Drawn to Distraction: Anxiety Impairs Neural Suppression of Known Distractor Features in Visual Search

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Abstract

■ When searching for a target, it is possible to suppress the features of a known distractor. This suppression may prevent distractor processing altogether or only after the distractor initially captures attention (i.e., search and destroy). However, suppression may be impaired in individuals with attentional control deficits, such as in high anxiety. In this study ($n = 48$), we used ERPs to examine the time course of attentional enhancement and suppression when participants were given pretrial information about target or distractor features. Consistent with our hypothesis, we found that individuals with higher levels of anxiety had lower neural measures of suppressing the template-matching distractor, instead showing enhanced processing. These findings indicate that individuals with anxiety are more likely to use a search-and-destroy mechanism of negative templates—highlighting the importance of attentional control abilities in distractor-guided search. ■

INTRODUCTION

When looking for your keys among many items on a table, your attention could be guided by something you already know about the keys, such as their color, or you could use information about what you know your keys do not look like (e.g., they are not silver). How you use that information, however, may depend on your cognitive strategy. For example, researchers have found that people who have higher anxiety initially pay attention to distracting items before suppressing them. In this study, we examined how people use target and distractor information to guide attention by measuring their electrical brain activity. We found that individuals with greater anxiety were more likely to pay attention to the item they were told not to look for, whereas less anxious individuals could ignore this distractor. These findings help us to understand how the brain deals with distraction and the cognitive consequences of anxiety.

Given the abundance of visual information in the world and the brain's limited processing capacity, we must use top–down control to delegate cognitive resources toward goal-relevant items. Without sufficient attentional control, we run the risk of becoming distracted by salient but task-irrelevant items that are competing for representation. This competition between goal-driven and stimulus-driven factors can be biased toward relevant items using an attentional set or template (Carlisle, Arita, Pardo, & Woodman, 2011; Carlisle & Woodman, 2011b; Desimone & Duncan, 1995). For example, knowing that a target item will be in a certain color or shape

(i.e., a featured-based template) allows attention to be guided toward the template-matching item, speeding search times and attentional selection of targets, despite the presence of distractors (Carlisle & Woodman, 2011a; Folk, Remington, & Johnston, 1992). This type of template is referred to as a *positive template,* which aids in the selection of goal-relevant over irrelevant information for further processing.

There is recent evidence that templates can also be used to down-weight the processing of goal-irrelevant items (Carlisle, 2019; Chang & Egeth, 2019). For example, it has been found that when given information about an upcoming distractor feature (referred to as a *negative template*; Arita, Carlisle, & Woodman, 2012), individuals can suppress processing of that item during search, resulting in a search benefit (for a review of distractor ignoring strategies; see Geng, Won, & Carlisle, 2019). Negative templates, however, are not always effective in guiding search, as there is behavioral evidence that individuals first attend to the features matching the negative template instead of inhibiting them (Chang, Cunningham, & Egeth, 2019; Moher & Egeth, 2012). This process has been termed the *search and destroy* mechanism of negative templates, suggesting that individuals do not inhibit template-matching distractors.

Evidence for distractor suppression given negative templates has largely been supported by behavioral measures, which are a summation of perceptual, attentional, and decision-making processes. However, using time-sensitive EEG recordings of brain activity, it is possible to identify the underlying time course of attentional suppression and selection. For example, Carlisle and Nitka (2019) examined the N2pc, an ERP related to attentional

selection and enhancement. When attention is directed toward a lateral item, the N2pc is observed as an increased negativity over contralateral compared with ipsilateral electrode sites from 200 to 300 msec poststimuli onset (Hickey, Di Lollo, & McDonald, 2009; Kiss, Velzen, & Eimer, 2008; Eimer, 1996). Carlisle and Nitka (2019) found an N2pc toward the target hemifield after negative cues, suggesting that participants were not initially attending to the distractor after the negative cue. In addition, they found that the target N2pc was delayed after a negative cue, suggesting that negative templates may take more time to implement than positive templates. Similarly, Berggren and Eimer (2021) found a delayed target N2pc after negative cues. Overall, contrary to the search-and-destroy hypothesis, these findings suggest that template-matching distractors are not always initially attended, despite slowed target selection (i.e., the "search" part of search and destroy).

Given the inconsistent findings on whether negative templates are beneficial to visual search performance, it remains possible that there are individual differences in how negative templates are used. For positive templates, it has been found that individuals with higher levels of anxiety have greater attentional capture by distractors than less anxious individuals, suggesting that anxiety is related to an overall deficit in top–down inhibitory control (Derakshan & Eysenck, 2009; Eysenck, Derakshan, Santos, & Calvo, 2007). Indeed, Gaspar and McDonald (2018) found that individuals with high levels of anxiety had an early, distractor-elicited N2pc, which was absent for those with lower levels of anxiety (but see Qi, Ding, & Li, 2014). They also examined an additional ERP component called the distractor positivity (P_D). The P_D measures the suppression of salient, task-irrelevant items and is observed as an increased positivity over contralateral compared with ipsilateral electrode sites when a distractor is presented laterally and a target is on the vertical midline (Sawaki, Geng, & Luck, 2012; Hickey et al., 2009). Gaspar and McDonald (2018) demonstrated that, although individuals with high anxiety initially showed attentional capture by the distractor item, both high- and low-anxiety individuals had a later P_D, suggesting that those with high anxiety suppressed the distractor, but only after it had initially diverted attention. Thus, whereas the findings of Gaspar and McDonald (2018) support later distractor inhibition for individuals with anxiety when given a positive template, the time course of how negative templates affect attention, with or without anxiety, remains unclear.

Consequently, the goal of this study is twofold: (1) to examine the neural time course of attentional selection and inhibition of distractors after positive and negative cues and (2) to examine whether anxiety affects the timing of attentional selection and suppression when using negative templates. By examining the N2pc and P_D, we can observe whether individuals are able to suppress the distractor (P_D with no N2pc) or if suppression of

the distractor only occurs after it has been attended (P_D after the N2pc). In addition, it is possible that an early P_D may occur before the time range of the N2pc, reflecting active suppression before attention is deployed (Gaspelin & Luck, 2018b; Sawaki & Luck, 2010). Given that the P_D can occur before, during, or after the time range of the N2pc (Jannati, Gaspar, & McDonald, 2013), this component can be used to determine the precise timing of suppression. However, flexible attentional control over preparatory distractor inhibition is contested in the literature (for a review, see van Moorselaar & Slagter, 2020).

Given that individuals with high levels of anxiety have reduced inhibitory control, we predicted that negative templates would amplify this attentional deficit. That is, we predicted that, compared with less anxious individuals, participants with higher levels of anxiety would not be able to suppress template-matching distractors, as reflected by larger subsequent distractor-elicited N2pcs. In contrast, individuals with less anxiety were predicted to have a P_D toward the negatively cued distractor instead of an N2pc. Using a visual search task with systematically lateralized targets and distractors, we aim to examine the underlying neural time course of attentional templates and how selection and suppression differ across individuals.

METHODS

Participants

Procedures were approved by and conducted in accordance with the Brock University Social Science Research Ethics Board. We aimed to collect a sample of 48 healthy participants after data rejection (normal vision, normal color vision, no history of neurological or psychological disorders), in line with previous studies that found medium effect sizes for individual differences in anxiety on the N2pc and P_D (Gaspar & McDonald, 2018; Qi et al., 2014). A total of 12 participants' data were excluded and replaced because of either experimenter recording error (3), task noncompliance (1), EOG artifacts (3), or low trial counts resulting from inaccurate behavioral responses and/or trial time-outs (5). The final sample consisted of 48 participants between the ages of 17 and 30 years (M_{age} = 20.3 years, seven male, all right-handed).

Apparatus

All tasks were completed on a Windows PC with a 41-cm NEC MultiSync LCD 2090UXi monitor (1600 × 1200 pixels, 60-Hz refresh rate) in a dimly lit room. Anxiety questionnaires and the change detection task were presented using PsychoPy 1.90.3, and the visual search task was presented using PsychoPy 3.2.4 (Peirce et al., 2019)

on a black background, with a viewing distance of approximately 57 cm.

Anxiety Questionnaires

At the beginning of the session, participants first completed a change detection task as part of our standard protocol (Luck & Vogel, 1997; not reported here). Next, participants completed both the State and Trait Anxiety Inventories on the computer (Spielberger, Gorsuch, Lushene, & Vagg, 1983). Each questionnaire consists of 20 questions on a 4-point Likert scale and has a minimum score of 20 and a maximum score of 80. In the present sample, both state ($M = 37.5$, $SD = 9.9$, range = 23–60) and trait ($M = 42.3$, $SD = 10.9$, range = 24–63) anxiety scores were similar to norms for undergraduate samples (Stout, Shackman, & Larson, 2013; Spielberger et al., 1983). One participant's anxiety questionnaire data did not save because of a computer error ($n = 47$).

Visual Search Task

After EEG cap setup, participants completed the cued visual search task (Figure 1). On each trial, after an intertrial interval of 1000 msec (fixation dot radius of 0.3°), participants were presented with a cue (800 msec) that indicated the likelihood (i.e., 0% or 100%, white text, 1° tall, presented above fixation) that the target line would be within a circle of a particular color (diameter = 1.5°, presented at fixation). In the neutral cue condition, a gray circle was presented at fixation without text.

After a delay (800–1200 msec), a search array consisting of 10 rings (width of 0.25°, diameter of 3°) was presented on an imaginary circle around fixation (10° from fixation to the center of ring). Eight of the 10 rings were gray (RGB = [140, 140, 140], ~6.74 cd/m²), and two were colored. Ring colors were chosen pseudorandomly on each trial and could be red (RGB = [255, 0, 0], ~5.77 cd/m²), blue

(RGB = [128, 128, 204], ~6.69 cd/m²), yellow (RGB = [147, 147, 0], ~6.94 cd/m²), or green (RGB = [0, 172, 0], ~6.58 cd/m²). On the critical 83.33% of trials (960), one of the colored rings was presented on the lateral and the other was presented on the vertical. On the remaining 16.66% of trials (192), the colored rings were presented either on the same side or directly across from one another (96 trials each). These trials were included so that participants could not reliably predict the potential target and distractor locations. Distractor and target colors were pseudorandomly selected on each trial.

Each ring had a gray line within it (1° long, 0.25° wide) that was either task irrelevant (angle pseudorandomly chosen every 18° from 0° to 360°) or a target (angle of 0° or 90°). Participants were instructed to find the vertical or horizontal line within a colored ring and to report its orientation as quickly as possible while also maintaining accuracy. The search array stayed on the screen for 200 msec before participants were provided with accuracy feedback (i.e., "Incorrect"; 800 msec), or the trial terminated after 2 sec. There were 1152 trials, 960 of which were used in the final analysis (lateralized positions only).

EEG Recording and Analysis

EEG was DC recorded at 512 Hz using a 64 Ag/AgCl electrode cap at the standard 10–20 sites (ActiveTwo system, BioSemi). The signal was online referenced to the common-mode sense and driven right leg electrodes. Preprocessing was completed in with EEGLAB (Delorme & Makeig, 2004; Version 14.0.0b) and ERPLAB (Lopez-Calderon & Luck, 2014; Version 6.1.2) toolboxes and custom scripts. Data were rereferenced offline to the average of the mastoids and filtered with a 40-Hz low-pass and 0.1-Hz high-pass Butterworth band-pass filter (slope: 12 dB/octave). Baseline correction was performed from −200 to 0 msec relative to the search array onset, and epochs were created between −200 and 600 msec.

Figure 1. Task schematic for the lateralized visual search task. A positive, negative, or neutral cue was presented followed by a jittered fixation interval. The search array was present until a key response or 2 sec elapsed. Example depicted is of a distractor lateral, target midline trial.
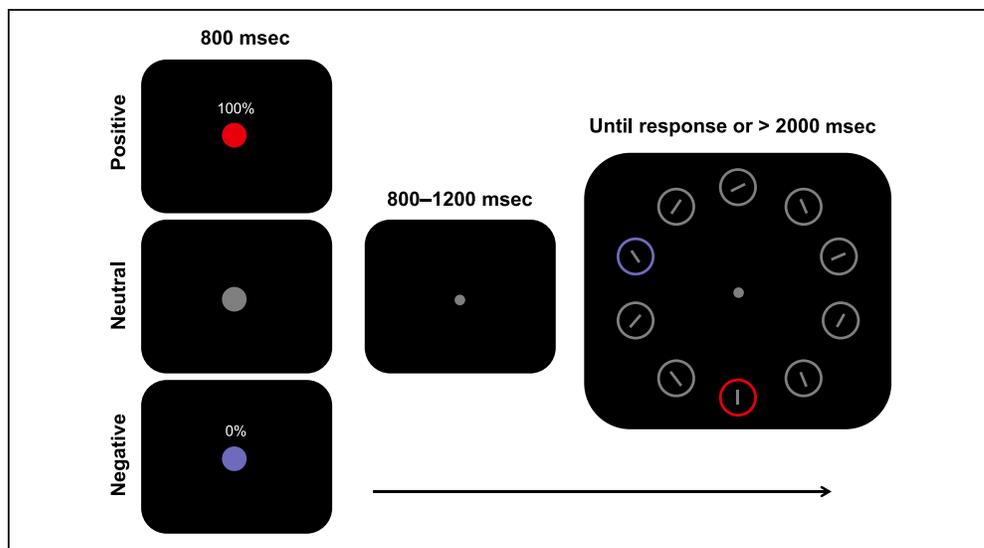
Horizontal EOG (HEOG) was measured from bipolar external electrodes placed laterally beside each eye. Vertical EOG was recorded as the difference between external electrodes placed below the eyes and activity at FP1 or FP2. Trials with HEOG activity ±32 μV and/or vertical EOG activity ±80 μV between −200 and 400 msec relative to search array onset were excluded. Any trials with voltage ±100 μV over the posterior channels (P1/2, P3/4, P5/6, P7/8, P9/10, PO3/O4, PO7/O8, and O1/2) were also removed. Across the entire epoch, no participant had average residual HEOG voltages greater than 3.75 μV (estimated voltage propagation to posterior electrode sites less than 0.1 μV; Lins, Picton, Berg, & Scherg, 1993). Participants whose data had >35% of total trials rejected because of EOG artifacts were replaced ($n = 3$). In the final data set, an average of 11.7% ($SD = 7.2\%$) of trials were rejected because of EOG artifacts.

For each participant, contralateral and ipsilateral waveforms were obtained in reference to the lateral target or distractor item at channel pair PO7/PO8 (correct trials only, $M_{incorrect} = 8 \pm 5\%$). Mean contralateral and ipsilateral amplitudes were measured for each participant and condition. This resulted in 12 measurements per time window: positive cue/target lateral, positive cue/distractor lateral, negative cue/target lateral, negative cue/distractor lateral, neutral cue/target lateral, and neutral cue/distractor lateral—contralateral and ipsilateral. Contralateral minus ipsilateral difference waveforms were also calculated at channel pair PO7/PO8.

On the basis of prior studies in our laboratory, we measured the N2pc as the mean amplitude between 200 and 300 msec after search array onset (Salahub & Emrich, 2020; Salahub, Lockhart, Dube, Al-Aidroos, & Emrich, 2019). If suppression occurs before attentional selection, then we would predict an early P_D to the lateral distractor before the N2pc (100–200 msec; similar to Sawaki & Luck, 2010). If suppression occurs after attentional capture, then we would predict a later P_D after the N2pc, from 300 to 400 msec. To reduce the chance of a Type I error for significant effects, we also conducted a signed-area permutation analysis on the late P_D during a wider time window (see Permutation Analysis below; Gaspar & McDonald, 2018; Gaspelin & Luck, 2018b).

Data Analysis

Statistical analyses were completed using JASP Version 0.12 (JASP Team, 2020) and custom scripts in MATLAB R2017a (The MathWorks). For the behavioral analyses, trial RTs greater or less than 3 SDs from that participant's mean were removed ($M = 1.5\%$, $SD = 3\%$). Incorrect and no response trials were also excluded from both the behavioral and ERP analyses ($M = 8\%$, $SD = 5\%$). All analyses involving behavioral data and anxiety scores have an n of 47 because of a computer saving error for one participant. Outlier ERP amplitudes that were greater or less than 3 SDs from the condition mean were removed;

however, the pattern of results was similar with outliers included. After artifact removal, any participant whose ERP data had less than 90 trials in any condition ($n = 4$) or less than 100 trials in more than two conditions ($n = 1$) was replaced. There were, on average, 132 trials per condition.

To determine whether a component was present or absent, we first performed a 2 (Contralateral/Ipsilateral) × 2 (Target/Distractor Lateral) × 3 (Cue Type) repeated-measures ANOVA. Next, to examine whether Cue type differentially affected target lateral and distractor lateral trials, we conducted two separate one-way repeated-measures ANOVAs with the three levels of Cue type. Greenhouse–Geisser corrected degrees of freedom and p values are reported wherever sphericity was violated. Post hoc t tests were Holm corrected. Bayes factors for repeated-measures ANOVAs are compared with the null model, with an r scale prior width of 0.5, default Cauchy prior centered on 0, and 10,000 Monte Carlo samples.

Spearman's rho (two-tailed) was used for correlations between anxiety scores and ERP amplitudes. We used the *robustcorrtool* toolbox in MATLAB to test multivariate assumptions and conduct robust correlation methods (Pernet, Wilcox, & Rousselet, 2013; Rousselet & Pernet, 2012; Wilcox, 1994, 2004). Multivariate normality was assessed using the Henze–Zirkler test, and homoscedasticity was tested by examining the 95% confidence intervals of a percentile bootstrap on the difference between variances (*variance_homogeneity.m*; Pernet et al., 2013). For all correlations, we found that the multivariate data were nonnormally distributed, $p_{hzs} < .001$, and heteroscedastic. To correct for these assumption violations, we rank-transformed the data (*tiedrank.m*) as was done in similar studies that examined correlations with anxiety scores (Stout, Shackman, Johnson, & Larson, 2015; Stout et al., 2013). After this correction, the data met the assumptions of normality and homoscedasticity. For all significant correlations, we also analyzed Spearman's skipped correlation and the 20% percentage bend correlation. These analyses minimize the effect of both bivariate and multivariate outliers on r values and significance testing (Pernet et al., 2013).

Permutation Analysis

To reduce the chance of a false positive because of the choice of measurement window from the grand-averaged waveform (Luck & Gaspelin, 2017), we conducted a signed-area permutation analysis on the late P_D during a wide time window (positive area only: 250–400 msec). We did not conduct a permutation test on the early P_D, as this component was not significant in the main analysis. In addition, because the N2pc is more temporally consistent than the P_D, we did not conduct the permutation analysis on the N2pc time window (Gaspelin & Luck, 2018a).

In the permutation analysis, the positive area measurement will never be less than 0, so a nonparametric permutation approach must be used to determine whether the P_D was greater than chance in each condition (Gaspelin & Luck, 2018b; Sawaki et al., 2012). This method estimates a null distribution from the noise inherent in the difference waveform by randomizing the left/right trial labels within each condition and then measuring the positive area from the noise-only difference waveform. One thousand permutations were completed and then compared with the observed values from the grand-averaged waveform. The p values were then calculated as

$$p = \frac{\text{Number of permuted positive areas} \geq \text{Observed positive area}}{1000}$$

RESULTS

Behavioral

To assess the effect of Cue type on search speed, we first compared search RTs for each cue condition. There was an overall main effect of Cue type, $F(1.39, 64.12) = 90.75$, $p <$ .001, $\eta_p^2 = .66$, $BF_M = 1.36^{19}$, such that mean RTs were faster after a positive cue ($M = 731$ msec, $SD = 100$ msec) than a neutral cue ($M = 791$ msec, $SD = 94$ msec), $t(46) = 11.34$, $p_{\text{Holm}} < .001$, $d = 1.66$, $BF_{10} = 1.03^{12}$, or a negative cue ($M = 795$ msec, $SD = 97$ msec), $t(46) = 11.97$, $p_{\text{Holm}} < .001$, $d = 1.75$, $BF_{10} = 4.97^9$. However, there was not a significant difference between RTs in the neutral and negative cue conditions, $t(46) = 0.62$, $p_{\text{Holm}} = .54$, $d = 0.09$, $BF_{10} = 0.24$. Neither state nor trait anxiety correlated with RTs in any cueing condition, rs $< .22$, ps $> .15$.

Kerzel and Burra (2020) proposed that, in small search displays, participants may systematically search lateral positions before vertical positions, even when the lateral item is a distractor. To examine this possibility, we compared RTs with lateral targets versus vertical targets in a 2 (Target Position) × 3 (Cue Type) repeated-measures ANOVA. Both main effects were significant, Fs > 6, ps $<$ .01, η_p^2s $> .1$, as well as the interaction, $F(1.6, 73.3) = 4.82$, $p = .017$, $\eta_p^2 = .1$, $BF_M = 1.13$. Contradictory to the scan path hypothesis, there was no significant difference in RTs between lateral and vertical targets after a positive or negative cue, ts < 1.5, $p_{\text{Holm}} > .7$. However, in the neutral condition, RTs were 15 msec faster toward a vertical
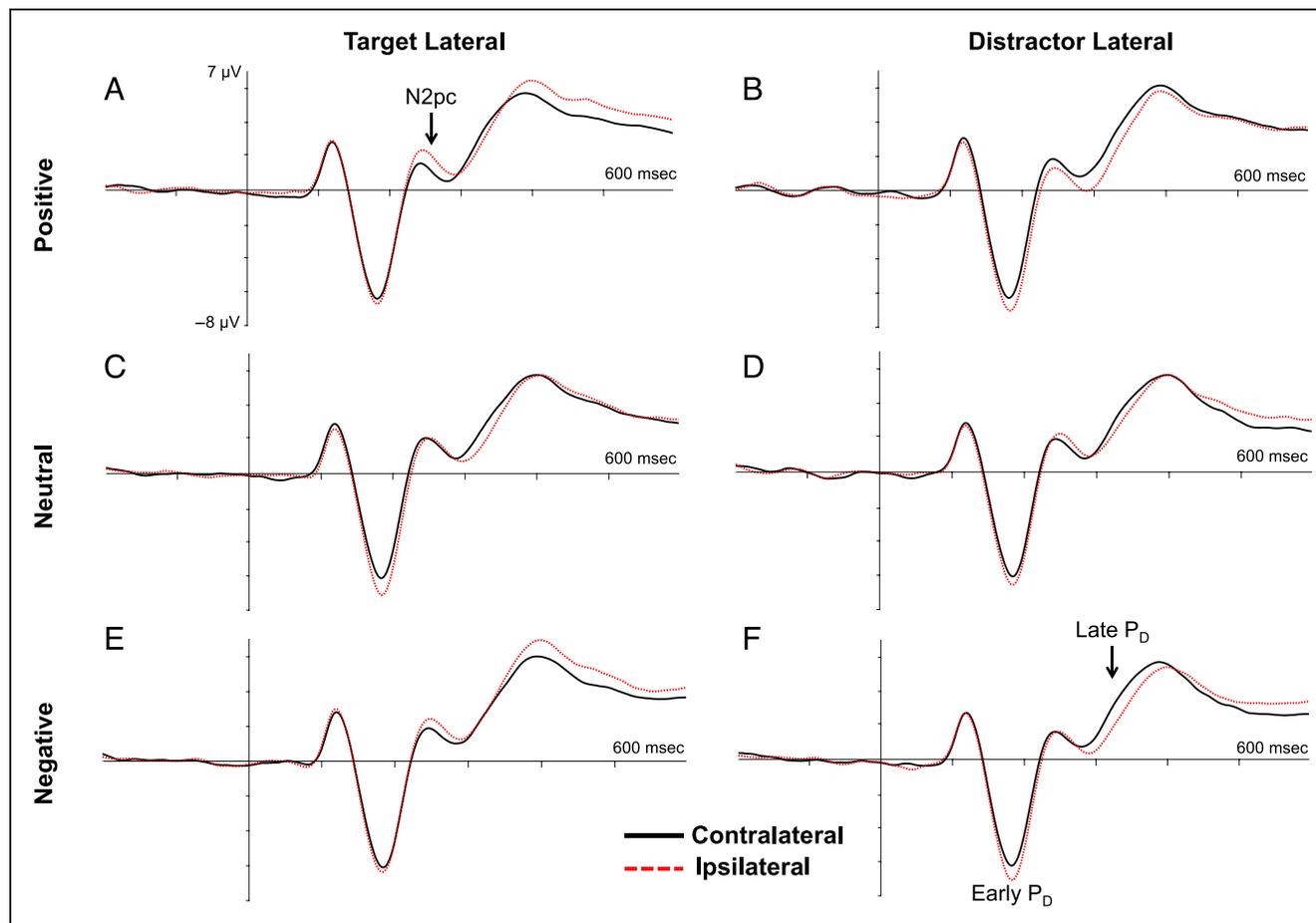

Figure 2. Contralateral (black solid lines) and ipsilateral (red dashed lines) waveforms, in reference to the lateral item, at channel pair PO7/PO8 for each condition. (A) Positive cue condition, lateral target. (B) Positive cue condition, lateral distractor. (C) Neutral cue condition, lateral target. (D) Neutral cue condition, lateral distractor. (E) Negative cue condition, lateral target. (F) Negative cue condition, lateral distractor.

target than a lateral target, $t = 3.5$, $p_{\text{Holm}} = .005$ (opposite to predictions). Overall, we do not find evidence to support the idea that participants were systematically scanning items opposite to the search item first.

Early P_D (100–200 msec)

Figures 2 and 3 display the grand-averaged contralateral/ipsilateral waveforms and the difference waveforms for each condition, respectively. One outlier value was removed from the negative, distractor-lateral, contralateral condition. However, the pattern of results remains similar with the outlier included.

To determine whether this early component was statistically present, we conducted a 2 (Contralateral/Ipsilateral) × 2 (Target/Distractor Lateral) × 3 (Positive, Neutral, or Negative Cue Condition) repeated-measures ANOVA on the mean amplitude. There was a main effect of Contralateral/Ipsilateral activity, such that the mean ipsilateral voltage (M_M ipsilateral = $-1.87\,\mu V$, 95% CI [-2.63, -1.11]) was more negative than the mean contralateral voltage (M_M contralateral = $-1.65\,\mu V$, 95% CI [-2.41, -0.88]), $F(1, 47) = 29.11$, $p < .001$, $\eta_p^2 = .38$. However, there was not a significant interaction between mean Contralateral/Ipsilateral voltage and any other factor, $Fs < 2.8$, $ps > .1$. The Bayesian model with only Contralateral/Ipsilateral as a factor was the most supported, $\text{BF}_M = 55.78$ versus $\text{BF}_{Ms} < 2$. These results suggest that the early P_D did not differ in
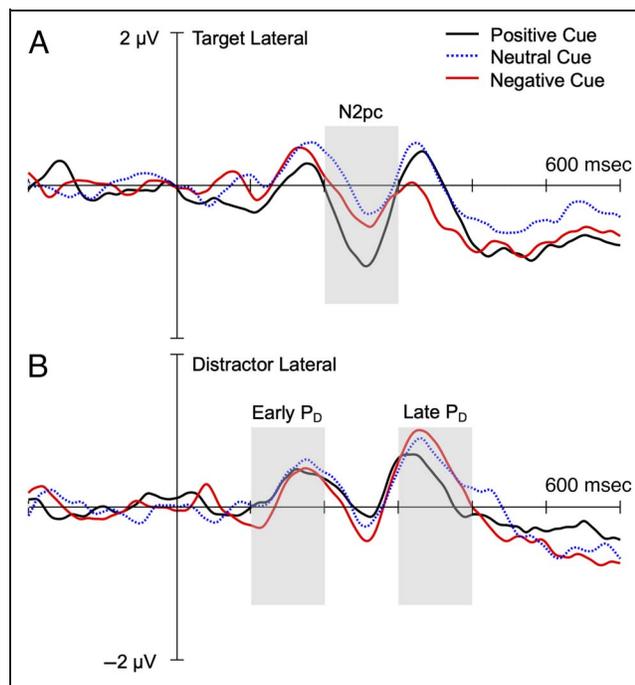
Figure 3. Grand-averaged difference waveforms at channel pair PO7/PO8 in the (A) target lateral and (B) distractor lateral conditions. Solid black lines = positive cue; dashed blue lines = neutral cue; solid red lines = negative cue. Waveforms are filtered at 30 Hz for illustrative purposes only.

amplitude whether a target or distractor was presented laterally, nor by Cue type.

N2pc (200–300 msec)

A 2 (Contralateral/Ipsilateral) × 2 (Target/Distractor Lateral) × 3 (Cue Type) repeated-measures ANOVA was conducted on the mean amplitude between 200 and 300 msec. There were nonsignificant main effects of Contralateral/Ipsilateral, whether the target or distractor was lateral, and Cue type, $Fs < 2.7$, $ps > .1$, $\eta_p^2 s < .06$. Cue type did not significantly interact with whether the target or distractor was presented laterally, $F(2, 92) = 0.49$, $p = .616$, $\eta_p^2 = .01$. There was a significant interaction between Cue Type and Contralateral/Ipsilateral activity, $F(2, 92) = 3.28$, $p = .042$, $\eta_p^2 = .067$. However, no post hoc t tests were significant after correcting for multiple comparisons, $p_{\text{Holm}} > .23$. In addition, there was a significant interaction between whether the target or distractor was lateral and contralateral/ipsilateral activity, $F(1, 46) = 19.68$, $p < .001$, $\eta_p^2 = .3$. However, there was also a three-way interaction between all factors, $F(2, 92) = 7.27$, $p = .001$, $\eta_p^2 = .14$. After a positive cue, the lateral target contralateral activity was significantly more negative than the lateral target ipsilateral activity, $t = -5.41$, $p_{\text{Holm}} < .001$. No other post hoc comparisons were significant, $ts < 3$, $p_{\text{Holm}} > .1$. Therefore, an N2pc was only present in the positive-cue, target lateral condition ($M = -0.58\,\mu V$, $SD = 0.78\,\mu V$; Figure 3A). The model that received the most support from the Bayesian analysis included target/distractor laterality alone, $\text{BF}_M = 7.06$. However, the model with contralateral/ipsilateral and target/distractor laterality as well as the interaction between these two factors also received similar support, $\text{BF}_M = 6.76$. Importantly, these results suggest that the lateral distractor did not elicit an N2pc, in disagreement with the "search and destroy" mechanism of negative templates.

To examine whether Cue type had a distinct effect on lateral target versus lateral distractor trials, we conducted two separate repeated-measures ANOVAs. Considering the target lateral trials only, there was a significant effect of Cue Type on mean amplitudes, $F(2, 90) = 7.55$, $p < .001$, $\eta_p^2 = .14$, $\text{BF}_{10} = 44.13$, such that amplitudes were more negative after a positive cue ($M = -0.58\,\mu V$, $SD = 0.78\,\mu V$) than a negative cue ($M = -0.20\,\mu V$, $SD = 0.84\,\mu V$) or a neutral cue ($M = -0.05\,\mu V$, $SD = 0.69\,\mu V$), $ts > 2.8$, $ds > 0.41$, $p_{\text{Holm}} < .012$, $\text{BF}_{10s} > 4.3$. There was no difference in target amplitude between the negative and neutral cue conditions, $t(45) = 0.91$, $d = 0.14$, $p_{\text{Holm}} = 0.36$, $\text{BF}_{10} = 0.24$. For the lateral distractor trials, there was not a significant effect of Cue Type, $F(2, 94) = 0.84$, $p = .44$, $\eta_p^2 = .02$, $\text{BF}_{10} = 0.14$. Therefore, an N2pc was only elicited toward a lateral target after a positive cue.

Late P_D (300–400 msec)

The 2 × 2 × 3 repeated-measures ANOVA showed a significant main effect of Contralateral/Ipsilateral activity,

$F(1, 47) = 9.18, p = .004, \eta_p^2 = .16$. In addition, there was an effect of Cue Type, $F(2, 94) = 3.85, p = .025, \eta_p^2 = .08$, but no effect of Target/Distractor Laterality, $F(1, 47) = 2.32, p = .134, \eta_p^2 = .05$. Contralateral/Ipsilateral activity interacted with whether the target or distractor was presented laterally, $F(1, 47) = 23.88, p < .001, \eta_p^2 = .34$. Distractor lateral contralateral amplitudes were more positive than ipsilateral amplitudes, $t = 5.5, p_{Holm} < .001$. There was not a significant difference between contralateral and ipsilateral amplitudes when the target was on the lateral, $t = -0.95, p_{Holm} = .92$. This suggests that the late P_D was present only when the distractor was presented laterally, not the target.

Importantly, there was also a significant three-way interaction, $F(2, 94) = 4, p = .022, \eta_p^2 = .08$, such that there was a significant positivity in the lateral distractor condition after a negative cue, $t = 4.68, p_{Holm} < .001$, and after a neutral cue, $t = 4.24, p_{Holm} = .002$, but not after a positive cue, $t = 2.36, p_{Holm} = .889$. No other conditions had a significant difference between contralateral and ipsilateral amplitudes, $ts < 2.7, ps_{Holm} > .4$. The model that received the most support from the Bayesian analysis included the three main effects and the interaction term between Contralateral/Ipsilateral × Target/Distractor Laterality, $BF_M = 36.26$. These findings suggest that there was a significant late P_D for lateral distractors after a neutral or negative cue, but not after a positive cue.

The permutation analysis found that the mean signed positive area was significantly greater than noise in all of the lateral distractor conditions: $p_{negative} < .001, p_{positive} = .003$, and $p_{neutral} = .005$. There was a marginally significant difference from noise in the positive- and neutral-cue target lateral conditions, $p_{positive} = .048$ and $p_{neutral} = .025$. This is likely because of the larger measurement window and may reflect suppression of the target after initial processing (see Discussion).

To examine how Cue Type differentially affected processing of targets and distractors, we conducted two separate repeated-measures ANOVAs. Mean amplitudes for lateral targets were affected by Cue Type, $F(2, 92) = 4.25, p = .017, \eta_p^2 = .09, BF_{10} = 2.69$. Amplitudes were more negative after a negative cue ($M = -0.34$ μV, $SD = 1.02$ μV), than after a neutral cue ($M = 0.16$ μV, $SD = 0.71$ μV), $t(47) = 2.81, p_{Holm} = .018, d = 0.41, BF_{10} = 10.51$. There was no statistical difference in target-related amplitudes between the negative and positive cue conditions, $t(47) = 2.08, p_{Holm} = .082, BF_{10} = 0.82$, or the neutral and positive conditions, $t(47) = 0.74, p_{Holm} = .46, BF_{10} = 0.21$. Cue type did not affect lateral distractor amplitudes, $F(2, 94) = 1.84, p = .17, \eta_p^2 = .04, BF_{10} = 0.36$. As a whole, these results suggest that lateral distractors elicited late P_Ds in all cue conditions, and there is some evidence for an increased negativity toward the lateral target after a negative cue during this later time window. As observed in prior studies, this negative-going component may be a delayed target N2pc (Berggren & Eimer, 2021; Carlisle & Nitka, 2019; see Discussion).

## Anxiety Correlates with Attentional Capture by Negatively Cued Distractors

Although the whole-group results provide evidence for late suppression of template-matching distractors, it is possible that there are individual differences in inhibitory ability. To this end, we examined Spearman's rho correlations between anxiety scores and mean amplitudes of all three ERP time windows.

There was a significant correlation between state anxiety scores and early P_D amplitudes toward the lateral distractor after a negative cue, $r_s = -.361, p = .013$, 95% CI [$-0.59, -0.08$] (Figure 4; $n = 47$). That is, the more anxious an individual was during the testing session, the smaller his or her early P_D amplitudes to the negatively cued, lateral distractor. Spearman's skipped correlation was significant at an alpha of 5%, $r_{ss} = -.361, t = -2.6$, 95% CI [$-0.59, -0.04$]. The 20% percentage bend correlation was also significant, $r_{pb} = -.330, p_{pb} = .024$, 95% CI [$-0.57, -0.04$]. There were no other significant correlations between early P_D amplitudes in any other condition and state or trait anxiety, $r_s < .2, ps > .18$.

During the N2pc time window, we found that neither state nor trait anxiety correlated with the target-elicited N2pc amplitude after any of the cue types, $r_s < .14, ps > .3$. However, state anxiety did correlate with mean amplitude toward the lateral distractor after a negative cue, such that greater anxiety scores predicted larger distractor-elicited N2pcs, $r_s = -.364, p = .012$, 95% CI [$-0.59, -0.09$] (Figure 5A; $n = 47$). This distractor-related correlation was not observed in the positive cue condition ($r_s = -.08, p = .60$) or the neutral cue condition ($r_s = -.06, p = .67$). The Spearman skipped correlation was significant at an alpha of 5%, $r_{ss} = -.364, t = -2.62$, 95% CI [$-0.58, -0.11$]. The percentage bend correlation (20%) was also significant, $r_{pb} = -.370, p_{pb} = .010$, 95% CI [$-0.59, -0.07$]. There were no significant correlations between N2pc amplitudes and trait anxiety, $r_s < .25, ps > .09$. An
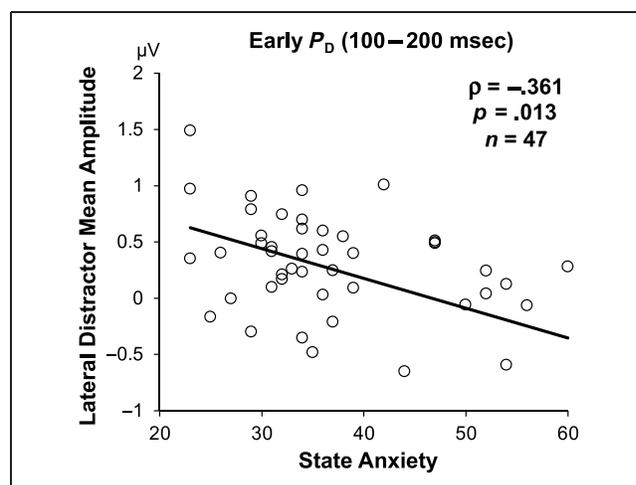
Figure 4. Spearman's rho correlation (two-tailed) between state anxiety scores and mean early P_D amplitudes (100–200 msec) toward a negatively cued lateral distractor ($n = 47$).
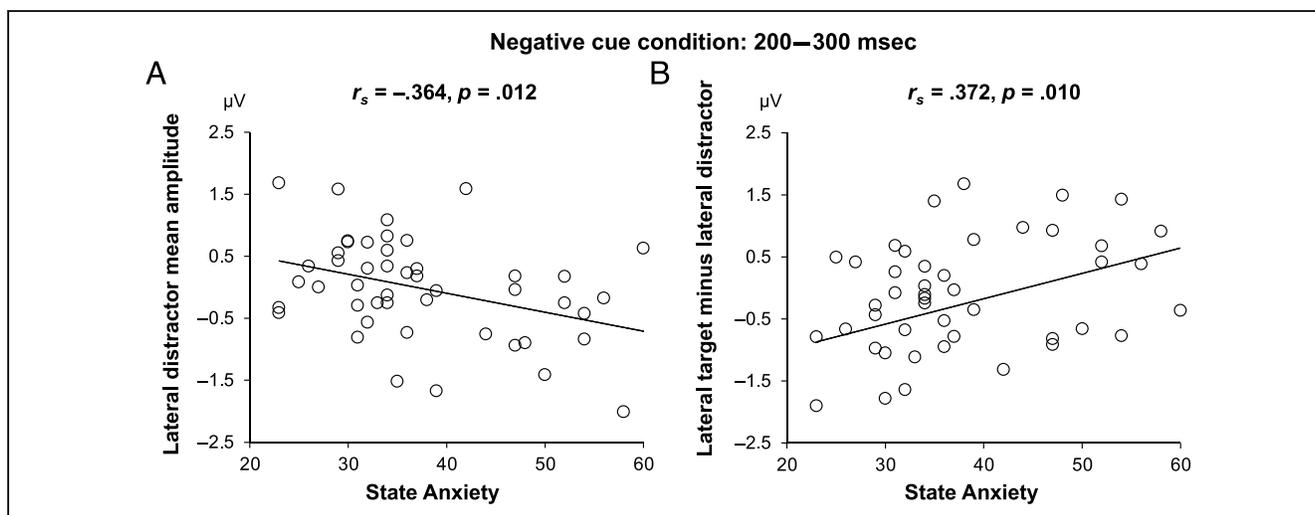
Figure 5. Spearman's rho correlations (two-tailed) between state anxiety scores and mean amplitudes (200–300 msec) in the negative cue condition. (A) Mean amplitudes toward the lateral distractor. (B) Mean amplitudes toward the lateral target minus the lateral distractor. More negative values reflect greater negativity (N2pc) toward the target than the distractor. $n = 47$.

exploratory median split analysis on state anxiety scores ($n = 47$) showed that, in the negative-cue, distractor lateral condition, individuals with higher anxiety scores had a more negative deflection during this time window ($M = -0.29$ μV, $SD = 0.85$ μV), whereas individuals with lower anxiety scores had a more positive deflection ($M = 0.27$ μV, $SD = 0.64$ μV), $t(46) = 2.55$, $p = .014$, $d = 0.74$, $BF_{10} = 3.71$.

Furthermore, we looked at the difference score between the negative-cue, lateral target minus lateral distractor conditions, which indicates whether participants were paying more attention to the lateral target versus the lateral distractor. We found that individuals with higher anxiety scores had larger N2pcs toward the lateral distractor than to the target, $r_s = .372$, $p = .01$, 95% CI [0.1, 0.6] (Figure 5B; $n = 47$). The Spearman skipped correlation was significant, $r_{ss} = .372$, $t = 2.69$, 95% CI [0.09, 0.6], as was the percentage bend correlation, $r_{pb} = .347$, $p_{pb} = .017$, 95% CI [0.06, 0.59].

Finally, we examined how suppression-related activity after the N2pc was related to anxiety scores. There was a significant correlation between state anxiety and mean amplitude toward the negatively cued, lateral distractor, $r_s = -.306$, $p = .037$, 95% CI [−0.55, −0.02]. The Spearman skipped correlation was significant, $r_{ss} = -.306$, $t = -2.16$, 95% CI [−0.55, −0.005]. However, the percentage bend correlation was not significant, $r_{pb} = -.285$, $p_{pb} = .052$, 95% CI [−0.055, −0.007]. Thus, although this correlation with state anxiety followed the same pattern as seen for the other time windows, it was overall less robust. No other correlations between state/trait anxiety and late P_D amplitudes were significant, $r_s < .26$, $ps > .09$.

Given that a similar pattern of correlations was observed between state anxiety and ERP amplitudes at all three time points, it could be that there was a systematic bias in ERP amplitudes for high-anxiety versus low-anxiety individuals.

To rule out this alternative, we measured mean amplitudes from 0 to 100 msec in each condition and correlated these values with state anxiety. If high-anxiety participants had more negative ERP amplitudes than low-anxiety participants by chance, then there should be a significant correlation during this very early time window. However, none of these correlations was significant, $r_s < .25$, $ps > .097$. In addition, the robust correlations were not significant, $rs < .25$, $ps > .12$, $ts < 1.7$, 95% CIs all encompassed 0. Importantly, the correlation between state anxiety and mean amplitude in the negative-cue, lateral distractor condition was not significant, $r_s = -.136$, $p = .362$, suggesting that the relationship between anxiety and ERP amplitudes emerged after 100 msec.

DISCUSSION

In this study, we aimed to examine the neural time course of selection and suppression of distractors given positive and negative attentional templates. In particular, we were interested in whether this time course varied across individuals, according to their levels of anxiety. Indeed, we found evidence for both early and late suppression of lateral distractors and that these attentional mechanisms differed by an individual's level of anxiety. That is, individuals with greater anxiety scores were more likely to attend negatively cued distractors, whereas individuals with lower anxiety levels could avoid attentional capture by the template-matching distractor.

Our conceptualization of the time course of suppression is based on two competing hypotheses about the attentional mechanisms of negative cues: the early suppression account (Zhang, Gaspelin, & Carlisle, 2019; Gaspelin & Luck, 2018a) and the search and destroy account (Moher & Egeth, 2012). If individuals can suppress negatively cued distractors, then we would predict no distractor-elicited N2pc and

a P_D either before or during the time range of the N2pc. Conversely, if individuals were initially attending the distractor, then we would predict no P_D but rather a distractor-elicited N2pc (search) followed by a later P_D (destroy).

Counter to the search and destroy account of negative templates, we did not find an N2pc toward the negatively cued distractor in the full sample, suggesting that participants did not initially search for the distractor feature. This finding is in agreement with several previous ERP studies, which did not find a distractor-elicited N2pc after a negative cue (Berggren & Eimer, 2021; Carlisle & Nitka, 2019). However, we did find some evidence for an attentional shift toward the lateral target, which was about 100 msec later than target selection after the positive cue (i.e., during the time range of the "late P_D"). This negativity did not appear to be as peaked as a typical N2pc, which may reflect increased between-participant or trial-by-trial variability. This delayed target N2pc after negative cues is in agreement with prior studies and may explain why we did not observe an RT benefit after negative templates, nor a target-related late P_D (Berggren & Eimer, 2021; Carlisle & Nitka, 2019). However, it is also possible that we did not observe a behavioral benefit after negative cues because the search task was not sufficiently difficult—making it not "worth it" for participants to use these counterintuitive cues (Rajsic, Carlisle, & Woodman, 2020; Heuer & Schubö, 2019). For example, it has been found that individuals only use negative cues when the search array consists of larger set sizes (>4 items) or high target/distractor similarity (Conci, Deichsel, Müller, & Töllner, 2019; Arita et al., 2012). In addition, it may be that negative cue benefits only emerge when the nontarget feature is consistent over time, reflecting a passive habituation process (Berggren & Eimer, 2021; Chelazzi, Marini, Pascucci, & Turatto, 2019). Further research is needed to understand the conditions under which negative templates are used to improve performance as well as the electrophysiological correlates of performance benefits.

The target-elicited N2pc was present only in the positive cue condition. The absence of a target N2pc after a negative cue suggests that negative cues were less effective in guiding attention, consistent with slower RTs after negative cues. Contrary to prior studies, we did not observe a significant N2pc toward the lateral target in the neutral cue condition (Gaspar & McDonald, 2018; Hilimire, Mounts, Parks, & Corballis, 2011). Here, on neutral cue trials, participants had to attend to both locations (lateral and vertical) to determine the orientation of the target line. Therefore, participants may have attended both colored items in parallel—a strategy that reduces the amplitude of lateralized components (Eimer & Grubert, 2014). However, it is unlikely that participants kept this diffuse state of attention after positive cues, as there was evidence of a target-related N2pc. Regardless, the overall task may have been easy enough for some participants to maintain a diffuse state of attention, such

that they did not use the cues at all. Future studies on negative templates should ensure that the search task is difficult enough that it cannot be completed without drawing attention to the cued features.

Although we did not find a significant difference in early P_D amplitudes across conditions, the late P_D was present when the distractor was presented on the lateral. This suggests that, across all participants, the distractor was being suppressed after the time window of the N2pc. However, during the later time window, we also observed a target-related P_D in the positive and neutral conditions, as determined by the signed area measurements. Although this may seem contradictory, there is evidence that this positivity can also reflect the termination of attention after initial selection (Sawaki et al., 2012). This pattern has been likened to inhibition of return (Posner & Cohen, 1984), such that once the target is selected, it is subsequently suppressed so that search does not return to that location in the future. This positivity was not present for the negatively cued target, likely because of the delayed target-elicited N2pc during this time window (Carlisle & Nitka, 2019).

Considering individual differences in anxiety, we predicted that individuals with greater levels of anxiety would have deficits in their ability to suppress negatively cued distractors, because of impaired attentional control. Behaviorally, we did not find an effect of anxiety on accuracy or RTs, suggesting that anxious individuals performed as well on the task as their less anxious counterparts (Gaspar & McDonald, 2018; Berggren & Derakshan, 2013). In line with the attentional control theory of anxiety, it could be that the present task was not difficult enough to elicit performance deficits, and anxious individuals used compensatory strategies to overcome their biases in attention (Berggren & Derakshan, 2013; Eysenck et al., 2007). In particular, given that the present sample consisted of individuals who were not clinically diagnosed with an anxiety disorder, this could explain why the observed neural attentional control deficits did not correlate with behavioral performance.

Despite not finding a behavioral effect of anxiety, we did observe that individuals with greater state anxiety levels had both reduced early P_D amplitudes and larger early N2pcs toward the negatively cued distractor than individuals with lower anxiety scores. Indeed, during the time window of the N2pc, individuals with lower state anxiety scores were more likely to have positive amplitudes. In fact, the exploratory median split analysis on state anxiety scores showed that individuals with higher levels of anxiety had a mean amplitude of -0.29 µV during the N2pc time window, compared with 0.27 µV for individuals with lower levels of anxiety. This suggests that individuals low in anxiety were capable of actively suppressing the negatively cued distractor, reflected by a more positive waveform, whereas individuals with higher anxiety scores were attending the distractor instead. Therefore, the search and destroy mechanism

of negative templates may only arise when attentional control abilities are depleted, such as in anxiety.

Similar to the N2pc findings, we found a significant correlation between early P_D amplitudes and state anxiety. However, the underlying cognitive process reflected by this early positivity remains contested. Weaver, van Zoest, and Hickey (2017) found that an early P_D (148–158 msec) predicted the accuracy of subsequent target saccades and proposed that this component reflects distractor inhibition. It is also possible that this early positivity marks a passive, sensory-related process (Jannati et al., 2013; Corriveau et al., 2012; Fortier-Gauthier, Moffat, Dell'Acqua, McDonald, & Jolicœur, 2012). For example, the positivity posterior contralateral occurs during a similar time range as the early P_D and is thought to reflect bottom–up processing of a salient stimulus, regardless of its task relevance (Corriveau et al., 2012). Here, the search display was identical across conditions, such that there was always a colored ring in a lateral and vertical position, inconsistent with sensory interpretation of the P_D. Despite this, the finding that the amplitude of the early P_D did not differ in amplitude across conditions suggests that it is perhaps unrelated to distractor processing and may instead reflect a sensory-driven process. If so, why did we find a robust correlation between state anxiety and early P_D amplitudes in the negative cue condition? We cannot rule out that this correlation is driven by the larger, distractor-related N2pc in individuals with high anxiety levels. Yet, it remains possible that anxiety impacts early visual activity before attention is deployed, perhaps reflecting greater arousal or vigilance, such as seen in stress (Shackman, Maxwell, McMenamin, Greischar, & Davidson, 2011). Further research is needed to determine whether the early positivity observed here reflects active suppression or passive, sensory-related activity.

Contrary to previous studies, we did not find any significant correlations with trait anxiety, only state anxiety. It has been suggested that state anxiety is more closely linked to attentional alerting and orienting, whereas trait anxiety is related to deficits in executive control (Crocker et al., 2012; Pacheco-Unguetti, Acosta, Callejas, & Lupiáñez, 2010). Therefore, the anxiety-related correlations observed here likely resulted from increased alerting toward negatively cued distractors. This increased alerting may be driven by greater perceived "threat" by the negatively cued distractor in individuals with higher levels of anxiety, as the distractor poses an obstacle to performing well in the task (Gaspar & McDonald, 2018). That is, knowing the distractor color in advance, and holding it in visual working memory (VWM), may have increased both perceived salience and threat of the cued feature. Indeed, it has been found that attention is automatically drawn to items held in VWM (Soto, Hodsoll, Rotshtein, & Humphreys, 2008). Therefore, the present findings suggest that individuals with higher anxiety levels have less control over capture by the contents of VWM than their less anxious counterparts, but only when the item held in memory is a distractor.

In contrast to the findings by Gaspar and McDonald (2018), we did not find a significant correlation between anxiety and distractor-elicited N2pc amplitudes in the positive cue condition, only in the negative cue condition. This could be because of differences in methodology between studies. Here, negative cue trials were interspersed with positive and neutral cue trials, preventing participants from building up a strategy over time (Noonan et al., 2016). Therefore, in the context of all three cue conditions, the negative cue may have felt the most difficult to use. This may be particularly true for individuals with anxiety, who already have inhibitory deficits that are more pronounced when greater demands are placed on cognitive control resources (Berggren, Richards, Taylor, & Derakshan, 2013; Berggren, Koster, & Derakshan, 2012; Derakshan, Smyth, & Eysenck, 2009). In addition, Gaspar and McDonald (2018) designed their stimulus display such that the distractor was consistently more salient than the target. That is, a red target among green nontargets is less salient than a yellow distractor among green nontargets (Gaspar, Christie, Prime, Jolicœur, & McDonald, 2016; Gaspar & McDonald, 2014). Here, the color of the target and distractor varied on each trial, such that averaged across all trials, the target and distractor should have been equivalent in salience. If individuals with high levels of anxiety are only captured by salient distractors, then this could be why we did not observe a correlation between anxiety and N2pc amplitudes in the positive cue condition. Conversely, in the negative cue condition, the distractor feature could have been made more salient by consequence of holding it in VWM. Therefore, our choice to vary target and distractor features on a trial-by-trial basis may explain why we did not observe a correlation between anxiety scores and distractor-elicited N2pc amplitudes in the positive cue condition.

Overall, the present results are consistent with previous findings that negative templates do not initially draw attention toward distractors (Berggren & Eimer, 2021; Carlisle & Nitka, 2019). However, we add the caveat that this only holds true for individuals who have sufficient levels of attentional control; as without these attentional control abilities, distractors capture attention instead. We propose that there is not a universal mechanism for negative templates and that individual differences in anxiety affect how search templates are used. These individual differences may partially explain the contradictory behavioral findings on negative cue benefits and are important to consider in cognitive tasks involving attentional control.

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Diversity in Citation Practices

A retrospective analysis of the citations in every article published in this journal from 2010 to 2020 has revealed 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(an)/M = .408, W(oman)/M = .335, M/W = .108, and W/W = .149, the comparable proportions for the articles that these authorship teams cited were M/M = .579, W/M = .243, M/W = .102, and W/W = .076 (Fulvio et al., *JoCN*, 33:1, pp. 3–7). 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. The authors of this article report its proportions of citations by gender category to be as follows: M/M = .549, W/M = .255, M/W = .137, and W/W = .059.

Open Practices Statement

All EEG and behavioral data, as well as analysis and task scripts, are available on the Open Science Framework at osf.io/5ak2y/. This experiment was not formally preregistered.

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