

The color of anxiety: Neurobehavioral evidence for distraction by perceptually salient stimuli in anxiety

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Abstract Anxiety is reliably associated with an attentional bias favoring threatening information which is thought to be a key mechanism in the etiology and maintenance of anxious pathology. However, whether and how anxiety is related to attentional capture at a more basic level (i.e., in the absence of threat) is less well understood. To address this gap in the literature, we examined the association between anxiety and attentional capture in the context of visually salient, yet affectively neutral, stimuli. Specifically, we used a visual search task in which participants were required to locate a target while ignoring a salient distractor stimulus. A total of 122 undergraduates—half of whom were assigned to a state-anxiety induction—completed this task while event-related potentials were recorded and also completed self-report measures of trait and state anxiety. The results revealed that trait anxiety, but not state anxiety, was associated with impaired attentional control in the presence of a salient distractor. That is, behavioral slowing and the N2pc event-related potential—a neural measure of attentional selection—were enhanced for trait-anxious participants when the distractor was proximate to the target and required controlled attention in order to inhibit it. These findings extend previous work by providing evidence from multiple levels of analysis that attentional aberrations in anxiety reflect broad deficits in inhibiting distracting stimuli and are not limited to threat-relevant contexts.

Keywords Anxiety · Attention · Attentional capture · N2pc

Attentional problems represent a core component of the pathological anxiety that is associated with impairments in daily

living (American Psychiatric Association, 2013; Eysenck, Derakhshan, Santos, & Calvo, 2007; Sylvester et al., 2012). Much of the research to date has focused on attentional biases that prioritize negative (i.e., threat-relevant) information (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Eysenck et al., 2007) since such biases appear to play a significant role in the development and maintenance of anxiety (Bögels & Mansell, 2004; MacLeod, Rutherford, Campbell, Ebsworthy, & Holker, 2002), and, more recently, have become the target of computer-based treatment programs (e.g., Amir, Beard, Burns, & Bomyea, 2009). Although informative, this approach does not address the possibility that anxiety is associated with broad attentional deficits irrespective of threat relevance. Indeed, theoretical work has suggested that anxiety is related to impaired attentional control more broadly—that is, even in the absence of threat-relevant information (Eysenck et al., 2007). Critically, there is very little direct evidence supporting a link between anxiety and attentional control in non-valenced tasks. The purpose of the present investigation was to probe basic attentional-control deficits in anxiety by examining modulations of behavioral and electrophysiological responses to salient, yet affectively neutral, distractor stimuli.

Previous research demonstrating that anxious individuals suffer from attentional-control deficits during the performance of non-valenced “cognitive” tasks has employed complex tasks/stimuli that likely involved multiple processes (e.g., reading skill, memory, etc.; see Eysenck et al., 2007, for a review) and thus have not allowed for an unambiguous interpretation (i.e., that anxiety affects attention specifically). To address this limitation, Derakhshan, Ansari, Shoker, Hansard, and Eysenck (2009) showed impaired attentional control in anxious individuals during performance of the antisaccade task, which involves overriding the automatic tendency to orient one’s gaze in the direction of a sudden-onset target and execute an eye movement in the opposite direction. This

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study, however, was limited by the fact that the sudden-onset target was always task-relevant; thus, this finding may have resulted from strategic adjustments rather than deficits in attentional control.

A more direct examination of attentional control in anxiety would pit a perceptually salient, yet irrelevant, distractor against the task-relevant target (Eysenck & Derakhshan, 2011). Along these lines, Moser, Becker, and Moran (2012) required participants to complete the additional-singleton search task which is considered to be a relatively pure measure of attentional capture—that is, the preferential processing of an object regardless of the goals of the observer on the basis of perceptual salience (Theeuwes, 2010). Participants were required to respond to the orientation of a line contained within a target shape (see Fig. 1). On some trials, an irrelevant color-defined distractor was also presented which has been shown to slow response times (RTs) to the target; that is, participants were able to orient attention to the target stimulus only after attention was automatically drawn to the distractor (Theeuwes, 2010). Moser et al. reported that trait anxiety was associated with increased attentional capture—that is, slowing in the presence of the color singleton. This effect has since been replicated by Esterman and colleagues (2013) in a sample of PTSD patients. Importantly, this task made it possible to demonstrate anxiety's association with attentional deficits in the absence of threat-relevant stimuli.

Moser and Derakhshan (Derakhshan et al., 2009; Moser et al., 2012) interpreted their results within the framework of the attentional control theory (ACT; Eysenck et al., 2007). Specifically, ACT proposes that anxiety is characterized by inefficient inhibition—an executive function that minimizes distractor interference in service of goal-directed activity. However, overt behavioral measures confound a number of processing stages (e.g., decisional and motoric processes; Handy, Green, Klein, & Mangun, 2007). That is, modulation of RTs may not reflect attentional processes per se; rather, it may also reflect later stages, such as decision making and response generation. Moreover, even within a processing

stage (e.g., attention), the specific operation under investigation can be ambiguous. For example, the breadth with which “attention” is used has made it a catch-all term for the control of the flow of information during processing (Chun, Golomb, & Turk-Browne, 2011). It is, therefore, not always clear which process produced RT modulations, even in a “process-pure” attention task. This rings true within the negative attention bias literature as well, in which anxiety has been associated with heightened hypervigilance/orienting in the presence of threat (e.g., MacLeod, Mathews, & Tata, 1986; Vuilleumier & Pourtois, 2007), delayed disengagement from threat (Koster, Crombez, Verschuere, & De Houwer, 2004), and inefficient filtering/inhibition of threat-relevant information (Stout, Shackman, & Larson, 2013) in RT tasks. It is therefore important to utilize a measure that is capable of distinguishing between various constituent processes.

Event-related potentials (ERPs)—that is, neuroelectric activity recorded at the scalp—are an online measure of cognitive processing that allows for a more direct assessment of attentional processes. One commonly used component in the study of attention is the N2pc. The N2pc is a negative-going component that is enhanced at electrode sites contralateral to an attended location (e.g., on the left side of the scalp when the participant attends to the right side of the screen; Hickey, McDonald, & Theeuwes, 2006; Luck & Hillyard, 1994a, 1994b; Woodman & Luck, 1999, 2003). It is named for its polarity (negative), latency (approximately 200 ms poststimulus), and topography (posterior/contralateral), and is defined as the difference wave computed by subtracting target-ipsilateral sites from target-contralateral sites (e.g., if a target is presented on the left, the N2pc is defined as the activity recorded at right/posterior sites minus the activity recorded at left/posterior sites). It has been proposed that the N2pc reflects the deployment of attention to minimize the interference from (or “filter out”) task-irrelevant stimuli presented concurrently with task-relevant targets (Luck, Girelli, McDermott, & Ford, 1997; Luck & Hillyard, 1994a, 1994b; see Luck, 2012, for a review).

Recent work has linked the N2pc to anxiety symptoms during performance of an emotional dot probe task (Buodo, Sarlo, & Munafò, 2010). Additionally, work by Hickey and colleagues (2006) has demonstrated that the singleton search task used by Moser et al. (2012) effectively elicits an N2pc component. In particular, they showed that (1) trials in which a lateralized target was present and a distractor was absent (see Fig. 1) elicited a greater negativity at electrode sites contralateral to the target location (see also Luck & Hillyard, 1994a, 1994b), (2) trials in which a lateralized target and an ipsilateral color singleton were presented together elicited a larger N2pc than did trials in which no distractor was present. The authors interpreted this effect as indicating that proximal distractors require a greater degree of suppression (see also Luck et al., 1997; Moran & Desimone, 1985). (3) Trials in which a

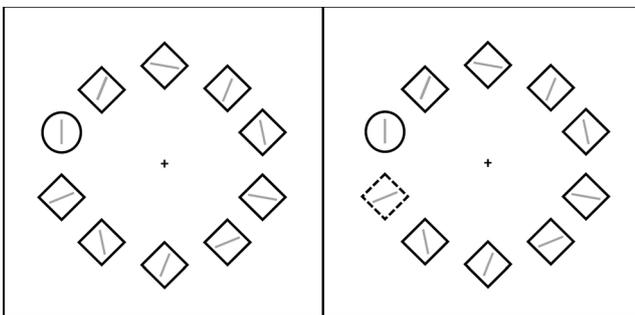


Fig. 1 Example stimuli in the singleton search task. The left panel depicts a distractor-absent trial in which a unique target stimulus (circle) is presented among nine non-targets (diamonds). The right panel depicts a distractor-present trial in which a distractor stimulus (color is represented by the dotted line) is presented ipsilaterally to the target stimulus (circle)

lateralized target was presented with a contralateral distractor elicited a considerably smaller N2pc than did either of the previously mentioned conditions, possibly because attention was oriented first to the color singleton and then to the target (thereby eliciting nearly equivalent neural activity in both hemispheres), or because attention shifted to the target first on some trials and to the distractor first on other trials (e.g., Woodman & Luck, 2003). Given the close link between the N2pc and attentional deployment and filtering, that it has been linked to anxious symptomology, and that the N2pc is reliably elicited in the singleton search task we have previously used with anxiety (Moser et al., 2012), the N2pc is the ideal complement to RTs in studying anxiety-related modulations of attention.

Although trait anxiety has been the focus of most research examining attentional processes, state anxiety has also been linked to attentional biases. For example, a study conducted with subclinically anxious participants noted that participants exhibited preferential processing of threat under high state anxiety, but that trait anxiety did not predict performance (Mogg, Mathews, Bird, & Macgregor-Morris, 1990; however, see Dennis, Chen, & McCandliss, 2008). Similarly, a second study reported that participants spent more time viewing threat-relevant distractor words after an anxiety induction (Derakhshan & Eysenck, 2009). Finally, Egloff and Hock (2001) demonstrated that interference during an affective Stroop task was produced by the interactive effects of trait and state anxiety. Taken together, the existing literature suggests that attentional biases are enhanced in participants with chronic anxiety as well as during transient anxious states (see also Bar-Haim et al., 2007), although the latter finding appears less well understood. This is consistent with Eysenck and colleagues' (2007) proposal that anxiety impairs attentional control especially during heightened states of anxiety. As with trait anxiety, the extant literature has tended to focus on the relationship between state affect and attentional biases favoring threat; it is not clear what effects state anxiety would have on saliency-based attentional capture. Thus, another aim of the present study was to assess the effects of state anxiety on behavioral and ERP markers of attentional capture in the singleton task.

In the present study, we aimed to be the first to probe the association between anxiety and attentional capture by salient, affectively neutral, stimuli more deeply by examining the underlying neural mechanisms and the effects of both trait and state anxiety. Participants were required to complete a variant of the additional-singleton search task (Moser et al., 2012) while electroencephalography (EEG) was recorded. In order to examine the role of state anxiety, half of the participants were randomly assigned to a stress condition (referred to as the "speech group"; described below). Finally, trait anxiety was measured using the State-Trait Anxiety Inventory-Trait edition (Spielberger & Gorsuch, 1983).

With respect to the baseline experimental effects, we expected to replicate previous studies. Specifically, we expected that (1) RTs on distractor-present trials would be longer than RTs on distractor-absent trials (e.g., Theeuwes, 1991, 1992); (2) the N2pc would be elicited by lateralized targets presented on distractor-absent trials (Hickey et al., 2006); (3) the N2pc would be larger when a lateralized target was presented with an ipsilateral distractor relative to distractor-absent trials (Hickey et al., 2006); and (4) the N2pc would be reduced when lateral targets were presented with contralateral distractors (Hickey et al., 2006).

With respect to individual differences, we expected that trait anxiety would relate to greater attentional capture as evidenced by slowed RTs on trials in which salient distractors were present (Moser et al., 2012). Regarding the N2pc, if mechanisms involved in filtering irrelevant information are related to anxiety, this should be evidenced by an enhanced N2pc relative to nonanxious participants. Specifically, we predicted that the N2pc elicited on distractor-present trials would be more negative in trait-anxious participants. Previous work (e.g., Esterman et al., 2013; Moser et al., 2012) has not compared ipsilateral and contralateral distractors. However, we hypothesized that, if anxiety differentially related to these conditions, anxiety would be most closely coupled with ipsilateral distractor trials since ipsilateral distractors would more strongly compete with targets. Given that there has been less work on the effects of state anxiety, we approached these analyses in a more exploratory fashion.

Method

A total of 131 undergraduates were recruited to participate in exchange for partial course credit. All participants reported normal or corrected-to-normal vision and normal color vision. Participants were excluded from the analyses if they reported substantial disbelief in the anxiety induction (described below). This resulted in a loss of nine participants. The final sample consisted of 122 participants; 61 participants were randomly assigned to each group (control and speech). The participants' characteristics are presented in Table 1; the control and speech groups did not differ on any demographic variable.

Stimuli and materials

Participants performed the additional-singleton search task (Theeuwes, 2010). As is shown in Fig. 1, a visual search array consisting of ten discrete shapes positioned along the radius of an imaginary circle (11° radius) was presented on each trial. The shape stimuli consisted of unfilled diamonds (4.5° × 4.5°) and circles (1.7° radius) with either a red or green outline. On half of the trials, one diamond was presented with nine circles;

Table 1 Participant characteristics

Variable	Control	Speech	χ^2 or t
Age (years)	19.6 (1.9)	19.3 (1.8)	0.90
% Female	75	80	0.43
% Caucasian	79	77	0.05
% Left handed	10	7	0.44
STAI-T	40.9 (10.6)	39.9 (9.9)	0.58
STAI-S (Time 1)	36.5 (7.5)	38.8 (7.9)	1.63
STAI-S (Time 2)	36.0 (9.9)	41.8 (9.9)	3.21**

The " χ^2 or t " column presents either a chi-square or an independent-samples t test comparing the speech and control groups. ** $p < .01$

on the other half of the trials, one circle was presented with nine diamonds. On each trial, the nine similar shapes (non-targets) contained a gray line segment ($1.5^\circ \times 0.2^\circ$) oriented 22.5° from either the vertical or horizontal plane (selected at random). The unique shape (target) contained a line segment oriented either horizontally or vertically (selected at random). On distractor-absent trials, all ten items were the same color. On distractor-present trials, one of the non-target items appeared in the opposite color (distractor) as the other non-target items. Distractor-absent and distractor-present trials were randomly intermixed. The participants' task was to identify the orientation of the line contained within the target shape by pressing the "a" and "l" keys on a standard keyboard. The response keys were covered with blank, white stickers, and stimulus–response mappings were counterbalanced between participants.

Procedure

Upon arrival, participants completed the Trait version of the STAI (STAI-T; Spielberger & Gorsuch, 1983). Following the STAI-T, participants who received the anxiety induction (referred to as the "speech group") were told that they would be required to deliver an impromptu speech in front of an evaluative audience following the singleton search task. They were read the following instructions (Mansell, Clark, Ehlers, & Chen, 1999):

"Following the EEG part of this experiment will be an assessment of your social skills and public speaking ability. In a while, I'm going to ask you to make a speech on a controversial topic. Your speech will be given in front of me as well as advanced graduate students in the lab. We will rate your performance on several measures of the effectiveness of your presentation. I won't be giving you the topic of the speech until about two minutes before you begin the speech."

All participants then completed the STAI-S (the state version of the STAI) immediately prior to and immediately after the visual search task in order to confirm that individuals in the speech group experienced more state anxiety. Following task completion, those in the speech group were also asked to rate the extent to which they believed they would be required to deliver a speech on a 0 %–100 % scale. Participants were excluded from the analysis if their self-reported belief fell below 80 % (for a similar method, see Mansell et al., 1999).

The stimuli for the singleton task were presented on a Pentium R Dual Core computer, using E-Prime software (Psychology Software Tools, Inc.). Participants were seated approximately 60 cm from the monitor. Each trial began with the presentation of a central fixation cross (+), which remained present for a variable duration (600–1,200 ms). The search array was then presented until a response was given. Incorrect responses were accompanied by auditory feedback. The entire task consisted of 1,440 trials divided into 30 blocks of 48 trials. The 1,440 trials were comprised of the complete counterbalancing of the 10 target locations \times 2 target line orientations \times 2 target shapes \times 2 target shape colors \times 2 distractor conditions \times 9 distractor locations. Between blocks there was a participant-terminated break. Within each block, the order of trials was randomized. Prior to beginning the experiment, each participant performed one practice block of 48 trials.

Psychophysiological data recording, reduction, and analysis

EEG activity was recorded from 64 Ag–AgCl electrodes fitted in a BioSemi (BioSemi, Amsterdam, The Netherlands) stretch-Lycra cap. In addition, two electrodes were placed on the left and right mastoids. The electro-oculogram (EOG) generated by eye movements and blinks was recorded at FP1, as well as by electrodes placed below the left eye and on the left and right outer canthi, all approximately 1 cm from the pupil. During data acquisition, the common mode sense active electrode and driven right leg passive electrode formed the ground. All bioelectric signals were digitized at 512 Hz.

Offline analyses were performed using BrainVision Analyzer 2 (BrainProducts, Gilching, Germany). Scalp electrode recordings were re-referenced to the numeric mean of the mastoids and band-pass filtered (0.1–30 Hz; 24 dB/oct rolloff). Ocular artifacts were then corrected using the method developed by Gratton, Coles, and Donchin (1983). The stimulus-locked data were segmented into individual epochs beginning 100 ms prior to the stimulus and continued for 600 ms. Individual trials were rejected on the basis of the following criteria: a voltage step exceeding $50\mu\text{V}$ between contiguous sampling points, a voltage difference of more than $200\mu\text{V}$ within a trial, or a maximum voltage difference less than $0.5\mu\text{V}$ within a trial. This resulted in the loss of an average of 9.64 % of trials across participants (a maximum

of 18.51 % for any individual participant). Additionally, to further verify that the electrical activity generated by ocular movements was not contaminating the N2pc waveform, we inspected the averaged HEOG activity. Overall, HEOG deflections were quite small and were similar in size across conditions: averages of $2.8\mu\text{V}$ for distractor-absent trials, $2.6\mu\text{V}$ for lateral target/ipsilateral distractor trials, and $2.5\mu\text{V}$ for lateral target/contralateral distractor trials (see below for a breakdown of the conditions). This indicates that (1) it is unlikely that ocular activity contributed substantially to the N2pc effects in the present study and (2) eye movements were generally less than 0.1° , suggesting that our findings cannot be accounted for by oculomotor capture (see Hickey et al., 2006; McDonald & Ward, 1999; and Woodman & Luck, 2003, for similar procedures). A baseline consisting of the average activity in the 100-ms prestimulus window was subtracted from each data point following stimulus onset.

There were three main conditions of interest (e.g., Hickey et al., 2006): (1) trials in which a lateralized target was presented in the absence of a distractor (referred to as “distractor-absent trials”), (2) trials in which a lateralized target was presented with a distractor in the same hemifield (referred to as “lateral target/ipsilateral distractor trials”), and (3) trials in which a lateralized target was presented with a distractor in the opposite hemifield (referred to as “lateral target/contralateral distractor trials”).

Given that the results were similar across posterior, lateralized electrode sites (e.g., PO3/4, P5/6, P7/8 and O1/2), that our main interests were in differences across conditions (rather than regions), and that studies using this task have focused on PO7 and PO8 (e.g., Hickey et al., 2006), we limited the analyses presented here to sites PO7 and PO8. For all conditions, waveforms were first computed for electrode sites contralateral to the target (e.g., if the target appeared in the left hemifield, this contralateral wave was computed at PO8). Waveforms were then computed for electrode sites ipsilateral to the target (e.g., if the target appeared in the left hemifield, this ipsilateral wave was computed at PO7). We collapsed across trials in which the target appeared in the left and right hemifields separately for each condition (i.e., we averaged PO7 when the target appeared in the right hemifield with PO8 when the target appeared in the left hemifield). These waves were then subtracted (the electrode contralateral-to-target minus the electrode ipsilateral-to-target) in order to create the N2pc difference waves. The N2pc for each condition was then defined as the average activity in the 200 to 300 ms window (see Hickey et al., 2006, for a very similar method; see also Luck, 2012).

Data preparation and analyses

Trials in which an erroneous response was committed were not included in subsequent analyses (error rates are presented

in Table 2). Trials were also excluded due to excessively slow responses ($>2,000$ ms). This resulted in the loss of 4.2 % of trials. Statistical analyses were conducted using SPSS v.20. RTs, error rates, and ERPs were submitted to separate repeated measures analyses of variance. These analyses included a three-level within-subjects factor (Distractor Condition: distractor absent vs. lateral target/ipsilateral distractor vs. lateral target/contralateral distractor) and a two-level between-subjects factor (Group: speech vs. control). STAI-T scores were entered as a continuous predictor and the Greenhouse–Geisser correction was applied to the repeated measures tests (although the original degrees of freedom are reported). Follow-up analyses are reported when effects involving group or STAI-T scores reached statistical significance in the omnibus analysis. When distractor condition interacted in the omnibus analysis, we computed capture scores as distractor-present minus distractor-absent trials in order to conduct follow-up correlations. Specifically, we computed the following distractor cost effects: RT ipsilateral cost (RTs on lateral target/ipsilateral distractor trials minus RTs on distractor-absent trials), RT contralateral cost (RTs on lateral target/contralateral distractor trials minus RTs on distractor-absent trials), N2pc ipsilateral cost (N2pc on lateral target/ipsilateral distractor trials minus N2pc on distractor-absent trials), and N2pc contralateral cost (N2pc on lateral target/contralateral distractor trials minus N2pc on distractor-absent trials).¹ STAI-S scores were compared using a 2 (Group: speech vs. control) \times 2 (Time: pre vs. post) analysis of variance. Follow-up *t* tests were conducted in order to confirm that the manipulation had the intended effect (see Table 1 for descriptive statistics for the STAI-T and STAI-S).

Results

Anxiety manipulation

With respect to state anxiety scores, we found a main effect of group [$F(1, 120) = 7.90, p < .01$], such that state anxiety scores were greater in the speech group. This was qualified by a Group \times Time interaction [$F(1, 120) = 5.67, p = .02$], indicating that the two groups were equivalent on state anxiety at pretest but that the speech group showed higher state anxiety scores at posttest (see Table 1 for the means and follow-up tests). Thus, self-reported state anxiety indicated that our speech manipulation had produced the desired effect.

¹ Referring to both the RT and N2pc as “distractors costs” is a convenience to aid in the reading of this text; it is not to imply a relationship between these measures or to posit a theoretical explanation for the effect of distractors on these measures.

Table 2 Descriptive statistics for performance measures in the search task

Variable	Control	Speech	<i>t</i>
% errors (distractor absent)	2.74 (1.73)	2.51 (1.81)	0.73
% errors (lateral target/ipsilateral distractor)	3.75 (3.16)	3.36 (3.17)	0.69
% errors (lateral target/contralateral distractor)	3.24 (2.79)	3.09 (2.57)	0.43
RT (distractor absent)	911.95 (122.78)	923.99 (137.69)	0.51
RT (lateral target/ipsilateral distractor)	1,088.03 (215.44)	1,074.27 (226.28)	0.34
RT (lateral target/contralateral distractor)	976.32 (148.46)	986.77 (175.53)	0.36
N2pc (distractor absent)	-0.46 (1.41)	-0.36 (1.64)	0.73
N2pc (lateral target/ipsilateral distractor)	-1.36 (2.29)	-1.23 (2.25)	0.63
N2pc (lateral target/contralateral distractor)	0.013 (0.95)	-0.021 (1.09)	0.37

The *t* column presents an independent samples *t* test comparing the speech and control groups. No comparisons reached significance.

Behavioral performance

Performance measures are presented in Table 2. For accuracy, participants were significantly less accurate when a distractor was present [$F(2, 242) = 21.46, p < .001$]. There were significantly more errors on lateral target/ipsilateral distractor trials than on lateral target/contralateral distractor trials [$t(121) = 2.14, p = .03$], and both distractor types were significantly less accurate than distractor-absent trials ($ts > 4, ps < .001$). No other effects were significant ($ps > .15$). With respect to RTs, the results revealed a significant effect of distractor condition [$F(2, 242) = 65.94, p < .001$; see Fig. 2], such that responses were slower when a distractor was present. Specifically, RTs on lateral target/ipsilateral distractor trials were significantly longer than those on lateral target/contralateral distractor trials [$t(121) = 4.74, p < .001$]. Both distractor conditions showed longer RTs than did the distractor-absent trials ($ts > 4, ps < .001$; see Hickey et al., 2006, for a similar pattern of behavioral results). The combined pattern of RT and accuracy data counter indicates a speed-accuracy trade-off.

We also observed a significant main effect of STAI-T scores on RTs [$F(1, 118) = 18.67, p < .001$]; consistent with previous work, this was qualified by a significant STAI-T \times Distractor Condition interaction [$F(2, 236) = 20.12, p < .001$; Moser et al., 2012]. As is shown in Table 3, follow-up correlations revealed that STAI-T scores were significantly correlated with RT ipsilateral cost scores ($r = .49, p < .001$). An examination of these correlations (see Table 3) suggests that the association between STAI-T and RT ipsilateral cost was driven largely by lateral target/ipsilateral distractor trials ($r = .46, p < .001$) and not by distractor-absent trials ($r = .15, p = .11$). Interestingly, RTs on lateral target/contralateral distractor trials were also associated with anxiety ($r = .25, p < .01$); however, the association between STAI-T and the RT contralateral cost did not reach significance ($r = .16, p = .09$). Finally, we conducted a partial correlation of STAI-T and RTs on lateral target/contralateral distractor trials, controlling for RTs on lateral target/ipsilateral distractor trials.

Doing so significantly reduced the correlation between STAI-T and RTs on lateral target/contralateral distractor trials ($r = .07, p = .45$). Importantly, the correlation between STAI-T and RTs on lateral target/ipsilateral distractor trials remained significant after controlling for RTs on lateral target/contralateral distractor trials ($r = .40, p < .001$). Therefore, all subsequent analysis of the RT data focuses on those associated with lateral target/ipsilateral distractor trials. We found no other effects of group or STAI-T ($ps > .60$).

N2pc

The N2pc waveforms are depicted in Fig. 2. A significant main effect of distractor condition on the N2pc was apparent [$F(2, 242) = 16.83, p < .001$]. Consistent with previous work (e.g., Hickey et al., 2006), the N2pc's elicited on distractor-absent and lateral target/ipsilateral distractor trials were significantly different from zero ($ts > 3, ps < .01$). The N2pc elicited on lateral target/contralateral distractor trials did not differ from zero [$t(121) = 0.01, p = .99$]. The N2pc elicited on lateral target/ipsilateral distractor trials was more negative than that elicited on distractor-absent trials; additionally, both were more negative than the N2pc elicited on lateral target/contralateral distractor trials ($ts > 2.2, ps < .03$).

As predicted, we also observed a significant STAI-T \times Distractor Condition interaction [$F(2, 236) = 12.33, p < .001$]. STAI-T scores were significantly correlated with greater N2pc costs, measured as lateral target/ipsilateral distractor trials minus distractor absent trials ($r = -.33, p < .001^2$; Table 3). As with RTs, this effect was largely driven by lateral target/ipsilateral distractor-present trials ($r = -.38, p < .001$) and not by distractor-absent trials ($r = -.06, p = .51$). With respect to lateral target/contralateral distractor trials, neither

² Note that, since the N2pc is a negative deflection, this negative correlation should be interpreted as a positive association. That is, greater anxiety predicted greater N2pc enhancement.

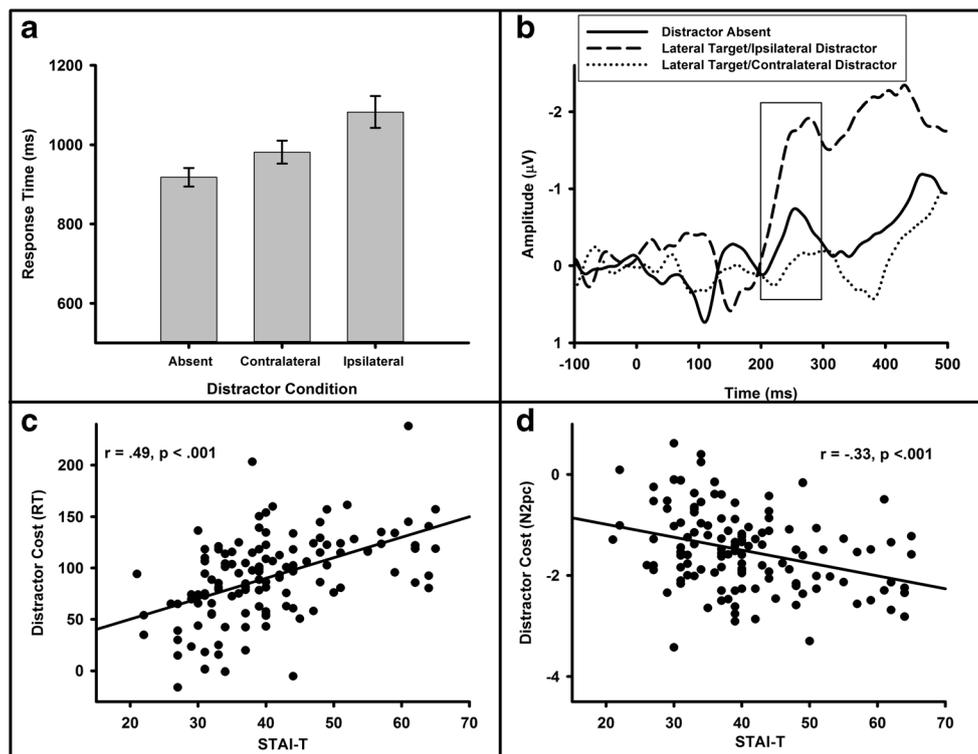


Fig. 2 (a) Response times (RTs) as a function of distractor condition. Error bars represent ± 2 SEs. (b) Stimulus-locked waveforms as a function of distractor condition. A rectangle is drawn over the N2pc time window.

Waveforms are averaged over PO7 and PO8. (c) Scatterplot depicting the association between STAI-T scores and RT ipsilateral cost. (d) Scatterplot depicting the association between STAI-T scores and N2pc ipsilateral cost

the N2pc elicited on lateral target/contralateral distractor trials ($r = -.13, p = .14$) nor the N2pc contralateral cost ($r = -.11, p = .23$) related to trait anxiety scores. No other effects reached significance ($F_s < 1.2, p_s > .3$).

A regression analysis was then conducted predicting STAI-T scores with measures of attentional capture (RT ipsilateral cost and N2pc ipsilateral cost). Overall, the regression was significant [$F(2, 119) = 26.79, p < .001, R^2_{adj} = .29$]. RT ($t = 4.86, p < .01, \beta = .36$) and N2pc ($t = -3.16, p = .001, \beta = -.26$) were both significant predictors.

Given the independence of the RT and N2pc measures of distractor cost and our hypothesis that the RT effects resulted from inefficient filtering/inhibition of distracting information (also see Moser et al., 2012), we examined the association between RT cost and N2pc cost separately for high- and low-trait-anxious participants (based on a median split of the STAI-T). We hypothesized that if anxiety is associated with inefficient filtering processes, then for high-anxious participants, RT distractor costs should not be related to N2pc costs (lateral target/ipsilateral distractor minus distractor absent),

Table 3 Correlations between anxiety and search task measures

Variable	1	2	3	4	5	6	7	8
1. STAI-T	–							
2. STAI-S (Time 1)	.62***	–						
3. STAI-S (Time 2)	.51***	.66***	–					
4. RT–Distractor absent	.15	.08	.04	–				
5. RT–Lateral target/ipsilateral distractor	.46***	.11	.09	.75***	–			
6. RT–Ipsilateral cost	.49***	.08	.06	.43**	.79***	–		
7. N2pc–Distractor absent	-.06	-.08	-.10	.06	.09	.08	–	
8. N2pc–Lateral target/ ipsilateral distractor	-.38***	-.16	-.15	.07	-.14	-.18*	.56***	–
9. N2pc–Ipsilateral cost	-.33***	-.13	.14	.10	-.20*	-.19*	.34***	.65***

* $p < .05$, ** $p < .01$, *** $p < .001$

indicating that the filtering process is not resulting in decreased distraction. For low-anxious participants, on the other hand, greater N2pc ipsilateral costs should lead to reduced distraction. Indeed, this was the case. For distractor costs associated with lateral target/ipsilateral distractor trials, high-anxious participants showed no association between RT and N2pc cost ($r = .05$, $p = .80$), whereas low-anxious participants showed a significant association ($r = .35$, $p < .01$; $z = 2.27$, $p = .02$), indicating that a larger N2pc ipsilateral cost was associated with a reduced RT ipsilateral cost. For costs associated with lateral target/contralateral distractor trials, we observed no difference between high- and low-anxious participants ($z = 0.43$, $p = .67$). Together, these data indicate that anxious individuals inefficiently filter/inhibit salient distractors (as evidenced by no association between the N2pc and RTs), but only when targets and distractors are in close proximity.

Self-reported state-anxiety analyses

The anxiety manipulation did not produce any effects on RTs or ERPs suggesting that attentional-capture effects are specifically related to dispositional anxiety. However, the effect of the manipulation on state anxiety was small and only apparent following the search task (see Table 1). This may have mitigated any effect of the manipulation on indices of attentional capture. In order to further explore this issue, we examined the relationships between self-reported state anxiety and measures of attentional capture. In opposition to the notion that anxious states enhance attentional capture, no effects involving the STAI-S were significant ($r_s < |.16|$, $p_s > .07$; see Table 3). In combination with the between-subjects results, these data suggest that capture is most closely related to trait anxiety.

Discussion

Basic science implications

Emerging theorizing on the interplay between anxiety and cognition posits much broader attentional deficits than have previously been considered. The present study has been the first to investigate attentional biases related to anxiety during a nonvalenced visual search task using both behavioral and electrophysiological techniques. Here, we have provided multiple sources of evidence linking anxiety to attentional biases favoring perceptually salient, but affectively neutral, stimuli. First, anxious individuals showed increased attentional capture on distractor-present trials, as evidenced by slowed RTs—particularly when the target and distractor were in close

proximity. Second, anxious individuals showed greater N2pc enhancement to lateral target/ipsilateral distractor trials³ than did nonanxious individuals. Third, we noted that anxious individuals were characterized by inefficient filtering of irrelevant information (i.e., an enhanced N2pc did not predict decreases in RT costs) when distractors were presented near targets. Finally, this study failed to find evidence that state anxiety, whether induced or measured via self-report, modulated any index of attentional capture in the present task.

Research focusing on neutral stimuli has typically utilized multifaceted tasks (see Eysenck et al., 2007, and Derakhshan & Eysenck, 2009, for reviews), which makes it difficult to identify the underlying mechanisms most affected by anxiety. The present study, along with our previous work (Moser et al., 2012), has demonstrated that anxiety is associated with increased attentional capture by salient, neutral stimuli. Importantly, since this task was relatively process-pure (i.e., it involved few types of cognitive processes, and the distractors were irrelevant to task performance), these effects likely resulted specifically from anxiety's effects on attention. The N2pc data were quite similar to those previously reported in this task (e.g., Hickey et al., 2006) and mirrored previous reports of enhanced N2pc amplitudes in phobic patients in response to fear-relevant stimuli (i.e., Buodo et al., 2010). Specifically, we noted that the lateralized targets presented without a distractor elicited an N2pc, that the N2pc was enhanced in the presence of a nearby (i.e., ipsilateral) color singleton and, finally, that trait anxiety was associated with the degree of enhancement on lateral target/ipsilateral distractor trials (relative to distractor-absent trials).

Previous work had suggested that posterior negativities in the latency range of the N2 reflect the activity of a functional network involving the prefrontal cortex that is necessary for top-down visual target detection (Potts & Tucker, 2001; see also Goldman-Rakic, 1988). Consistent with this notion, the N2pc appears to be more reflective of top-down filtering processes than of bottom-up salience detection processes (Luck & Hillyard, 1994a, 1994b). In the present study, anxious individuals exhibited increased activity related to filtering irrelevant information (i.e., enhanced N2pc), but slowed RTs and unchanged accuracy. This effect was most prominent on trials in which the distractor was ipsilateral to the target—that

³ We quantified the N2pc elicited on lateral target/contralateral distractor trials across the entire time window (200–300 ms). However, some authors (Hickey et al., 2006) have divided this time window into two segments: an early segment characterized by a positivity (i.e., target-contralateral activity was less negative because attention was initially allocated to the distal distractor), and a later time window characterized by the standard N2pc effect (greater negativity at target-contralateral sites). On the basis of visual inspection, we divided the contralateral distractor N2pc wave into two segments: 200–240 and 240–300 ms. However, neither of the costs were related to anxiety ($p_s > .31$).

is, on trials that required the greatest degree of distractor suppression (Hickey et al., 2006; Luck et al., 1997; Moran & Desimone, 1985). Thus, these results suggest that anxiety is characterized by inefficient filtering of irrelevant information (Stout et al., 2013), but only when the irrelevant information strongly competes with goal-relevant information and needs to be actively inhibited. Importantly, when we split participants on the basis of STAI-T scores, we found that the N2pc cost predicted distractor costs only for low-anxious participants on ipsilateral distractor trials. For high-anxious participants this effect was near zero suggesting that the filtering process is functioning inefficiently and not acting to reduce distraction in anxious participants. This notion is consistent with Eysenck and colleagues' (2007) proposal that distractor inhibition processes will operate inefficiently (e.g., overactive filtering processes unaccompanied by behavioral improvements) in anxiety.

Clinical implications

Work by Amir and colleagues (e.g., Amir et al., 2009) has led to the development of a treatment protocol specifically aimed at addressing the attentional biases underlying anxious pathology. The results from the present study suggest that anxiety is associated with attentional-control deficits more broadly. Thus, the present data suggest that a fruitful avenue for future work would be to develop attention training programs that include salient, neutral stimuli as an alternative to threatening stimuli. For example, Leber and Egeth (2006), using a variant of the additional-singleton search task utilized in the present study, noted that when participants adopted a feature-based search strategy—that is, a top-down search strategy focused on locating target-specific features—it was possible to override the attentional capture typical of this task. We are currently examining the effect that adopting such top-down strategies has on anxiety symptoms.

Similarly, previous research has demonstrated that attentional biases play an important causal role in the etiology of anxiety. MacLeod and colleagues (2002) experimentally induced attentional biases for threat-relevant stimuli, which subsequently resulted in higher levels of negative emotionality. These results provide important initial insights into the development of anxiety disorders. Specifically, they suggest that individual differences in attention allocation to threat may represent an important causal mechanism in the development of anxiety. The present study has extended such findings by suggesting that individual differences in attentional control at a more basic level may contribute to anxiety. An important avenue for future research, then, will be to determine what, if any, causal role nonaffective attentional biases play in the etiology of anxiety.

Limitations/future directions

We note that the effectiveness of our state-anxiety manipulation may have limited the interpretability of the state-anxiety effects. That is, although the speech group did show significantly higher posttask STAI-S scores, this effect was (1) somewhat small (5.8 points on the STAI-S/Cohen's $d = 0.59$) and (2) not present prior to the search task. It is possible that the manipulation did not “take effect” right away since participants were aware that they would be completing a search task and could defer anxiety regarding the speech. Thus, it seems possible that a manipulation that induced anxiety more quickly might still modulate measures of capture. However, we also supplemented these data with self-reported anxiety scores, which led to the same conclusion. It therefore seems likely that the association between anxiety and attentional capture is limited to anxiety as measured as a dispositional trait, with the caveat that additional work will be needed to determine whether other anxiety manipulations might effectively modulate capture.

It is also important to point out that the N2pc elicited on ipsilateral trials cannot be interpreted completely unambiguously. That is, it is difficult to know whether attention was focused on the target or the distractor. However, trait anxiety interacted with distractor condition such that greater anxiety predicted greater N2pc ipsilateral costs—that is, the lateral target/ipsilateral distractor N2pc after the distractor-absent N2pc had been subtracted out. Thus, our results cannot be explained by suggesting that anxiety influences some aspect of target processing alone. It is possible, however, that, although we interpreted our data as resulting from inefficient filtering of distractors (i.e., a process that is carried out on representations of the distractor stimuli *per se*), anxiety may have influenced some operation applied to the target that was only apparent when distracting items were also present (e.g., some target identification process that operates by suppressing distractors; Luck, 2012; Luck & Hillyard, 1994a). Alternatively, it is also possible that the effects observed in the present study could be interpreted as a form of “freezing behavior” in response to salient or deviant stimuli. For example, Gray (1982) suggested that such stimuli prompt a “stop-signal” that inhibits ongoing behavior (see also Corbetta, Patel, & Shulman, 2008) until the stimulus has been analyzed—that is, salient or deviant stimuli may represent an ambiguous threat until they have been processed and deemed safe. Although these issues cannot be completely resolved with the present data, we note that (1) the N2pc has generally been interpreted as reflecting a filtering operation applied to distractors (e.g., Hickey et al., 2006; Luck, 2012; Luck & Hillyard, 1994a, 1994b; Woodman & Luck, 1999, 2003; however, see Eimer, 1996); (2) anxiety has regularly been associated with aberrant distractor processing, but not with target processing (see Derakhshan & Eysenck, 2009; Eysenck

& Derakhshan, 2011; Eysenck et al., 2007, for reviews); and (3) the fact that anxiety was associated with RTs/N2pc on lateral target/ipsilateral distractor trials in particular argues against a “freezing-behavior” interpretation because a mechanism that functions to detect potential threats would be most effective if it operated over the entire visual field. Thus, although the present data do not settle this issue conclusively, it would seem that our initial interpretation—that is, that anxiety affected a filtering process—is the interpretation that is most consistent with the extant literature.

Conclusions

In sum, the present study is among the first to directly demonstrate that trait anxiety is associated with not only an attentional bias favoring threat, but enhanced attentional capture by salient stimuli in general. Importantly, this study utilized a “process-pure” task and multiple indices of attentional capture thereby demonstrating specific deficits in attentional processes. The present study failed to find evidence for the notion that state anxiety, whether induced or measured via self-report, enhances attentional capture by salient, neutral stimuli; rather, this increased distractibility appears to be characteristic of the general propensity to experience anxiety. Future research should investigate the causal role for this non-affective saliency bias in anxiety and the possibility of targeting it in attention-based treatment regimens.

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