



## Anxiety and spatial attention moderate the electrocortical response to aversive pictures

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### ABSTRACT

Aversive stimuli capture attention and elicit increased neural activity, as indexed by behavioral, electrocortical and hemodynamic measures; moreover, individual differences in anxiety relate to a further increased sensitivity to threatening stimuli. Evidence has been mixed, however, as to whether aversive pictures elicit increased neural response when presented in unattended spatial locations. In the current study, ERP and behavioral data were recorded from 49 participants as aversive and neutral pictures were simultaneously presented in spatially attended and unattended locations; on each trial, participants made same/different judgments about pictures presented in attended locations. Aversive images presented in unattended locations resulted in increased error rate and reaction time. The late positive potential (LPP) component of the ERP was only larger when aversive images were presented in attended locations, and this increase was positively correlated with self-reported state anxiety. Findings are discussed in regard to the sensitivity of ERP and behavioral responses to aversive distracters, and in terms of increased neural processing of threatening stimuli in anxiety.

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A variety of evidence suggests that aversive stimuli readily capture attention, alerting organisms to potential threats in the environment (e.g., Eastwood, Smilek, & Merikle, 2001; LeDoux, 1996; Öhman, Lundqvist, & Esteves, 2001). Though this may generally be viewed as adaptive, the prioritization of threatening information can come at the cost of other, task-relevant needs. For example, participants perform relatively worse on simple choice tasks in the face of threatening compared to neutral distracters (e.g., Hartikainen, Ogawa, & Knight, 2000; VanDamme, Crombez, & Notebaert, 2008). Some researchers have hypothesized that the processing of threat-related stimuli may occur in an obligatory fashion, resulting in reduced availability of attentional resources (e.g., Dolan & Vuilleumier, 2003; Vuilleumier, Armony, Driver, & Dolan, 2001).

Studies using fMRI have supported the notion that the automatic processing of threatening information may depend on activity of the amygdala. For instance, Vuilleumier et al. (2001) designed a task in which participants simultaneously viewed a pair of houses and a pair of faces, presented above and below and to the left and to the right of fixation. Participants were required to decide whether a pair of houses or faces, presented in attended spatial locations, were the same or different. Results indicated that fearful faces presented in unattended spatial locations elicited increased

activity in the amygdala. Using the same paradigm in patients with lesions involving the amygdala, hippocampus, or both, as well as matched controls, Vuilleumier, Richardson, Armony, Driver, and Dolan (2004) found that only patients with amygdala lesions failed to show increased activation in the visual cortex for unattended fearful faces—further suggesting that the processing and detection of unattended emotional stimuli may depend on the amygdala. Finally, increased amygdala activation to fearful faces presented in the unattended visual field has also been documented among patients with unilateral spatial neglect—and because patients were unaware of the stimuli, these results also indicate that the amygdala response to threatening facial stimuli is not mediated by spatial attention or awareness (Vuilleumier et al., 2002).

Nevertheless, work by Pessoa and colleagues (Pessoa, McKenna, Gutierrez, & Ungerleider, 2002; Pessoa, Padmala, & Morland, 2005) has suggested that unattended emotional stimuli might elicit amygdala activity, but only when task-related attentional demands are low. In one study, unattended emotional faces elicited increased neural activity in easy, but not in medium or hard task conditions. Using a design similar to that of Vuilleumier et al. (2001), Silvert et al. (2007) also explored the effects of task difficulty by presenting participants with pairs of faces and houses; however, faces and houses were tilted slightly. Participants were asked to either indicate whether two images were the same or different ('identification') or whether they were tilted at the same or different angles ('orientation'), while ignoring the other pair of images. The authors reported that in the easier orientation task, greater amygdala activ-

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ity was evidenced for unattended fearful compared to neutral faces; however, in the more difficult identification task, threatening stimuli presented in unattended locations did not influence amygdala activity. Collectively, these results suggest that attentional demands may impact whether amygdala activity is observed when aversive stimuli are presented in unattended spatial locations.

The effect of spatial attention on the processing of emotional stimuli has also been explored using event-related potentials (ERPs). In particular, the late positive potential (LPP) component of the ERP is a parietal positivity that is larger for emotional compared to neutral stimuli (Cuthbert, Schupp, Bradley, Birbaumer, & Lang, 2000; Dillon, Cooper, Grent-'t-Jong, Woldoff, & LaBar, 2006; Hajcak & Nieuwenhuis, 2006; Hajcak & Olvet, 2008; Schupp et al., 2000; Schupp, Junghöfer, Weike, & Hamm, 2003, 2004). The available evidence suggests that emotional stimuli presented in unattended locations do not elicit increased LPPs. Using a task similar to Vuilleumier et al. (2001), Holmes, Vuilleumier, and Eimer (2003) found that fearful faces elicited larger electrocortical positivities than neutral faces when they were presented in spatially attended, but not unattended locations. Likewise, only emotional faces presented in attended spatial locations elicited increased parietal positivities in Eimer, Holmes, and McGlone's (2003) work. Moreover, Dunning and Hajcak (2009) recently found that directing spatial attention *within* aversive pictures influenced the LPP: when participants were instructed to direct attention to a less emotional part of an aversive picture, the LPP did not differ from neutral pictures (cf. Hajcak, Dunning, & Foti, 2009). Thus, although the LPP appears to reflect increased processing of salient emotional stimuli, this effect appears to depend heavily on spatial attention.

There is further evidence that individual differences in anxiety may interact with spatial attention to determine the extent of emotional interference from task-irrelevant stimuli. In particular, biased attention toward threat-related stimuli has been theorized to play a role in the development and maintenance of anxiety (e.g., Beck & Emery, 1985; Eysenck, 1997; Mathews & Mackintosh, 1998; Mogg & Bradley, 1998; Williams, Watts, MacLeod, & Mathews, 1997). For instance, individuals with greater anxiety are slower to disengage attention from threatening stimuli (Derryberry & Reed, 2002; Fox, Russo, Bowles, & Dutton, 2001; Fox, Russo, & Dutton, 2002; Yiend & Mathews, 2001) and faster to detect objects that appear in locations previously occupied by threatening or fearful faces (Bradley, Mogg, Falla, & Hamilton, 1998; Fox, 2002). Indeed even when awareness of threatening stimuli is minimized using backward masking, high anxious participants continue to evidence greater interference than low anxious participants (Fox, 1996; Mogg, Bradley, Williams, & Mathews, 1993). These data have been taken as support for the notion that anxiety is associated with *increased* automatic processing of threatening information (e.g., Mathews, Mackintosh, & Fulcher, 1997). Using fMRI and a task similar to Vuilleumier et al.'s (2001), Bishop, Duncan, and Lawrence (2004) found that among *low state anxious* participants, fearful faces elicited less amygdala response when presented in unattended locations. For *high state anxious* participants, however, amygdala response to fearful faces was comparable when they were presented in both unattended and attended locations. Like task difficulty, then, individual differences in anxiety may moderate the neural response to aversive stimuli presented in unattended spatial locations.

The present study aimed to build upon this previous work to determine if the parietal positivity (i.e., the LPP) elicited by emotional stimuli is modified by spatial attention and state anxiety. To this end, an image-matching task similar to that used by Vuilleumier et al. (2001) was employed, which required participants to determine whether two pictures presented in attended locations were the same or different; on each trial, two images were also presented in unattended locations. In the current study, pictures from the International Affective Picture System (IAPS; Lang,

Bradley & Cuthbert, 2005) were used instead of faces and houses for two reasons. First, this would facilitate comparison with a wider body of ERP research on emotion and attention using IAPS pictures. Second, unpleasant IAPS pictures are more emotionally arousing than faces (Britton, Taylor, Sudheimer, & Liberzon, 2006). Thus, previous failures to find modulation of parietal positivities by stimuli in unattended locations may have been related to the use of less arousing facial stimuli.

Prior studies using this type of task have allowed *either* targets or distracters – but not both simultaneously – to be threat-related. The present study, however, fully crossed target (neutral, aversive) and distracter (neutral, aversive) stimuli so that the effect of emotional as compared to neutral distracters could be examined in the context of processing both emotional and neutral stimuli presented in attended locations. In all conditions, picture type (neutral, aversive) was irrelevant to the task at hand. In this way, the present study focused exclusively on how task-irrelevant aversive content impacts ERP and behavioral measures—and whether these effects were moderated by spatial attention and state anxiety. It was hypothesized that both aversive targets and distracters would elicit longer reaction times (Bishop et al., 2004) and a greater percentage of errors (Keil, Moratti, Sabatinelli, Bradley, & Lang, 2005). Based on existing work using faces, it was hypothesized that aversive pictures presented in attended locations – but not aversive pictures presented in unattended locations – would elicit significantly larger parietal positivities (Eimer et al., 2003; Holmes et al., 2003). Based on previous fMRI work, however, we expected that the LPP *would* be increased for aversive compared to neutral distracters as a function of participants' reported anxiety (Bishop et al., 2004).

## 1. Method

### 1.1. Participants

Fifty-four undergraduate students participated in the study. Three participants were excluded from analyses because their behavioral responses were not recorded; one participant was excluded because of excessive errors on the task (i.e., greater than 50%), and one participant was excluded due to poor quality EEG recording. Data from 49 participants (16 male, 33 female) were included in the final analysis of EEG data. Self-report responses on the state version of the State Trait Anxiety Inventory (STAI; Spielberger, 1983) were collected from 46 of these participants (14 male, 32 female). All participants received course credit.

### 1.2. Stimulus materials

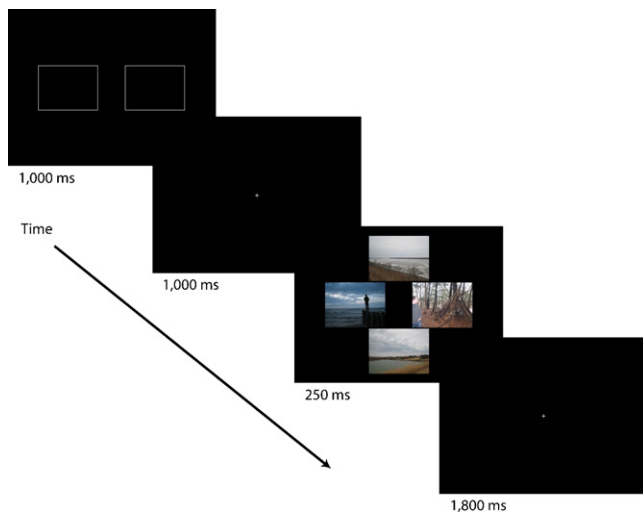
A total of 96 pictures were selected from the IAPS (Lang et al., 2005). There were 48 aversive pictures (e.g., attack scenes, mutilated bodies) and 48 neutral pictures (e.g., household objects, neutral faces).<sup>1</sup> Normative ratings (Lang et al., 2005) indicated that the aversive pictures were less pleasant (valence  $M = 2.50$ ,  $SD = 1.58$ ) than the neutral pictures ( $M = 5.12$ ,  $SD = 1.32$ ); ratings have been reverse-scored so that higher numbers indicate more pleasant ratings, and were higher in arousal ratings ( $M = 6.26$ ,  $SD = 2.20$ ) than neutral pictures ( $M = 3.45$ ,  $SD = 1.99$ ); ratings have been reverse-scored so that higher numbers indicate higher arousal.

Stimuli were presented on a Pentium D computer, using Presentation software (Neurobehavioral Systems Inc.; Albany, CA). Pictures were displayed in color for 250 ms at a size of 293 pixels across by 219 pixels high, or approximately 1/12 of the total monitor area (1024 × 768 pixels; 48.26 cm). Participants were seated approximately 60 cm from the screen.

### 1.3. Procedure

Following verbal instructions indicating that they would be viewing pictures of varying emotional quality, participants were seated and electroencephalograph

<sup>1</sup> The IAPS pictures used were aversive (1050, 1090, 1120, 1205, 1220, 1240, 1270, 1280, 1300, 1930, 1932, 2120, 2800, 2811, 3030, 3051, 3060, 3068, 3069, 3080, 3100, 3102, 3120, 3140, 3170, 3230, 3250, 3261, 3350, 3530, 6260, 6313, 6315, 6350, 6360, 6370, 6510, 6530, 6540, 6550, 6560, 6570, 9040, 9042, 9140, 9301, 9320, 9570) and neutral (1390, 1450, 1650, 1670, 1810, 1935, 2038, 2102, 2190, 2200, 2210, 2214, 2357, 2383, 2393, 2397, 2446, 5500, 5510, 5530, 7000, 7002, 7030, 7034, 7036, 7037, 7040, 7041, 7054, 7057, 7060, 7110, 7130, 7175, 7234, 7491, 7493, 7496, 7500, 7501, 7546, 7547, 7550, 7560, 7595, 7620, 7710, 7920).



**Fig. 1.** A sample trial from the task: a pair of horizontal (or vertical) white rectangles on a black background directed participants' attention to the upcoming 'target' pictures. Following the presentation of four images, participants indicated as quickly and as accurately as they could whether the two target images (those that replaced the rectangles) were identical ('same') or different ('different').

sensors were attached. Immediately prior to the start of the task, participants were asked to complete the state version of the STAI (Spielberger, 1983). This questionnaire consists of 20 items; responses are made on a scale ranging from 1 ("Not At All") to 4 ("Very Much So"). Responses can reach a maximum of 80; greater scores indicate higher levels of state anxiety.

Participants were told that on each trial of the task, they would see four total pictures—two to the right and left, and two above and below the center of the screen; they were told that on each trial, they would have to indicate whether two of the pictures were the same or different. In particular, participants were instructed that on some trials, they would make this same/different decision about the top and bottom pictures, and on other trials, they would make this same/different decision about the left and right pictures.

Fig. 1 depicts the sequence of events during a trial of the task. On each trial, a pair of horizontal or vertical rectangles measuring  $293 \times 219$  pixels with a 2 pixel-wide white border appeared on a black screen for 1000 ms. The rectangles indicated which pictures (i.e., horizontal or vertical) would be the targets for the same/different decision in the upcoming trial. Next, a white fixation cross was presented on a black screen for 1000 ms, after which four color pictures appeared on the screen simultaneously for 250 ms, arranged so that they formed a pair of horizontal and a pair of vertical images. After picture offset, a white fixation cross was presented again on a black screen for up to 1800 ms. Participants were asked to indicate as quickly and as accurately as possible whether the two target pictures were identical ('same') or different ('different'); this decision was made using the left and right arrow keys (key correspondence was counterbalanced across participants). The trial ended as soon as participants responded or at 1800 ms following picture offset if no response was made. Each trial was followed by a random inter-trial interval (a black screen) of 50–150 ms duration.

Participants performed 10 practice trials while the experimenter observed their responses and ensured that they understood the task. Following the practice trials, all participants performed 320 trials. There were 32 trial types, corresponding to all the possible combinations of picture type, picture location and whether the pictures were the same or different:  $2$  (target: neutral, aversive)  $\times 2$  (target: same, different)  $\times 2$  (target: horizontal, vertical)  $\times 2$  (distracter: neutral, aversive)  $\times 2$  (distracter: same, different). Trials and pictures were presented pseudo-randomly—every participant saw all 32 trial types and each picture exactly 10 times. The task required 960 picture selections; these selections were evenly and randomly distributed between the conditions—240 in each of the four conditions. Both picture types (in the horizontal or vertical pairs) were always the same; in other words, neutral and aversive pictures were never mixed *within* the horizontal and vertical pairs. For the purpose of analysis, only the effects of target and distracter type (neutral, aversive) were of importance and yielded four conditions: 80 trials in which target pictures were aversive and distracters were aversive; 80 trials in which target pictures were neutral and distracters were neutral; 80 trials in which the target pictures were aversive and distracters were neutral; and 80 trials in which target pictures were neutral and distracters were aversive. Participants received breaks after every 64 trials.

#### 1.4. Electroencephalographic recording

An elastic cap and the ActiveTwo BioSemi system (BioSemi, Amsterdam, Netherlands) were used to record the continuous EEG. Sixty-four electrode sites, based

on the 10/20 system, were used, as well as one electrode on each of the left and right mastoids. Four facial electrodes recorded the electrooculogram (EOG) generated from eye blinks and eye movements: vertical eye movements and blinks were measured with two electrodes placed approximately 1 cm above and below the right eye; horizontal eye movements were measured with two electrodes placed approximately 1 cm beyond the outer edge of each eye. Online data were referenced according to BioSemi's design, which replaces the ground electrode used in conventional systems with two separate electrodes (the Common Mode Sense active electrode and the Driven Right Leg passive electrode). These electrodes form a feedback loop, driving the common mode potential of the participant down and reducing the effective impedance of the ground.

ActiView software (BioSemi, Amsterdam, Netherlands) was used to digitize the EEG data at 512 Hz. Off-line analyses were performed using Brain Vision Analyzer software (Brain Products, Gilching, Germany). Data were re-referenced to the average of the two mastoids and band-pass filtered with low and high cutoffs of 0.1 and 30 Hz, respectively. The EEG was segmented for each trial beginning 200 ms prior to picture onset and continuing for 1200 ms (1000 ms beyond picture onset). For each trial, the baseline was defined as the 200 ms prior to picture onset. Only trials in which participants made correct responses were included in the ERP analyses. Eye blink and ocular corrections were made using the method developed by Gratton, Coles, and Donchin (1983). Artifact analysis identified a voltage step of more than  $50.0 \mu\text{V}$  between sample points, a voltage difference of  $300.0 \mu\text{V}$  within a trial, and a maximum voltage difference of less than  $0.50 \mu\text{V}$  within 100 ms intervals; trials were also inspected visually for artifacts. Intervals containing artifacts were rejected from individual channels in each trial; the percentage of intervals rejected as artifacts did not vary by target or distracter type.<sup>2</sup> Parietal positivities were scored by averaging activity from 400 to 800 ms at six centro-parietal sites where the LPP was maximal: C1, Cz, C2, CP1, CPz, and CP2.

Four averages (80 trials of each condition) were created for each participant: neutral images paired with neutral distracters, neutral images paired with aversive distracters, aversive images paired with neutral distracters and aversive images paired with aversive distracters. Trials on which participants had answered correctly were those on which a correct response ('same' or 'different') was made within 1800 ms following picture offset. Trials on which participants responded outside of this time frame were considered incorrect. The percentage of correct responses per condition was calculated as the number of correct trials divided by 80 trials in each condition. Average reaction time per condition was determined as the average time taken to respond following picture onset, on correct trials only.

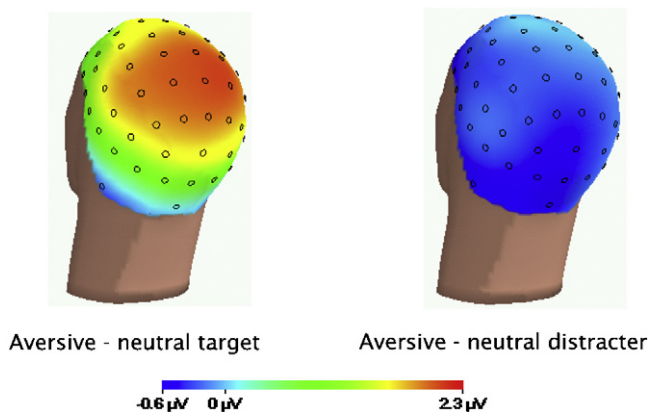
The LPP, reaction time and percentage of errors were evaluated with a 2 (target type neutral, aversive)  $\times 2$  (distracter type neutral, aversive) repeated-measures analysis of variance (ANOVA). Statistical analyses were performed using SPSS (Version 16.0) General Linear model software.

## 2. Results

### 2.1. Parietal positivity (LPP)

Fig. 2 depicts the spatial distribution of voltage (scalp topographies) associated with aversive compared to neutral pictures presented in attended (Fig. 2, left) and unattended (Fig. 2, right) locations. Consistent with past research, the LPP appeared largest at centro-parietal sites following the presentation of aversive versus neutral pictures (Codispoti, Ferrari, & Bradley, 2007; Cuthbert et al., 2000; Foti, Hajcak, & Dien, 2009; Hajcak, Dunning, & Foti, 2007; Hajcak et al., 2009; Hajcak, Moser, & Simons, 2006; Hajcak & Olvet, 2008); however, this effect was only evident when aversive pictures were presented in attended locations. Fig. 3 presents ERPs at each centro-parietal site for each of the four conditions. The impression from Figs. 2 and 3 was confirmed statistically: the LPP was larger following aversive than neutral targets ( $F(1,48) = 52.63, p < .0001, \eta_p^2 = .52$ ; see Table 1 for means), but did not differ following aversive as compared to neutral distracters ( $p > .12$ ). There was no interaction between target and distracter type ( $p > .84$ ).

<sup>2</sup> The percent of intervals rejected due to artifacts per condition was as follows: neutral targets and neutral distracters,  $M = 1.67\%$ ,  $SD = 3.39\%$ ; neutral targets and aversive distracters,  $M = 1.86\%$ ,  $SD = 3.79\%$ ; aversive targets and neutral distracters,  $M = 1.55\%$ ,  $SD = 3.21\%$ ; aversive targets and aversive distracters,  $M = 1.76\%$ ,  $SD = 3.64\%$ . A 2 (target type: neutral, aversive)  $\times 2$  (distracter type: neutral, aversive) repeated-measures ANOVA confirmed that the percentage of artifacts did not vary as a function of target or distracter type (all  $ps > .18$ ).



**Fig. 2.** Topographic maps depicting voltage differences (in  $\mu\text{V}$ ) for aversive minus neutral targets (left) and aversive minus neutral distracters (right), between 400 and 800 ms following picture onset.

**2.2. Behavioral data**

Overall, participants performed well on the task ( $M = 90.42\%$  correct,  $SD = 6.32$ ). Table 1 presents the average percentage of correct responses according to condition. Participants made significantly more errors on trials with aversive as compared to neutral distracters ( $F(1,48) = 7.98, p < .01, \eta_p^2 = .14$ ). Error rate did not vary as a function of target type ( $p > .91$ ); the interaction between target and distracter type did not reach significance ( $p > .52$ ). Table 1 also presents the average reaction times (for correct trials) according to condition (overall  $M = 686, SD = 140$ ). Participants were significantly slower to respond to trials containing aversive as compared

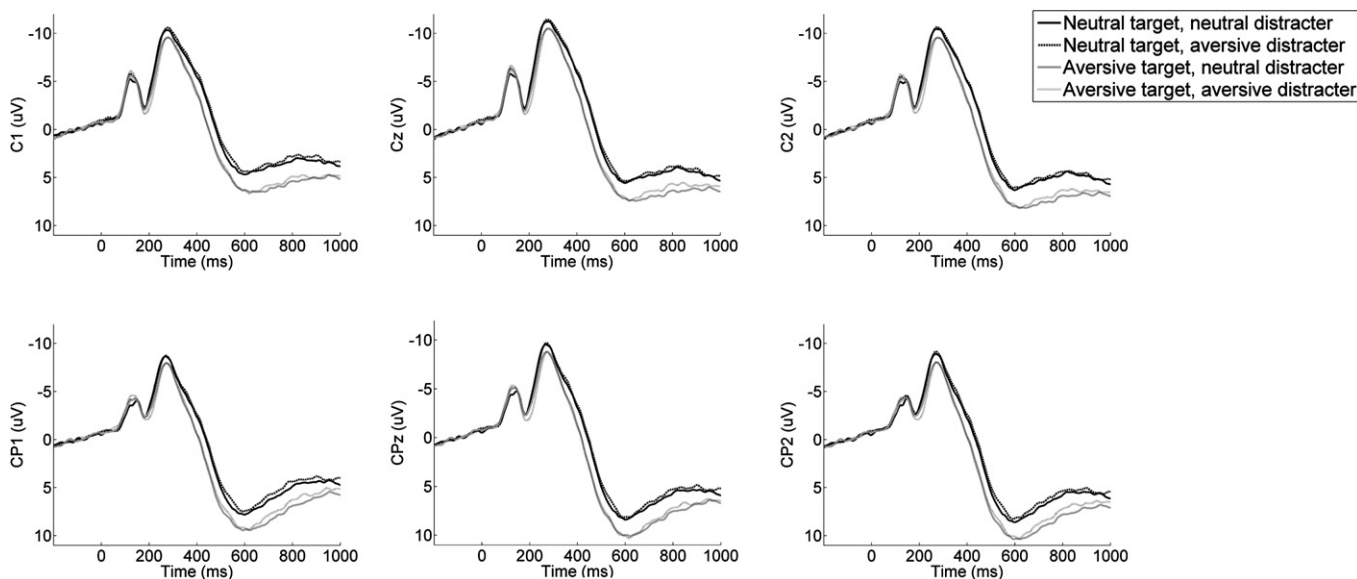
to neutral distracters ( $F(1,48) = 7.14, p < .02, \eta_p^2 = .13$ ). Reaction time did not vary as a function of target type ( $p > .55$ ); the interaction between target and distracter type also did not reach significance ( $p > .19$ ).

**2.3. State anxiety**

State anxiety scores ranged from 20 to 66 ( $M = 35.26, SD = 11.03$ ); this is in line with published norms for college-aged students (norm  $M = 36, SD = 10$ ; Spielberger, 1983). To determine whether the effect of target or distracter type on the LPP correlated with state anxiety scores, difference scores were calculated for amplitudes to aversive and neutral targets collapsing across distracter type, and again for aversive and neutral distracters collapsing across target type. There was a significant bivariate correlation between state anxiety scores and LPP amplitude for aversive compared to neutral targets ( $r(46) = .36, p < .05$ ), such that greater anxiety was associated with larger LPP difference scores to aversive compared to neutral targets. Fig. 4 presents the LPP difference to aversive versus neutral targets as a function of state anxiety. State anxiety did not correlate with the effect of distracter type on the LPP ( $p > .28$ ) or with the effects of target or distracter type on reaction time (all  $ps > .77$ ) or on the number of errors ( $ps > .69$ ).

**3. Discussion**

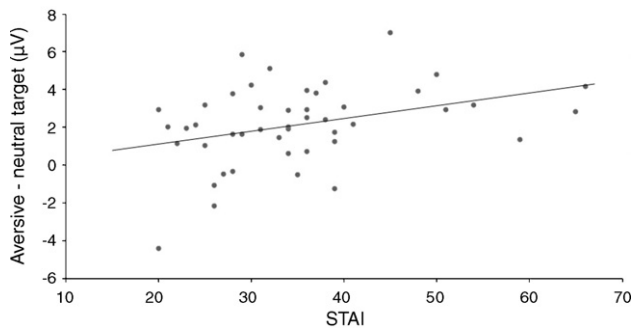
In the present study, aversive compared to neutral pictures elicited a larger parietal positivity, but only for pictures presented in attended spatial locations. That is, aversive distracters did not elicit a larger electrocortical response than neutral distracters. Moreover, higher state anxiety was specifically associated with a larger



**Fig. 3.** Grand average waveforms (in  $\mu\text{V}$ ) for the four conditions: neutral targets and neutral distracters; neutral targets and aversive distracters; aversive targets and neutral distracters; and aversive targets and aversive distracters, at each of the electrodes used in the centro-parietal pooling: C1, Cz, C2 (top, from left to right); CP1, CPz and CP2 (bottom, from left to right).

**Table 1**  
Mean LPP (and standard deviations) in  $\mu\text{V}$ , reaction time and percentage of trials correct for (top row to bottom): neutral targets and neutral distracters; neutral targets and aversive distracters; aversive targets and neutral distracters and aversive targets and aversive distracters.

Target	Distracter	LPP ( $\mu\text{V}$ ; 400–800 ms)	Reaction time (ms)	Accuracy (% correct)
Neutral	Neutral	4.21 (4.22)	684 (141)	91.2 (6.1)
Neutral	Aversive	3.85 (4.08)	687 (140)	89.6 (6.9)
Aversive	Neutral	6.29 (4.34)	682 (139)	91.0 (6.0)
Aversive	Aversive	6.00 (4.03)	692 (140)	89.9 (6.5)



**Fig. 4.** Scores on the state version of the STAI correlated positively with amplitude (in  $\mu\text{V}$ ) to aversive minus neutral targets at central pooling, C1, Cz, C2, CP1, CP2 and CP2, 400–800 ms following picture onset.

electrocortical positivity following the presentation of aversive compared to neutral pictures in attended locations.

Evidence as to whether spatially unattended emotional stimuli elicit enhanced neural activity has been limited to facial stimuli in previous ERP work. Results from the present study are in line with work by Holmes et al. (2003), who found increased ERP amplitudes for fearful compared to neutral faces only when presented in spatially attended locations. Similarly, Eimer et al. (2003) found that emotional compared to neutral faces presented in unattended locations did not elicit greater electrocortical activity. The present study extends these findings to more complex and arousing aversive stimuli—and further suggests that the increased parietal positivity (i.e., the LPP) elicited by aversive images is not evident when stimuli are presented in unattended locations. These results are also consistent with previous work from our laboratory in which directing spatial attention *within* aversive images reduced the amplitude of the LPP (Dunning & Hajcak, 2009; Hajcak et al., 2009).

Although the parietal positivity was not larger for aversive *distracters*, the behavioral data suggest that aversive distracters received sufficient processing to interfere with the task: participants were slower to respond and made more errors when distracters were aversive than neutral. These behavioral data are consistent with previous studies (Keil et al., 2005; Vuilleumier et al., 2001), and suggest that the present task did not consume sufficient attentional resources to eliminate behavioral effects from threatening distracters (cf. Pessoa et al., 2005; Silvert et al., 2007). Collectively, these data suggest that electrocortical measures may be more sensitive to attentional manipulations than behavioral measures.

Previous studies that have employed this type of task using fMRI have found increased amygdala activity in response to threatening faces presented in unattended spatial locations (e.g., Silvert et al., 2007; Vuilleumier et al., 2001, 2002, 2004), especially under conditions of low attentional load (Pessoa et al., 2002, 2005; Silvert et al., 2007). In light of these data, it is possible that electrocortical activity indexed by the LPP is more sensitive than the hemodynamic response in the amygdala to attention-related manipulations. Indeed, previous work suggests that parietal positivities may reflect elaborated processing related to stimulus meaning (e.g., Foti & Hajcak, 2008; MacNamara et al., *in press*) and may depend on the conscious recognition of stimulus content (Williams et al., 2007). Interestingly, ERPs may differ from other forms of EEG activity such as steady state evoked potentials (ssVEPs), which have been shown to be larger for emotional compared to neutral pictures even when stimuli are presented in unattended spatial locations (Keil et al., 2005).

Importantly, the difference between LPPs to aversive compared to neutral pictures presented in attended locations was correlated with state anxiety; these results are in line with a large body

of research suggesting that anxiety is associated with an attentional bias towards threatening information (see Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007 for a meta-analysis, 2007). Using an fMRI paradigm, Bishop et al. (2004) also found an association between neural response to unpleasant pictures and state anxiety, however in their study, state anxiety was associated with increased amygdala response to *unattended* unpleasant pictures. This discrepancy may be due in part to differences in task design. For instance, the present study utilized aversive IAPS pictures, whereas previous tasks have employed pictures of fearful faces. Additionally, previous work has not emphasize speeded responding (Bishop et al., 2004) and trials were blocked by target location so that participants' spatial attention was constant throughout each block. Future work might clarify whether methodological differences including stimuli and task design differentially impact associations between anxiety and neural response to spatially attended and unattended stimuli.

It is interesting to note that the emotional nature of the stimuli were completely task irrelevant in the current study. Thus, increased neural activity to aversive compared to neutral pictures in attended locations could be conceptualized in terms of emotional distraction or interference. These data suggest that the LPP might provide a sensitive index of the degree to which threatening stimuli in attended locations capture attention—even when the emotional aspect of such stimuli are irrelevant to the task at hand. Furthermore, the magnitude of this neural response may reflect threat-related biases that characterize anxious individuals. Future work in anxious clinical samples will be important to substantiate this possibility. Moreover, it will be important to determine whether the relationship between an increased LPP to aversive stimuli presented in attended locations and its relationship with anxiety generalizes to appetitive emotional stimuli. Another potential avenue for future research is to explore the extent to which threat-related biases in anxiety depend on task-related attentional load. Recent work by Bishop, Jenkins, and Lawrence (2007) – in which anxious individuals exhibited increased processing of threat-related stimuli under conditions of low, but not high perceptual load – suggests that increased processing of threat-related stimuli amongst anxious individuals is most evident when attentional resources are available to process this unattended information.

Insofar as anxiety related to neural but not behavioral measures of emotional processing, the present study is consistent with previous work (e.g., Bishop et al., 2004) that suggests a dissociation between the effect of anxiety on neural and behavioral measures. Other studies have also found anxiety-related differences using ERPs that were not evident in behavioral data: Moser, Hajcak, Huppert, Foa, and Simons (2008), for example, found ERP evidence of a positive bias that distinguished low from high socially anxious individuals, though the groups did not differ on behavioral measures. Likewise, individuals scoring high on obsessive-compulsive traits, anxiety and worry exhibit larger error-related ERPs but equivalent task performance as controls (Hajcak, Franklin, Foa, & Simons, 2008; Hajcak, McDonald, & Simons, 2003; Hajcak & Simons, 2002). Finally, threatening faces elicit larger ERPs among high anxious participants—even though reaction times are equivalent for all types of faces (Bar-Haim, Lamy, & Glickman, 2005). Taken together, these results suggest that anxiety may be characterized by the abnormal recruitment of neural resources when processing aversive information—and that this may not necessarily be reflected in behavioral data. Work by Derryberry and Reed (2002) suggests that among anxious individuals, other variables such as attentional control may interact with biases towards threatening information to determine whether behavioral responses are affected. Future work might continue to use ERPs as a sensitive measure of emotional interference associated with anxiety, while continuing to elucidate links with other variables that may moderate behavioral effects.

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