High level of trait anxiety leads to salience-driven distraction and compensation

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Author Notes

This study was supported by the Natural Sciences and Research Council of Canada, Canadian Foundation for Innovation, and the Canada Research Chairs program (to J.J.M.).

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Author Contributions

Both authors contributed to the design of the experiment and the writing of the manuscript. J. M. Gaspar performed the experiments and analyzed the data.

Abstract

Individuals with high levels of anxiety are hypothesized to have impaired executive control functions that would otherwise enable efficient filtering of irrelevant information. Pinpointing specific deficits is difficult, however, because anxious individuals may compensate for deficient control functions by allocating greater effort. Here, we used event-related potential (ERP) indices of attentional selection (the N2pc) and suppression (the P_D) to determine whether high trait anxiety is associated with a deficit in preventing the misallocation of attention to salient, but irrelevant, visual-search distractors. Like their low-anxiety counterparts (N=19), anxious individuals (N=19) were able to suppress the distractor, as evidenced by the presence of a P_D. Critically, however, the distractor was found to trigger an earlier N2pc in the high-anxiety group but not in the low-anxiety group. These findings indicate that, whereas low-anxiety individuals can prevent distraction in a proactive fashion, anxious individuals deal with distractors only after they have diverted attention.

Keywords

Anxiety, distraction, visual search, suppression, event-related potentials, N2pc, P_D.

High levels of trait anxiety have long been associated with the preferential biasing of attention toward threat-related information, even when this information is known to be irrelevant to the task at hand (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg & van IJzendoorn, 2007). Highly anxious individuals appear to have an impaired ability to filter out emotionally salient information, and consequently, they are more likely to inadvertently attend to threatening stimuli (Eimer and Kiss, 2007; Fox, Russo & Georgiou, 2005; McTeague, Shumen, Wieser, Lang & Keil, 2011; Moser, Becker & Moran, 2012). It has been proposed that this filtering deficit may play a causal role in the etiology and maintenance of clinical anxiety disorders. Specifically, additional processing of emotionally salient information may serve to promote the intrusive thoughts, heightened rumination, and other anxiety-related behaviours that are typically associated with affective pathologies (Wadlinger & Isaacowitz, 2010).

Although trait anxiety is usually linked to impaired filtering of emotionally salient stimuli, the impairment might also influence the way individuals process emotionally neutral stimuli. Consistent with this notion, highly anxious individuals are slower to initiate anti-saccades away from emotionally neutral stimuli (Derakshan, Ansari, Hansard, Shoker & Eysenck, 2009; Wieser, Pauli, Alpers, & Mühlberger, 2009) and take longer to search for visual targets that are presented alongside perceptually salient distractors (Moran & Moser, 2015; Moser et al. 2012; Moser, Moran & Leber, 2015). Such findings are broadly consistent with the *attentional control theory* of anxiety, which states that anxiety impairs two top-down control processes: (i) inhibitory processes that would otherwise resist disruption by task-irrelevant stimuli, and (ii) shifting processes that enable rapid changes in attentional control (Derakshan & Eysenck, 2009; Eysenck, Derakshan, Santos & Calvo, 2007).

While trait anxiety appears to disrupt attention control in some behavioural tasks, the specific attention processes that are impaired remain poorly understood. In particular, it is unclear whether the performance impairments in anxious individuals reflect failures to prevent stimulus-driven attention capture or to recover from capture in a timely fashion. Moreover, it has been hypothesized that anxious individuals compensate for top-down attention control deficits by investing more attentional resources in the task at hand and can perform as well as low-anxiety individuals on many tasks (Eysenck et al. 2007). Thus, measures of behavioural performance are not accurate indicators of a specific attention deficit.

Here, we recorded event-related potentials (ERPs) to track processing of a salient but irrelevant distractor in a visual search task. A 40-item self-evaluation anxiety questionnaire (the State-Trait Anxiety Inventory; STAI; Spielberger, Gorsuch, Lushene, Vagg. & Jacobs, 1983) was used to prescreen potential participants for the study. Individuals whose trait anxiety scores were among the highest and lowest were invited to participate in the experiment. Participants searched for a colour-singleton target and attempted to ignore a more salient color-singleton distractor that was present on half the trials (Figure 1a). Distractor processing was then assessed by isolating ERP components associated with attentional selection (N2pc; Luck and Hillyard, 1994) and suppression (the P_D; Hickey, Di Lollo & McDonald, 2009; Gaspar & McDonald, 2014). If anxious individuals have impaired attention control, then the high-anxiety individuals should exhibit a distractor N2pc (evidence for distractor-driven capture) rather than a P_D (evidence for suppression) while low-anxiety individuals should exhibit a P_D.

Methods

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

STAI Prescreen

In total, 218 students from Simon Fraser University volunteered to be prescreened for potential inclusion into an EEG experiment. Students were prescreened using STAI (Spielberger et al. 1983). Subjects were contacted and invited to participate in the full EEG experiment if their trait-anxiety score was above 50 (*n* = 20; high-anxiety group) or below 35 (*n* = 20; low-anxiety group). This extreme-groups design was used to maximize the power to detect potential differences in brain responses (Yarkoni & Braver, 2010; Preacher, Rucker, MacCallum & Nicewander, 2005). The specific STAI cutoffs were chosen to match cutoffs from previous ERP studies of anxiety (Fox, Derakshan & Shoker, 2008; Eldar, Yankelevitch, Lamy & Bar-Haim, 2010).

Participants

Forty students from Simon Fraser University participated after giving informed consent. These students were given course credit for their participation as part of a departmental research participation program. Prior to the EEG collection, subjects were again asked to complete the STAI to ensure that they still fulfilled the predetermined criteria for high- or low-anxiety. Of the 40 subjects, one was excluded due to excessive noise in the ocular channels and another was excluded for failing to answer all questions on the STAI. Of the remaining 38 participants, 19 (16 women, age 20.26, *SD* = 1.97; 1 left-handed) were characterized as high-anxiety and 19 (14 women, age 20.94, *SD* = 5.60; 4 left-handed) were characterized as low-anxiety. All subjects reported normal or corrected-to-normal visual acuity and had normal color vision (tested in lab using Ishihara color test plates). ERP studies involving measurement of the N2pc or P_D typically have 12–20 participants within each sub-group of the analysis, and so our sample size is ample to reveal differences in N2pc or P_D across the low-anxiety and high-anxiety groups here. Data collection stopped at the pre-determined sample size (*n* = 20 per group).

Apparatus

The experiment was conducted in an electrically shielded chamber dimly illuminated by DC-powered LED lighting. Stimuli were presented on a 23-inch, 120-Hz LCD monitor viewed from a distance of 57 cm. Stimulus presentation was controlled by Presentation (Neurobehavioral Systems, Inc., Albany, CA) from a Windows-based computer. Participants were encouraged to blink infrequently during blocks and to take a short rest break between blocks.

Stimuli and Procedure

Visual search arrays were comprised of 10 unfilled circles presented equidistant (9.2°) from a central fixation point. Each circle was 3.4° in diameter with a 0.3° thick outline. Eight or nine of the circles were uniformly colored non-targets, one was a target color singleton, and one was a distractor color singleton (on distractor-present trials). The target was dark yellow (x = 0.42, y = 0.52, 7.9 cd/m^2) and the distractor was red (x = 0.64, y = 0.32, 7.0 cd/m^2), and the non-target circles were green (x = 0.29, y = 0.64, 7.9 cd/m^2). A randomly oriented vertical or horizontal gray line (x = 0.30, y = 0.36, 7.9 cd/m^2) was contained within each of the circles. All stimuli were presented on a uniform black background (0.5 cd/m^2). On each trial, a search display was preceded by an 800–1,200 ms fixation period. During this time only the central fixation point was visible. Upon the presentation of the search display, participants were instructed to maintain fixation on the central point and to identify the orientation of the gray line inside the target singleton by pressing one of two response buttons as quickly as possible. The search array remained visible for 100 ms after a response was registered, at which point the next trial began.

Displays contained a target singleton and one distractor singleton on 50% of trials (distractor-present trials). On the remaining 50% of trials, the target was the only singleton in the array (distractor-absent trials). Target and distractor locations were varied to produce the following display configurations: lateral target, no distractor (22.0%); midline target, no distractor (11.3%); lateral target, midline distractor (14.7%); lateral target, ipsilateral distractor

(14.7%); lateral target, contralateral distractor (14.7%); midline target, lateral distractor (14.7%); midline target, midline distractor (8.0%). The order of the display configurations was randomly intermixed within each block of trials. Each experimental block comprised 36 trials. At the end of the block, participants were given a minimum 5-s rest period and were permitted to begin the next block whenever they decided. The experiment contained 35 blocks, for a total of 1,260 trials per participant. At least 36 practice trials were given to each participant prior to the start of the experiment.

Behaviour

Median reaction times (RTs) were derived for distractor-present and distractor-absent trials for each participant. Trials on which the participant responded incorrectly, too quickly (RT < 200 ms) or too slowly (RT > 1,500 ms) were excluded from the analysis. The means of these median RTs were then computed separately for high- and low-anxiety groups. Distractor interference in a mixed-factor analysis of variance (ANOVA) with Trial Type (distractor present vs. distractor absent) as a within-subjects factor and Group (high-anxiety vs. low-anxiety) as a between-subjects factor.

Electrophysiology

Electroencephalographic (EEG) signals were recorded from active sintered Ag-AgCl electrodes (Biosemi Active Two system) from 32 electrodes, using our standard procedures, including rejection of trials with ocular artifacts. All EEG and EOG signals were digitized at 512 Hz, referenced in real time to an active common-mode electrode, and low-pass filtered using a fifth-order sinc filter with a half-amplitude cutoff at 104 Hz. Electrode offsets were monitored to ensure the quality of the data. After the data acquisition, EEG signals were high-pass filtered (half-amplitude cutoff at 0.05 Hz) and then converted from 24-bit to 12-bit integers. EEG processing and ERP averaging were performed using the event-related potential software system (ERPSS; University of California, San Diego). Artifact-free epochs associated with the various display configurations of interest were then averaged separately to create ERP waveforms. The resulting ERPs were digitally low-pass filtered (half-amplitude cutoff at 32 Hz) and digitally re-referenced to the average of the left and right mastoids. All ERP amplitudes and baselines were computed using a 200 ms pre-stimulus window.

For each participant, ERPs to the search displays were collapsed across left and right visual hemifields, as well as left and right electrodes to produce waveforms recorded contralateral and ipsilateral to a lateralized singleton. Lateralized ERP difference waveforms were then computed for the display configurations of interest by subtracting the ipsilateral waveform from the corresponding contralateral waveform at electrode sites P07 and P08. Negative voltages were plotted upward so that the N2pc would appear in these difference waveforms as an upward deflection and the P_D as a downward deflection.

All ERP measurements were taken from these contralateral-ipsilateral difference waveforms. Mean-amplitude measures were used to quantify the magnitudes of all components of interest. In most cases, the measurement window was selected a priori based on prior research. However, the distractor-elicited ERP components (specifically N2pc and P_D) were predicted to have a somewhat unusual time course in the high-anxiety group of the present study. To further reduce the likelihood of a spurious positive finding (cf. Luck & Gaspelin, 2017), we followed the primary mean-amplitude analyses with analyses of signed areas that were measured in wider time windows. This was done sparingly (that is, for distractor-elicited N2pc and P_D only; see next section) to avoid unnecessary increases in the number of statistical tests performed. Unless otherwise noted, statistical tests were two-tailed. 95% confidence intervals were computed for Cohen’s d measures using JASP .0.9.0.1.

Midline target, lateral distractor displays

The distractor was predicted to elicit an early N2pc followed by a reduced P_D in the high-anxiety group, and so we tailored our measurement windows to minimize component overlap. The sequence of an early N2pc and a subsequent P_D has been observed previously in response to both distractors (e.g., Kiss, Grubert, Petersen, & Eimer, 2012) and targets (e.g., Jannati et al., 2013; Sawaki, Geng, & Luck, 2012). Mean amplitudes for the distractor-elicited N2pc were computed in a 50-ms window from 170–220 ms (the same window used by Eimer and Kiss, 2007, to test for an early N2pc to emotionally salient stimuli that were hypothesized to capture attention). Mean amplitudes of the P_D were computed in a 270–310 ms measurement window (relative to stimulus onset) that was approximately centered around the peak of the component for both groups. The 40-ms width of the window was selected to match the width of the measurement windows used in previous studies (Hickey et al. 2009; Gaspar & McDonald. 2014), while the entire window was shifted later in time to avoid temporal overlap with an immediately preceding distractor N2pc that was predicted to occur in high-anxiety individuals.

Variations in each ERP measure (N2pc mean amplitude, P_D mean amplitude) were evaluated in three ways. First, unpaired t-tests were conducted to determine whether the mean amplitude differed between low-anxiety and high-anxiety groups. These tests were performed as one-tailed tests because we predicted a priori that the high-anxiety group would exhibit poorer attentional control relative to the low-anxiety group, resulting in a *smaller* P_D and/or a *larger* distractor N2pc compared to the low-anxiety group. Second, because the between-groups tests do not indicate whether a component was present or absent in each group, we also performed a one-sample t-test for each group to determine whether the measured amplitude was significantly different from zero (i.e., the component was present). Third, mean amplitudes of the distractor N2pc and P_D were assessed separately for fast-response and slow-response trials. Individual trials with RTs falling below or above the median RT for the midline target/lateral distractor display configuration were defined as fast-response and slow-response trials, respectively.

Two signed-area analyses were performed to buttress the main mean-amplitude effects. Signed negative area associated with the distractor-elicited N2pc was computed 170–250 ms post-stimulus, and the signed positive area associated with the P_D was computed 200–350 ms post-stimulus. These measurements were taken from the grand-averaged contralateral-ipsilateral difference waves obtained in each group, not from the fast-response and slow-response sub-averages. Like the mean-amplitude analyses, variations in each area measure were analyzed statistically to look for between-groups differences (unpaired t-tests, one-tailed) and for the presence of individual components (one-sample t-tests). All between-groups tests were done using the "raw" signed area measurements, but because such measures are biased to be non-zero due to the presence of noise in the waveforms (Sawaki and Luck, 2010), the one-sample t-tests (vs. zero under the null hypotheses) required additional steps to estimate and remove noise-related area from each "raw" signed area measure (which was the sum of signal area and noise area). Following the procedures introduced by Gaspar et al. (2016), we measured signed area due exclusively to noise in intervals that preceded stimulus onset (when no signal could contribute to the measured area) and then subtracted the noise-area estimates from the corresponding "raw" signed area measures. The polarity of the noise-area estimates and width of the pre-stimulus intervals were matched to the corresponding "raw" area measures. Specifically, we measured (i) signed negative area in a 70-ms pre-stimulus interval for the distractor N2pc, and (ii) signed positive area within a 150-ms pre-stimulus interval for the P_D. The resulting unbiased signed area measures associated with the distractor N2pc and P_D (N2pc area minus negative noise area; P_D area minus positive noise area) were then tested statistically against the null (zero area) using a parametric statistical measure (in this case, one-sample t tests) that is robust against moderately large deviations from normality (Keppel & Wickens, 2004).

Onset latencies of the distractor N2pc and P_D were measured using jack-knife sub-averages (each sub-averaged based on 18 individual datasets) following conventional jack-knife methods to correct statistical values (Ulrich & Miller, 2001). Onset latency was defined as the time at which the activity reached 50% of its peak amplitude. These measurement decisions were made a priori based on prior studies.

Lateral target, no distractor displays

The general approach to evaluating target-elicited N2pc components followed the measurement and analysis approach outlined above, but because the timing of the target N2pc is less variable than that of the distractor-elicited ERP components, signed area measures were not required to buttress the mean-amplitude analyses. Mean amplitudes for the target-elicited N2pc were computed in the same 230–290 ms post stimulus onset window used by Hickey and colleagues (2009). Unpaired t tests were performed to determine whether the target N2pc differed across groups. These tests were two-tailed because we had no specific directional prediction regarding the target N2pc. One-sample t tests were then used to determine whether or not the N2pc was present in the individual groups. Following analysis of the grand-average contralateral-ipsilateral difference waves, mean amplitudes were assessed separately for fast-response and slow-response trials, as described in the preceding section. Finally, target N2pc latencies were measured and tested using conventional jack-knife procedures, as outlined in the preceding section.

Results

STAI Scores

Prior to their participation in the EEG experiment, subjects were required to complete the STAI for the second time. Mean trait anxiety scores were 62.4 (*SD* = 6.0) for the high-anxiety group (*n* = 19) and 26.8 (*SD* = 3.5) for the low-anxiety group (*n* = 19).

Search performance does not differ between high- and low-anxiety individuals

Responses were faster for distractor-absent trials (671 ms) than for distractor-present trials [693 ms; $F(1,36) = 114.10$, $p < .001$, $\eta^2 = .759$]. Although low-anxiety individuals were marginally faster than high-anxiety individuals on both distractor-absent trials (664 vs. 678) and distractor-present trials (685 vs. 702), this difference was not found to be statistically significant [$F(1,36) = 0.28$, $p = .60$, $\eta^2 = .008$]. The Group x Trial Type interaction was non-significant [$F(1,36) = 0.21$, $p = .65$, $\eta^2 = .001$], indicating that the magnitude of behavioural interference (that is, the RT difference between distractor present and distractor absent trials) was statistically indistinguishable across groups (23 ms and 21 ms, for low-anxiety and high-anxiety groups, respectively). Lastly, RT standard deviations were computed to determine if response speed was more variable among either group. RT standard deviation was not found to differ between high- and low-anxiety participants for either distractor-present trials [$t(36) = 0.74$, $p = .47$, $d = 0.24$, 95% CI (-0.40, 0.88)] or distractor-absent trials [$t(36) = 0.13$, $p = .90$, $d = 0.043$, 95% CI (-0.59, 0.68)].

Distractor captures attention and is later suppressed in high-anxiety individuals

Figures 1b and 1c show grand-averaged ERPs and corresponding contralateral-ipsilateral difference waveforms elicited by midline target, lateral distractor displays, separately for high-anxiety and low-anxiety individuals. For both groups, the ERPs recorded contralateral and ipsilateral to the salient distractor consisted of a series of positive and negative peaks (P1, N1, P2, and N2) that largely overlapped in the initial 150 ms following the appearance of the search display. For the low-anxiety group, the contralateral and ipsilateral waveforms overlapped throughout the time ranges of the P1, N1, and P2 peaks and only diverged in the time range of the N2. During that latter time range (roughly, 250–325 ms post-stimulus), the contralateral waveform was more positive than the ipsilateral waveform in the time range of the N2 peak. This is precisely the time range of the P_{D} component in prior studies that utilized similar colour

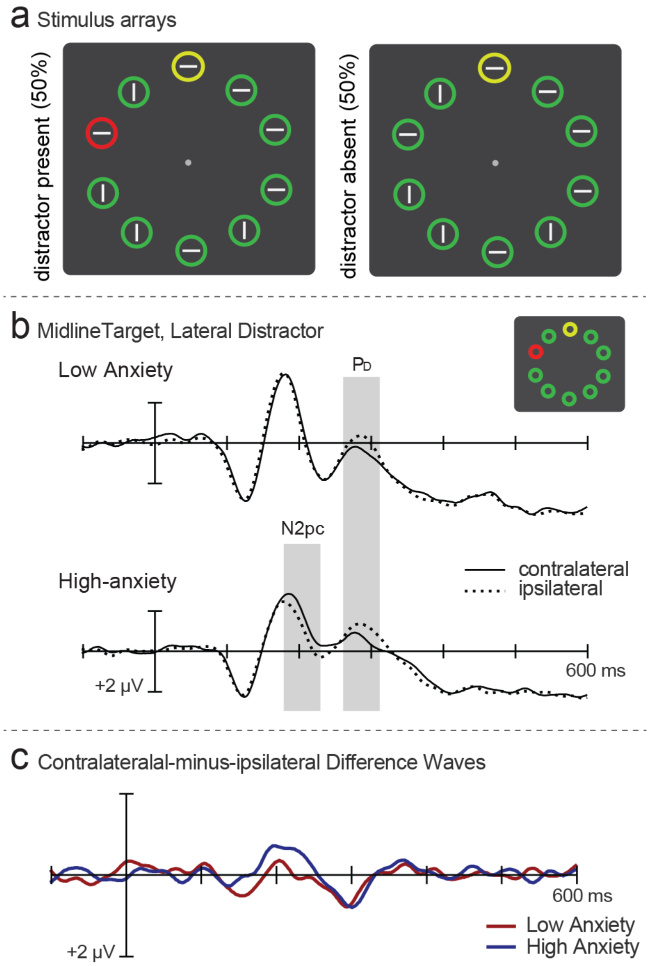

Figure 1. ERPs elicited by search displays containing a midline target (yellow singleton) and a lateral distractor (red singleton). (**a**) Example of midline-target displays (with and without a lateral distractor). (**b**) Grand-averaged ERP waveforms recorded contralateral and ipsilateral to the salient distractor, plotted separately for high- and low-anxiety groups. Shaded boxes represent the time windows of the distractor-elicited N2pc and P_{D}. (**c**) Contralateral-minus-ipsilateral difference waveforms for high-anxiety and low-anxiety groups.

singletons as target and distractor (Gaspar & McDonald, 2014; Gaspar et al. 2016). Thus, the results from the low-anxiety group appear to replicate prior results that were obtained from the general population (that is, without regard for measuring anxiety levels).

Like the ERPs from low-anxiety group, the ERPs from the high-anxiety group appeared to show a P_D contralateral to the salient distractor. Immediately prior to the P_D, however, the ERPs from the high-anxiety group appeared to show a distractor-elicited N2pc. More specifically, in the time range spanning the N1 and P2 peaks, the contralateral waveform was more negative than the ipsilateral waveform. Although beginning quite early—at approximately 170 ms—the timing of this contralateral negativity is consistent with previously reported early N2pc components (Eimer & Kiss, 2007; Gaspar & McDonald, 2014). This indicates that high-anxiety individuals may have inadvertently attended to the salient distractor (evidenced by the N2pc) before eventually suppressing signals arising from that item (evidenced by the P_D).

Statistical tests confirmed these findings. The mean P_D amplitudes for the midline-target/lateral-distractor display configuration were found to differ significantly from zero for the high-anxiety group [$t(18) = 2.63$, $p = .017$, $d = 0.60$, 95% CI (0.11, 1.09)] as well as the low-anxiety group [$t(18) = 2.45$, $p = .025$, $d = 0.56$, 95% CI (0.07, 1.04)]. Both P_D amplitudes and P_D latencies were statistically indistinguishable across the low-and high-anxiety groups [amplitudes: 0.58 μV vs. 0.55 μV; $t(36) = 0.08$, $p = .469$, $d = 0.03$, 95% CI (-0.51, ∞), one-tailed][latencies: 278 ms vs. 273 ms; $t_c = 0.35$, $p = .73$]. The mean amplitude of the distractor N2pc (measured on midline-target/lateral-distractor trials) was found to be larger for the high-anxiety group than for the low-anxiety group [$t(36) = -1.823$, $p=.038$, $d = -0.59$, 95% CI (-∞, -0.04), one-tailed]. Within each group, the distractor-elicited N2pc was significantly different from zero for the high-anxiety group [$t(18) = -3.12$, $p = .006$, $d = -0.72$, 95% CI (-1.21, -0.20)] but not for the low-anxiety group [$t(18) = 0.60$, $p = .56$, $d = -0.14$, 95% CI (-0.59, 0.32)].

In the high-anxiety group, the presence of a distractor-elicited N2pc preceding the P_D may indicate that, after an initial shift of attention to the distractor singleton, a corrective mechanism was invoked to suppress the distractor and reorient attention toward the target (see Geng, 2014). This may reflect a search strategy unique to high-anxiety individuals, whereby reactive, rather than proactive, mechanisms of attentional control are more readily invoked during visual search (Braver, Gray & Burgess, 2007; Fales, Barch, Burgess, Schaefer, Mennin, Gray et al. 2008). However, an alternative explanation is that high-anxiety individuals exhibit greater variability in their capacity to maintain top-down attentional control which could lead to a different sequence of processing on different trials. In line with this notion, it is plausible that the distractor captured attention only on a subset of trials during which top-down control waned and that such distractor-driven capture was avoided on a different subset of trials. To test these possibilities, distractor processing in high-anxiety individuals was assessed separately for fast-response and slow-response trials (Figure 2). This median-slit analysis is predicated on the assumption that implementing top-down control processes would facilitate behavioural performance (see also Jannati, Gaspar, & McDonald, 2013; McDonald, Green, Jannati, & Di Lollo, 2013). However, neither the distractor-elicited N2pc nor the subsequent P_D differed across fast-response and slow-response trials. More specifically, the mean amplitude of each component was statistically indistinguishable across fast-response and slow-response trials (Distractor N2pc: $t(18) = 1.10$, $p = .29$, $d = 0.25$, 95% CI (-0.21, 0.71); P_D: $t(18) = -1.21$, $p = .24$, $d = -0.28$, 95% CI (-0.73, 0.18)].

Subtle differences in target processing distinguish high-anxiety and low-anxiety individuals

To assess the relationship between selective target processing and anxiety, target-elicited N2pc waves were isolated for lateral target, no distractor display configurations. Trials on which the distractor was absent were used to assess target processing here, as the N2pc elicited on

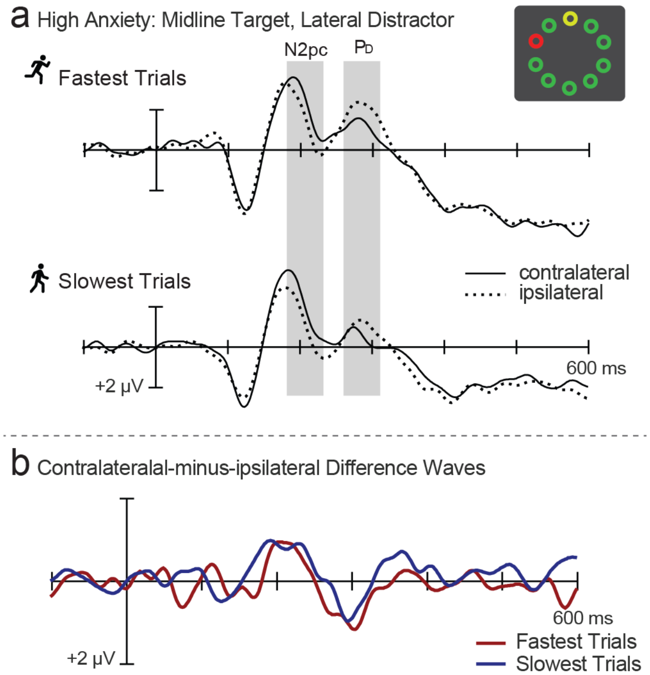

Figure 2. Lateral-distractor ERPs from the high-anxiety group, plotted separately for fast-response and slow-response trials. (**a**) Grand-averaged ERPs recorded contralateral and ipsilateral to the salient distractor. The shaded boxes represent the time windows of the distractor-elicited N2pc and P_D. (**b**) Contralateral-minus-ipsilateral difference waveforms for fast-response and slow-response trials.

these trials would in no way be confounded by any attentional processing associated with the salient distractor. Figure 3a shows ERP waveforms recorded contralateral and ipsilateral to the target, averaged separately over high-anxiety individuals and low-anxiety individuals. For both groups, the contralateral and ipsilateral waveforms largely overlapped in the time range of the initial positive and negative (P1 and N1) peaks, but the contralateral waveform became more negative than the ipsilateral waveform beginning in the time range of the second positive (P2) peak. The contralateral-ipsilateral difference waves displayed in Figure 3b show the timing and amplitude of the contralateral negativities for both groups. Whereas the distractor-elicited N2pc emerged approximately 170 ms after the appearance of a lateral-distractor display (Figures 1 and 2), the negativity observed contralateral to the target emerged ~50 ms later. Prior studies have shown that the timing of the N2pc component depends on the salience of the attended item (Brisson, Robitaille, & Jolicœur, 2007; Gaspar & McDonald, 2014); consequently, we interpret the contralateral negativity shown in Figure 3 as a target-elicited N2pc. Statistical analysis revealed that the target-elicited N2pc was present in both groups [high anxiety: *t*(18) = -5.57, *p* < .001, *d* = -1.28, 95% CI (-1.88, -0.66); low-anxiety: *t*(18) = -2.87, *p* = .01, *d* = -0.66, 95% CI (-1.15, -0.15)]. Numerically, the N2pc was larger for the low-anxiety group than the high-anxiety group (-0.86 µV vs. -0.48 µV); however, statistical analyses revealed no significant difference [*t*(36) = -1.65; *p* = .11, *d* = -0.53, 95% CI (-1.18, 0.12)]. Finally, onset latency was found to be statistically indistinguishable across high- and low-anxiety groups [244 ms vs. 250 ms; t_c = 0.95, *p* = .36].

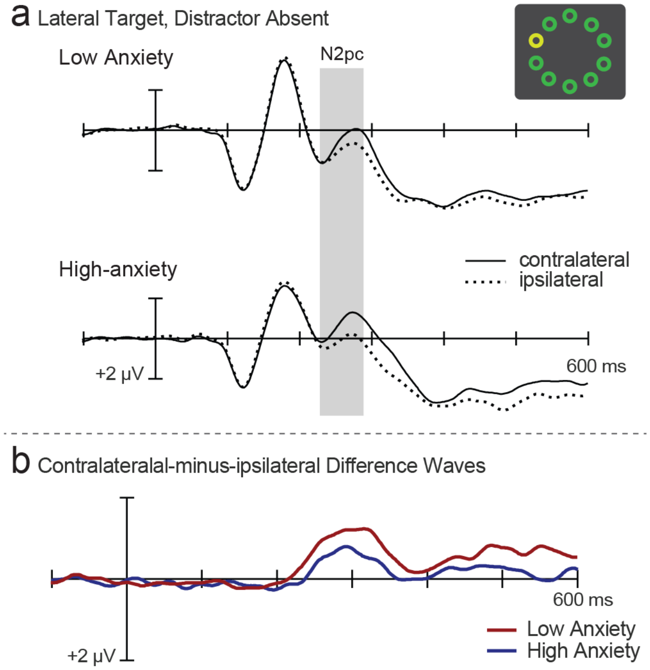

Figure 3. ERPs elicited by search displays containing a lateral target and no distractor. (**a**) Grand-averaged ERP waveforms recorded contralateral and ipsilateral to the target singleton, plotted separately for high- and low-anxiety groups. The shaded boxes represent the time windows of the target-elicited N2pc. (**b**) Contralateral-minus-ipsilateral difference waveforms for high- and low-anxiety groups.

To determine if response efficiency was associated with a unique sequence of target processing, differences in lateral-target (no-distractor) ERPs were examined separately for fast-response and slow-response trials (Figure 4). For the high-anxiety group, the N2pc component did not differ across fast-response and slow-response trials [$t(18) = -0.05$, $p = .96$, $d = -0.01$, 95% CI (-0.46, 0.44)]. For the low-anxiety group, however, the N2pc was markedly attenuated on slow-response trials relative to fast-response trials [-0.24 µV vs. -0.87 µV; $t(18) = 3.38$, $p = .003$, $d = 0.78$, 95% CI (0.25, 1.3)]. A reduction in the amplitude of the N2pc component on slow response trials has been previously reported by Jannati and colleagues (2013). Considered together, the results indicate that selective target processing—as measured by the target N2pc—is typically attenuated on slow-response trials but that individuals with high anxiety exhibit no such attenuation.

Discussion

The main objective of the present study was to investigate whether the attention control deficits hypothesized to accompany high levels of trait anxiety would be evident in ERP measures that reflect attentional selection and suppression in a competitive visual search task. On the assumptions that anxiety results in deficits in inhibitory control (Eysenck et al. 2007) and that the P_D component reflects active inhibition of irrelevant stimuli, we predicted that high-anxiety individuals might show a distractor N2pc rather than the usual P_D. This prediction was partially confirmed: a distractor N2pc was observed in the high-anxiety group, but no attenuation in the P_D was evident. For the low-anxiety group, only a P_D was in evidence.

On the basis of these findings, we conclude that highly anxious individuals and their low-

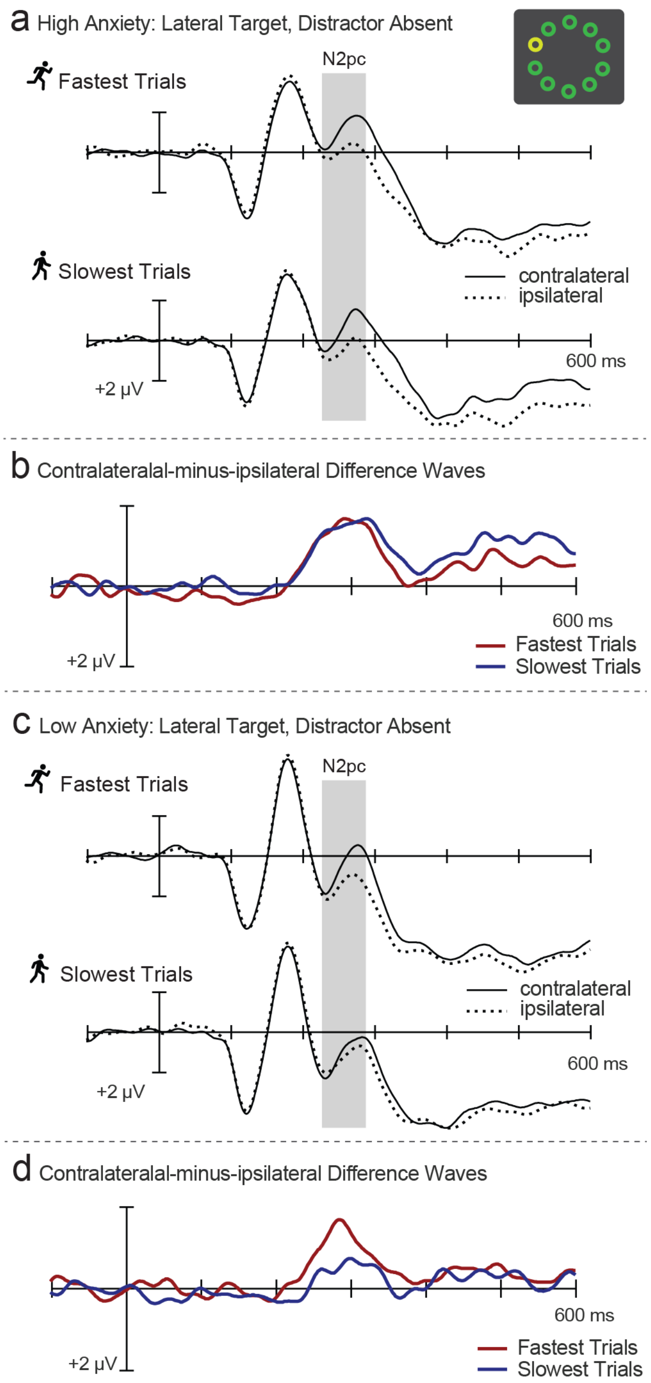

Figure 4. Lateral-target ERPs plotted separately for fast-response and slow-response trials. (**a**) ERP waveforms from the high-anxiety group. (**b**) Contralateral-ipsilateral difference waves from the high-anxiety group. (**c**) ERP waveforms from the low-anxiety group. (**d**) Contralateral-ipsilateral difference waveforms for the low-anxiety group.

anxiety counterparts deal with salience-driven distraction in different ways. It is possible, for example, that low-anxiety individuals set up a suppressive filter proactively, whereas high-anxiety individuals suppress the distractor more reactively, after distractor-driven capture has taken place. The ERP findings are consistent with this possibility. Namely, the presence of a P_D with no early distractor N2pc indicates that low-anxiety individuals set up a suppressive filter proactively to prevent in-depth processing of the most salient (but irrelevant) visual-search item (for related theoretical considerations, see Gaspelin & Luck, 2017; Gaspar & McDonald, 2014; Geng, 2014; Hickey et al. 2009; Sawaki & Luck, 2010). In contrast, the presence of an early distractor N2pc followed by a P_D indicates that highly anxious individuals might not engage the attention control processes necessary to prevent attention capture by an irrelevant distractor and thus have to rely on suppression processes to terminate processing of the distractor once attention has been diverted (Eysenck et al. 2007). The hypothesized difference between the low-anxiety group's proactive distractor suppression and the high-anxiety group's reactive distractor suppression might itself be due to the adoption of different search strategies (cf. Bacon & Egeth, 1994). Namely, low-anxiety individuals might adopt a feature-based strategy that enables rapid selection of the yellow target, whereas high-anxiety individuals might adopt a less cognitively demanding singleton-detection strategy that leads to selection of the distractor on some trials.

It might be assumed that there would be a behavioural cost to relying on a reactive strategy to recover from salience-driven distraction. According to attentional control theory, however, anxiety has less impact on performance than it does on processing *efficiency*. More specifically, it is hypothesized that highly anxious individuals can perform as well as their less-anxious counterparts by putting in more effort to compensate for an impairment in attentional control. The results of the current study are perfectly in line with this hypothesis. Behaviourally, the presence of a salient distractor delayed search for a less-salient target by about 22 ms in each group (24 ms in the high-anxiety group and by 21 ms in the low-anxiety group; the 3-ms difference was found to be non-significant). Such distractor interference effects sometimes reflect distractor-driven diversions of attention (as indexed by a distractor N2pc; Hickey, McDonald, & Theeuwes, 2006; McDonald et al., 2013) and sometimes reflect the cost of suppressing the distractor (as indexed by the P_D; Jannati et al., 2013; Gaspar & McDonald, 2014)(**insert Footnote 1**). Here, the behavioural interference was due to proactive suppression in the low-anxiety group, but was associated with a more effortful reactive-suppression strategy (to recover from a distractor-driven diversion of attention) in the high-anxiety group. Additionally, whereas the low-anxiety group showed a typical attenuation of the target N2pc on slow-response trials (cf. Jannati et al., 2013), the high-anxiety group showed no such attenuation. This latter finding indicates that highly anxious individuals may compensate for distractor-centered deficits by applying greater effort to select the target or by applying target-selection processes more consistently across trials.

Of course, given the statistical equality of performance across the low- and high-anxiety groups, our conclusions rely heavily on the wealth of evidence linking our electrophysiological measures to attentional control processes. Several studies have shown that the N2pc is elicited by task-relevant target singletons that pop out from arrays of otherwise identical stimuli, by nontarget singletons that require careful scrutiny before being rejected (e.g., Luck et al., 1994), by salient distractors that are hypothesized to capture attention reflexively (Hickey, McDonald, & Theeuwes, 2006; McDonald et al., 2013), but not by task-irrelevant singletons that can be filtered out easily (Luck & Hillyard, 1994). Monkeys trained to search for a target show enhanced cellular responses in the prefrontal cortex before a homolog of the human N2pc emerges over the posterior scalp (Cohen, Heitz, Schall, & Woodman, 2009). The P_D, on the other hand, is normally elicited by irrelevant items that could cause significant distraction (Hickey et al., 2009; Gaspar et al., 2014; Sawaki & Luck, 2010). Distractors elicit larger P_D components when participants respond quickly to a target appearing in the same display (i.e., when distraction is minimal) than when participants respond more slowly to the target (i.e., when distraction is increased; McDonald et al., 2013; Sawaki, Geng, & Luck, 2012). Individuals with high visual short term memory spans—long considered to be “good attenders (e.g., Kane, Bleckley, Conway, & Engle, 2001)—have larger P_D components than do individuals with low memory spans (Gaspar et al., 2016). Finally, monkeys that are trained to avoid a salient distractor show reduced distractor interference, suppressed neurophysiological activity in an attention-control area of prefrontal cortex, and a homolog of the human P_D over the posterior scalp, whereas monkeys not trained to ignore the same distractor show greater interference, no suppression of activity in prefrontal cortex, and no P_D over the posterior scalp (Cosman, Lowe, Woodman, & Schall, 2017). Taken together, these and other results indicate that the N2pc is associated with attentional selection while the P_D is associated with suppression.

The results of the present study are surprising in two ways when viewed against the backdrop of attentional control theory. First, the theory proposes that anxiety impairs high-level control processes as well as verbal working memory processes but does not necessarily impair processes within the visuospatial subsystem of working memory. Here, however, different levels of anxiety were associated with different patterns of distractor processing in a visuospatial task. Based on our findings, we surmise that that disturbances in higher-level attentional control functions can feed back onto any modality-specific subsystem of working memory. Thus, for example, highly anxious individuals would likely have difficulty avoiding salient tactile distractors as well as salient auditory and visual distractors. Second, the theory highlights difficulties in avoiding distracting stimuli that are threat-related, but in the current study, high-anxiety individuals could not prevent themselves from attending to a salient, but nonthreatening, stimulus. It could be argued that high-anxiety participants worried about their target-identification performance and considered the salient distractor to be the main obstacle—or "threat"—to efficient target-identification performance. In other words, the normally neutral distractor stimulus may have acquired some degree of emotional salience over the course of the experiment, at least for anxious individuals. Alternatively, trait anxiety might involve a broader dysregulation in attentional control that extends beyond threatening stimuli (Bishop, 2009).

Finally, we note that there appears to be some similarity between the ERPs obtained from our highly anxious individuals and ERPs obtained from individuals with low visual working memory capacity (e.g., Gaspar et al., 2016). This is not particularly surprising since it has been hypothesized that low-capacity individuals, like highly anxious individuals, suffer from deficits in inhibitory control (e.g., Kane, Bleckley, Conway, & Engle, 2001; Vogel, McCollough, & Machizawa, 2005). Because memory capacity was not measured in the present study, it is possible that some of the reported effects were associated with low memory capacity rather than anxiety per se. At least one key finding is inconsistent with this option: Whereas high-anxiety individuals were able to suppress the distractor (as evidenced by a P_D), low-capacity individuals were not (as evidenced by the absence of a P_D). Still, future studies are needed to tease apart the contributions of anxiety and memory capacity to the individual differences in target and distractor processing in visual search.

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Footnotes

1. For decades, the behavioural interference effect was chalked up to either distractor-driven attention capture (Theeuwes, 1991, 1992) or a non-spatial filtering process that merely delays the initial deployment of attention to the target (Folk & Remington, 1998). In contrast to the latter, non-spatial explanation, Mounts (2000) showed that the magnitude of interference varies with the spatial separation between target and distractor, with interference being greatest when the two items are side-by-side. Based on this finding, Mounts argued that (i) attention is deployed to the distractor, (ii) an inhibitory surround is centered on the attended distractor location, and (iii) nearby targets fall in the inhibitory surround. By contrast, we have argued elsewhere (Gaspar & McDonald, 2014; Jannati, et al., 2013) that when the distractor elicits a P_D rather than an N2pc, (i) the distractor location is suppressed, not attended, (ii) inhibition spreads from the distractor location, and (iii) nearby targets fall within inhibited regions.