explain results at the posterior electrodes PO7/PO8. Lins, Picton, Berg, and Scherg (1993, Table 5) showed that only  $1\% \pm 3\%$  of the voltage propagates from ocular to posterior electrodes (in their case, electrodes O1/O2, which are adjacent to electrodes PO7/8). That is, the expected voltage changes at electrodes PO7/8 based on propagation from the eye muscles would range between  $-0.03$  and  $0.01$ , which is negligible. Furthermore, we confirmed that the average HEOG traces for each participant and condition were within the range of  $\pm 3$   $\mu\text{V}$ .

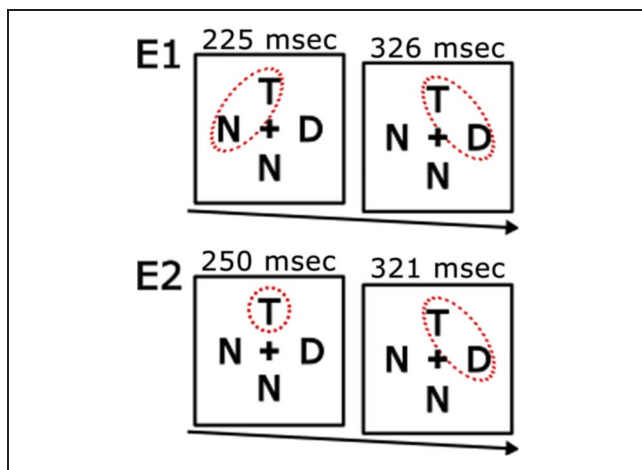
## DISCUSSION

We investigated whether the occurrence of a presumed index of attentional suppression, the P<sub>D</sub> component, was related to search strategies. To induce attentional suppression of a distractor, we cued the color of the distractor before onset of the search display. The negatively cued color changed on every trial to force participants to actively employ attentional suppression. We expected that participants would suppress the distractor in the subsequent search display to locate the target stimulus. To change the search strategies, we manipulated the placements of target and distractor in two experiments. In Experiment 1, target and distractor were adjacent in eight

out of 12 possible placements and opposite in four. This choice of placement type is consistent with previous research on the P<sub>D</sub> component using at least four search stimuli and manual responses (e.g., Stilwell et al., 2022; Feldmann-Wüstefeld et al., 2021; Liesefeld et al., 2017; 2021; van Moorselaar et al., 2021; van Moorselaar & Slagter, 2019; Wang et al., 2019; Donohue et al., 2018; Gaspelin & Luck, 2018a; Barras & Kerzel, 2017; Kadel et al., 2017; Barras & Kerzel, 2016; Feldmann-Wüstefeld et al., 2015; Burra & Kerzel, 2014; Gaspar & McDonald, 2014; Burra & Kerzel, 2013; Jannati et al., 2013; McDonald et al., 2013; Kiss et al., 2012; Hickey et al., 2009). In Experiment 2, we only presented adjacent placements, similar to a minority of studies (Berggren & Eimer, 2021; Corriveau et al., 2012). We propose that the presence of opposite placements in Experiment 1 induced a search strategy whereby participants searched the location opposite to the distractor. In contrast, Experiment 2 avoided this search strategy because opposite placements were absent. Consistent with effects of search strategy, we found a distractor-elicited P<sub>D</sub> when adjacent and opposite placements were mixed, but not when only adjacent placements were shown. That is, the trial context changed the ERP for the same displays, which is unexpected under the assumption that the P<sub>D</sub> reflects attentional suppression. Our findings suggests that the P<sub>D</sub> is not a correlate of trial-by-trial suppression but reflects search strategies. We suggest that when adjacent and opposite placements are mixed, the presumed P<sub>D</sub> to the distractor is actually an N2pc to the opposite nontarget. That is, participants searched the position opposite to the distractor because this strategy was sometimes successful. Thus, the presumed P<sub>D</sub> to the distractor was in fact an N2pc to the opposite nontarget. In addition, the idea that search strategies differed as a function of trial context is corroborated by differences in RTs between horizontal and vertical targets. When opposite placements were included in Experiment 1, RTs to horizontal targets were shorter than to vertical targets. When placements were only adjacent in Experiment 2, the difference disappeared.

The onset of the N2pc to the opposite nontarget occurred at about the same time as the N2pc to the target, suggesting that participants selected these stimuli in parallel (see Eimer & Grubert, 2014; Müller, Malinowski, Gruber, & Hillyard, 2003). The time course of object selection as indexed by the N2pc is illustrated in Figure 3. Although the ERPs were derived from separate sets of trials, the overlap suggests that participants selected two stimuli at the same time (for similar reasoning, see Grubert & Eimer, 2015; Eimer & Grubert, 2014). In Experiment 1, participants initially selected the target together with the opposite nontarget as evidenced by the simultaneous occurrence of the target-elicited N2pc and the distractor-elicited "P<sub>D</sub>" component. In Experiment 2, they initially only selected the target as there was only a target-elicited N2pc. In both experiments, participants continued to attend to the target as shown by the prolonged target-





**Figure 3.** The assumed time course of stimulus selection in Experiments 1 and 2. Our analysis of N2pc latencies suggests that selection of the target started around 225–250 msec. In Experiment 1, the nontarget opposite to the distractor was selected in parallel, which was not the case in Experiment 2 because target and distractor were never shown on opposite positions. In both experiments, target and distractor were subsequently selected in parallel, starting around 321–326 msec. Note that simultaneous deployment of attention to target, nontarget, or distractor cannot be measured on the same trials but requires separate trials where each stimulus is lateralized. To illustrate our hypothesis, however, we show allocation of attention to vertical targets, which we did not measure. T = target; D = distractor; N = nontarget.

elicited N2pc. Surprisingly, they subsequently attended to the distractor as there was a distractor-elicited N2pc during the prolonged target-elicited N2pc. This finding may be related to the well-known “white bear” phenomenon. It has been shown that trying to ignore a stimulus prompts allocation of attention to it (Moher & Egeth, 2012; Tsal & Makovski, 2006). Here, participants attempted to ignore the distractor and initially succeeded in doing so by focusing attention on the target stimulus. Subsequently, however, they attended to the distractor, which resulted in shorter RTs on trials where the dot location inside the distractor corresponded to the dot location inside the target. Although this search behavior is not functional, it is consistent with previous reports of the ignoring paradox. Perhaps the late distractor selection served to reassure participants of their choice.

Furthermore, we replicated the distractor-elicited polarity flip in Experiment 1 where the presumed  $P_D$  was followed by a late N2pc (see Drisdelle & Eimer, 2021; Liesefeld et al., 2017, 2021; Kerzel & Burra, 2020; Gaspelin & Luck, 2018a). In Experiment 2, there was no positivity, but only a late N2pc. Following the logic of Drisdelle and Eimer (2021), the distractor-elicited N2pc may in fact be a  $P_D$  to the nontarget on the opposite side. However, our behavioral data make it more likely that it was indeed a distractor-elicited N2pc. In the analysis of RTs, we found shorter latencies when the dot location inside the distractor disk was the same as in the target disk. This kind of compatibility effect was previously considered

evidence of distractor selection (Becker, 2007; Theeuwes & Burger, 1998). Therefore, it is likely that the late negativity was indeed an N2pc to the distractor because this would fit with the occurrence of the congruency effect. It is unclear how attentional suppression of the distractor could account for it. If the distractor was suppressed, it should not affect processing of the target. Consistent with the current proposal that the distractor may be attentionally selected, Förschack, Gundlach, Hillyard, and Müller (2022a, 2022b, 2023) found evidence for attentional selection of salient distractors in frequency-based measures. That is, the steady-state visual evoked potentials increased for the distractor and the contralateral alpha-band amplitudes decreased. Attentional suppression would predict changes in the opposite direction. Furthermore, the effect of trial context on the  $P_D$  appears incompatible with recent modelling work to explain the polarity flip. Tam and colleagues (2022) suggested that the polarity flip resulted from a sequence of proactive distractor suppression and reactive nontarget suppression. Although the model does a good job of explaining existing data (e.g., effects of display size), it cannot handle effects that go beyond a single trial, such as search strategies.

Finally, the difference between trial contexts explains the discrepancy between two previous studies using similar stimuli and tasks. Donohue and colleagues (2018) and Corriveau and colleagues (2012) used colored target and distractor stimuli among blue or black nontarget stimuli. Both studies used a compound task where a feature of the target other than its color had to be identified (i.e., the orientation of a line or letter). Consistent with the present results, Donohue and colleagues (2018) included opposite placements and found a  $P_D$ , whereas Corriveau and colleagues (2012) only presented adjacent placements and failed to find a  $P_D$ . Unless the placement types are considered, the different results are hard to reconcile because the studies are highly similar otherwise.

### Functional Significance

The present study provides some evidence that participants searched the location opposite the distractor before returning to the distractor location. In electrophysiological terms, there was an N2pc to the nontarget opposite the distractor before there was an N2pc to the distractor. The initial selection of the opposite nontarget was eliminated when opposite placements were excluded, which reflects an adaptive response to the trial context. However, inspection of Figure 1C shows that only 1/3 of all placements were opposite. Thus, the search strategy was useful on only in a minority of trials but was nonetheless adopted. So why did observers attend a nontarget opposite the distractor? Our answer is that participants readily adopted this strategy to avoid the distractor. That is, participants attended away from the distractor instead of suppressing it, which resulted in an N2pc to the nontarget opposite the

distractor. Our suggestion presumes that the initial localization of the distractor occurred pre-attentively. Subsequently, attention did not stay at fixation, but was biased away from the distractor in the opposite direction. This bias is reminiscent of “attentional momentum” in the literature on inhibition of return (Spalek & Hammad, 2004; Pratt, Spalek, & Bradshaw, 1999). For instance, Pratt and colleagues (1999) cued one out four positions arranged in a cross-like arrangement similar to the present displays. After an SOA of 950 msec, the target appeared in one of the four locations. Simple detection responses showed longer RTs for the cued location, which is consistent with inhibition of return. Interestingly, RTs to targets at uncued locations were not the same, but RTs were shortest to targets at the uncued location directly opposite the cue. Thus, attention was not only inhibited in returning to the cued location, but also facilitated in moving in the opposite direction, suggesting that explanations in terms of inhibitory processes need to be supplemented by facilitatory processes that redirect attention. A similar argument may be made here. The assumption that distractors are avoided by attentional suppression may need to be supplemented (or replaced) by the idea that attention is redirected to avoid the distractor. The present experiments suggest that attention is redirected to the position opposite to the distractor location when the trial context promotes this strategy. Thus, one important methodological conclusion is that the trial context needs to be carefully controlled in studies on attentional suppression of distractors. Our study suggests that a trial context with opposite placements may induce a search strategy to avoid the distractor, but other trial contexts may induce other search strategies. Finally, the effect of a minority of trials on the occurrence of the  $P_D$  suggests that it may not be possible to study effects of stimulus placement in a within-participant design because only a few encounters with opposite placements may be sufficient to induce a lasting search strategy. Similar carry-over effects have been observed in the context of search modes (e.g., Kerzel & Barras, 2016; Leber & Egeth, 2006). Future research should determine how many encounters with opposite placements are necessary for a change of the search strategy to occur.

### Scope

In the current study, we focused on a search task with manual responses and at least four stimuli, including two nontarget stimuli. With these displays, it is possible to manipulate attentional avoidance by changing the target-distractor configuration. In related research, only a target and distractor stimulus were used, which makes a similar manipulation more difficult. The question is whether the current account could be applied to these tasks, or whether a  $P_D$  in these studies rules out the current interpretation. For instance, in the original report of the  $P_D$  by Hickey and colleagues (2009), there was a target and a

distractor stimulus, but nontargets were absent. As in the current study, the target was placed above or below fixation and the distractor on the left or right to measure the distractor-elicited  $P_D$ . Different from the present study, however, there was no stimulus opposite the distractor. One may argue that an N2pc to the location opposite to the distractor depends on the presence of a nontarget stimulus and cannot be observed to an empty location, which would invalidate the current account. However, N2pc components have been observed to empty gaps (Kiss & Eimer, 2011) and the N2pc does not require a discrimination response, but may occur to response-irrelevant stimuli (Kerzel & Huynh Cong, 2021; Livingstone, Christie, Wright, & McDonald, 2017; Grubert & Eimer, 2016; Kiss & Eimer, 2011). Thus, it cannot be ruled out that the  $P_D$  in Hickey and colleagues (2009) was an N2pc to the empty side opposite the distractor, but we have no evidence to confirm or disconfirm this idea.

Furthermore, a  $P_D$  was observed when participants were asked to make a saccade to a vertical target when a lateral distractor was presented (van Zoest, Huber-Huber, Weaver, & Hickey, 2021; Weaver et al., 2017). In these saccade tasks, the orientation-defined target and distractor stimuli were shown on a homogeneous background of vertical lines. Again, it may be possible that participants shifted attention to the “empty” hemifield to avoid the distractor instead of suppressing it. It is debatable whether participants could make a vertical saccade while shifting attention laterally. On the one hand, the focus of attention usually coincides with the saccade target (Deubel & Schneider, 1996). On the other hand, it is possible to remember one location and make a saccade to another location (e.g., Theeuwes, Olivers, & Chizk, 2005), suggesting that eye movements and attended location can be dissociated to some degree. Furthermore, it may be that the  $P_D$  in research involving saccadic eye movements has different underlying processes. For instance, van Zoest and colleagues (2021) linked the  $P_D$  amplitude to the amplitude of brain oscillations in the alpha frequency range. Previous research suggested that increased alpha oscillations contralateral to a stimulus correlate with its attentional suppression (e.g., Foster & Awh, 2019; Jensen & Mazaheri, 2010). In Experiment 2 of van Zoest and colleagues (2021), an increase in the amplitude of prestimulus alpha contralateral to a cued distractor location was linked to the emergence of a  $P_D$ , providing evidence that the  $P_D$  indicated suppression. However, conflicting results were reported in a search task similar to the present study. Notably, Forschack et al., (2022a, 2022b) reported reduced alpha oscillations at electrodes contralateral to the distractor, which is contrary to the observations in van Zoest and colleagues (2021) and indicates that the distractor was attended, not suppressed.

Finally, it may be that attentional mechanisms underlying the  $P_D$  may not be the same in all latency ranges. In the current study, we focused on the time range of the N2pc between 200 and 300 msec. However, a  $P_D$

was also observed earlier (Hickey, Pollicino, Bertazzoli, & Barbaro, 2019; Sawaki & Luck, 2010, 2013) and later (Liesefeld et al., 2017, 2021; Sawaki, Geng, & Luck, 2012). Possibly, the  $P_D$  with short latency is more influenced by saliency signals whereas the later component reflects redirection of attention after attentional capture. Thus, the present account of nontarget selection may not provide an adequate explanation for all instances of the  $P_D$  component. There may be differences according to the task, search displays, and time range. More research is required to evaluate whether the current account can be applied to a wider range of experimental situations.

### Negative Attentional Templates Without Attentional Suppression

As outlined in the introduction, Berggren and Eimer (2021) found no  $P_D$  to nontargets in the color of a negative cue shown before onset of the search display. Consistent with previous research on negative attentional templates (e.g., Arita, Carlisle, & Woodman, 2012; Woodman & Luck, 2007), the main search task of the participant was to look for a particular shape (i.e., with a vertical instead of horizontal gap). The cued nontarget color helped to reject a subset of the nontargets but was not necessary to find the target. That is, the target could be located based on its shape alone and there were only four items in the search display, which resulted in an easy search task. Because the use of negative cues is contingent on strong incentives to use the cue (Kerzel & Huynh Cong, 2022b; Zhang et al., 2022; Conci et al., 2019), it may be that participants in Berggren and Eimer (2021) did not use it. In the current research, we forced participants to rely on the negatively cued color to find the target, which may explain why we observed a presumed  $P_D$  in Experiment 1. However, Experiment 2 showed that the presumed  $P_D$  was unrelated to attentional suppression but resulted from search strategies. Thus, it is also very likely that the ERP in Carlisle and Nitka (2019) was an  $N2pc$  to the hemifield containing the target and not a  $P_D$  to the hemifield containing the items in the color of the negative cue. Furthermore, other behavioral evidence for attentional suppression, such as same location costs in the contingent capture paradigm (Forstinger et al., 2022; Kerzel & Huynh Cong, 2022b), may arise from different processes, such as lack of enhancement at the cued location (Kerzel & Huynh Cong, 2021) or object-file updating (Harris, Bradley, Yoo, & Mattingley, 2022).

### When Does Attentional Suppression Occur?

Although the present experiments suggest that the  $P_D$  is not (always) the correlate of attentional suppression, it may be premature to conclude that there is no attentional suppression at all. However, it may not occur at the

perceptual level, but at decision-related stages. For instance, strong evidence for attentional suppression was provided by the probe letter paradigm developed by Kim and Cave (1995). In the probe letter paradigm, a search task is performed on most trials, and on a minority of trials, masked letters are presented on each of the stimuli to evaluate the distribution of attention. The search task employed by Gaspelin, Leonard, and Luck (2015) was to locate a specific shape among various shapes (i.e., feature search; Bacon & Egeth, 1994). On some of the trials, a salient distractor was shown. Gaspelin and colleagues (2015) observed that performance for probe letters on the distractor was worse than for probe letters on inconspicuous nontargets, which suggests that the distractor was suppressed below baseline. Although suppression in the probe letter task has been replicated many times (e.g., Stilwell & Gaspelin, 2021; Wang & Theeuwes, 2020), it is unclear whether it provides evidence for the suppression of salient-but-irrelevant stimuli. First, Lien, Ruthruff, and Hauck (2022) found that suppression occurs also for inconspicuous nontargets that can be excluded from search. Second, Kerzel and Renaud (2022) showed that uncertainty about which letter to report contributed to the suppression of the distractor stimulus. Possibly, attentional suppression operates at the level of decisions and not at the level of perception. Therefore, there is no reason to expect ERPs occurring in the time range of perceptual-level processing, such as  $P_D$ . Rather, attentional suppression can be achieved at a later, decision-related stage.

In summary, we investigated whether search strategies contribute to the occurrence of electrophysiological evidence for attentional suppression. To induce attentional suppression, we cued the color of the distractor before onset of the search display. In the subsequent search display, participants were expected to suppress the distractor to locate the target. The electrophysiological results of Experiment 1 showed a positivity between 200 and 300 msec at electrodes PO7/8 in response to the distractor, consistent with an index of attentional suppression, the  $P_D$ . However, the presumed  $P_D$  was absent in Experiment 2. The only difference between Experiments 1 and 2 was that opposite placements of target and distractor were possible in Experiment 1, but not in Experiment 2. We suggest that opposite placements encouraged participants to search the location opposite the distractor, regardless of the stimulus type at this location. Thus, for trials with lateral distractor and vertical target, the presumed  $P_D$  to the distractor was in fact an  $N2pc$  to the opposite nontarget. These results suggest that participants do not suppress distractors but avoid them by redirecting attention elsewhere. Furthermore, we observed that after avoiding the distractor, attention returned to the distractor. The reasons for the attentional selection of the distractor are not entirely clear, but behavioral congruency effects suggest that the distractor stimulus was in fact attended.



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## Data Availability Statement

Neither of the experiments reported in this article was formally preregistered. The data are available at <https://osf.io/vy83s/>, and requests for the program code can be sent via e-mail to D. K.

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## Diversity in Citation Practices

Retrospective analysis of the citations in every article published in this journal from 2010 to 2021 reveals a persistent pattern of gender imbalance: Although the proportions of authorship teams (categorized by estimated gender identification of first author/last author) publishing in the *Journal of Cognitive Neuroscience (JoCN)* during this period were  $M(\text{an})/M = .407$ ,  $W(\text{oman})/M = .32$ ,  $M/W = .115$ , and  $W/W = .159$ , the comparable proportions for the articles that these authorship teams cited were  $M/M = .549$ ,  $W/M = .257$ ,  $M/W = .109$ , and  $W/W = .085$  (Postle and Fulvio, *JoCN*, 34:1, pp. 1–3). Consequently, *JoCN* encourages all authors to consider gender balance explicitly when selecting which articles to cite and gives them the opportunity to report their article's gender citation balance.

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