doi:10.1093/scan/nsu098 SCAN (2015) 10, 577–583

Electrocortical evidence for rapid allocation of attention to threat in the dot-probe task

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Threatening stimuli have been shown to preferentially capture attention using a range of tasks and measures. However, attentional bias to threat has not typically been found in unselected individuals using behavioral measures in the dot-probe task, one of the most common ways of examining attention to threat. The present study leveraged event-related potentials (ERPs) in conjunction with behavioral measures in the dot-probe task to examine whether more direct measures of attention might reveal an attentional bias to threat in unselected individuals. As in previous dot-probe studies, we found no evidence of an attentional bias to threat using reaction time; additionally, this measure exhibited poor internal reliability. In contrast, ERPs revealed an initial shift of attention to threat-related stimuli, reflected by the N2pc, which showed moderate internal reliability. However, there was no evidence of sustained engagement with the threat-related stimuli, as measured by the late positive potential (LPP). Together, these results demonstrate that unselected individuals do initially allocate attention to threat in the dot-probe task, and further, that this bias is better characterized by neural measures of attention than traditional behavioral measures. These results have implications for the study of attention to threat in both unselected and anxious populations.

Keywords: attentional bias; dot probe; ERPs; IAPS; threat

Emotional stimuli that depict threat or fear are thought to receive preferential processing over non-emotional stimuli because they convey important information about the environment. Attention is the process by which the perception and processing of objects is enhanced (Hillyard *et al.*, 1998); therefore, attention has been proposed as one likely mechanism for prioritizing the processing of threatening information in the environment (MacNamara *et al.*, 2013). Attention to threatening stimuli has been examined in the laboratory using a variety of paradigms adapted from cognitive psychology, including visual search (e.g., Öhman *et al.*, 2001a,b; Rinck *et al.*, 2003; Flykt and Caldara, 2006), Stroop (e.g. MacLeod, 1991; Mogg *et al.*, 1993a,b) and the dot-probe task (e.g., MacLeod *et al.*, 1986; Mogg *et al.*, 1997; Mogg and Bradley, 1999; Koster *et al.*, 2004; Salemink *et al.*, 2007). In general, these tasks assess attention to threat by comparing a measure of performance [such as reaction time (RT)] between trials with threatening stimuli and trials with emotionally neutral stimuli. For example, in the dot-probe task, RTs are compared between targets that replace a threat-related image and targets that replace a neutral image. Faster responses to targets that replace threat-related images are thought to reflect increased allocation of attention to threat, typically termed an 'attentional bias' to threat.

Many studies have supported the idea that attention is preferentially allocated to threat-related stimuli. For example, threatening faces (Öhman *et al.*, 2001b) and fear-related stimuli (Öhman *et al.*, 2001a) are detected faster in a visual search task compared with happy or neutral stimuli. In addition, the presence of threat-related compared with emotionally neutral distractors has been shown to divert attentional resources from target items, resulting in increased RTs (MacNamara and Hajcak, 2009). However, across dozens of studies, research using the dot-probe task has generally failed to find evidence of an attentional bias to threat-related images in unselected individuals (see Bar-Haim *et al.*, 2007 for a review). The present study was aimed at understanding why unselected individuals fail to show evidence of an attentional bias to threat in the dot-probe task, despite showing this bias in other tasks. Understanding the role of attention to threat in the dot-probe task is of particular importance, given that this task has become a 'gold standard' in examining attention to threat. Indeed, despite showing no evidence of an attentional bias to threat in unselected individuals, the dot-probe task has been highly successful at uncovering an attentional bias for threat-related stimuli in anxiety (see Bar-Haim *et al.*, 2007 for a review).

One possible reason previous dot-probe studies may have failed to find an attentional bias to threat in unselected individuals may be related to the behavioral measures used to characterize attentional bias to threat-related stimuli in this task. In general, behavioral measures reflect the sum of many distinct mental processes that occur between the onset of a stimulus and the execution of a behavior. This may be problematic for measuring attention to threat in the dot-probe task, in which the behavioral measures are removed from the threat-related stimuli in two ways. First, the behavioral response is not made directly to the emotional stimulus itself but to a subsequently presented target item that appears at the location of a previously presented emotional image. Although the task-irrelevant nature of the emotional stimuli allows researchers to assess attention in the absence of task-related incentives, a consequence of this design is that behavior in the task is only indirectly related to the emotional image. Second, hundreds of milliseconds separate the onset of the threat-related stimulus and the onset of the target item in the dot-probe task; therefore, it is possible that individuals may initially attend to the threatening image but disengage before the target item is presented. Indeed, shifts of covert visual attention can occur on a rapid timescale, sometimes requiring as little as 50–100 ms (Müller and Rabbit, 1989). Thus, behavioral measures may not capture an initial shift of attention to threat in the dot-probe task if attention has shifted away from threat by the time the target item is presented.

Received 28 December 2013; Revised 17 April 2014; Accepted 17 July 2014
Advance Access publication 25 July 2014

The contributions of the first and the second author to this paper are equal.

This study was made possible by grants R03MH098119 (E.S.K. and G.H.P.) and T32MH067631-09 (A.M.) from the National Institute of Mental Health, and by a Research Fellowship Training Award from the Society for Psychophysiological Research (A.M.).

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The present study investigated whether more direct measures of attention might reveal an attentional bias to threat among healthy individuals in the dot-probe task by leveraging event-related potentials (ERPs) in conjunction with traditional behavioral measures. In contrast to behavior, ERPs can be measured time-locked to the onset of the threat-related stimulus, allowing for a direct assessment of attention to threat. We used the well-established N2pc and late positive potential (LPP) ERP components (described more below), which are ideally suited to dissecting the time course of attention to threat in the dot-probe task. Specifically, we examined whether attention is initially allocated to threat-related stimuli in the dot-probe task using the N2pc wave, and further, whether this attentional bias is sustained over time using the LPP.

The N2pc is a negative-going potential at posterior electrode sites contralateral to the location of an attended item, and it has been used to index covert visual attention in cognitive psychology for over 25 years (see Luck, 2012 for a recent review). More recently, the N2pc has been used to examine the allocation of attention to emotional images, with results showing that attention is often initially allocated to threat-related stimuli, even when these stimuli are irrelevant to the task (Eimer and Kiss, 2007; Fox *et al.*, 2008; Buodo *et al.*, 2010; Brosch *et al.*, 2011; Shaw *et al.*, 2011; Ikeda *et al.*, 2013). However, the N2pc has not been used previously to measure attention to threat in the dot-probe task. The present study investigated whether healthy individuals initially shift attention to threat-related stimuli in this task by measuring the N2pc time-locked to the onset of the cue images. To maximize the potential for threatening stimuli to capture attention, we used complex threatening images from the International Affective Picture System (IAPS) image set (Lang *et al.*, 2008), which may be stronger elicitors of emotion than the angry or fearful faces that are typically used in the dot-probe task (Britton *et al.*, 2006).

Electrophysiological evidence also suggests that threatening stimuli not only capture attention but can 'sustain' engagement, maintaining processing resources throughout stimulus presentation and for as long as several hundred milliseconds after stimulus offset (Hajcak and Olvet, 2008; Hajcak *et al.*, 2009). Specifically, previous studies have shown that compared to neutral stimuli, threat-related stimuli elicit an increased positive-going ERP component—the LPP—maximal at centroparietal electrode sites starting around 300 ms following stimulus onset (see Hajcak *et al.*, 2012 for a recent review). The LPP reflects sustained engagement with emotional images, and its presence, duration and magnitude can be modulated by task-specific factors. In particular, affective modulation of the LPP is highly dependent on the allocation of spatial attention. For example, affective modulation of the LPP is not observed for aversive pictures that are presented in unattended locations (MacNamara and Hajcak, 2009). In addition, emotional modulation of the LPP is decreased by directing attention to a neutral portion of an attended negative image (Dunning and Hajcak, 2009; Hajcak *et al.*, 2009, 2013). The present study used the LPP to investigate whether threatening images in the dot-probe task elicit sustained engagement. If attention is initially shifted to threatening stimuli (reflected by an N2pc) but not maintained on those images, threat-related modulation of the LPP would likely not be observed. This may help explain the failure to find behavioral evidence of attentional bias to threat in the dot-probe task, as the behavioral measures assess attention at a relatively late point in time (during or after the LPP).

We predicted that we would find no behavioral evidence of an attentional bias to threat in the present study, in line with previous dot-probe studies. In contrast, we predicted that our neural measures would reveal an initial shift of attention to threatening images, as evidenced by the N2pc. However, we expected to find no evidence of later threat-related effects on the LPP, which could explain the absence of a behavioral effect.

To further examine the measures of threat-related processing used in the present study, we also assessed the internal (split-half) reliability of each measure. This allowed us to determine which measure (RT, N2pc, LPP) provided the most consistency—an important step in determining the validity of each measure in the context of the present task. Based on previous studies, we predicted that the behavioral measure traditionally used in the dot-probe task would have poor internal reliability (Schmukle, 2005; Staugaard, 2009; Waechter *et al.*, 2014). However, we tentatively predicted that internal reliability would be higher for more direct measures of attention to threat (i.e., the N2pc).

METHOD

Participants

Thirty-five undergraduate students between the ages of 18 and 30 were tested. Three subjects were excluded for poor performance on the task (<50% trials correct), and two subjects were excluded for excessive artifacts in the EEG recording, leaving 30 subjects (16 female); all analyses reflect this final sample. The study was approved by the Stony Brook University Institutional Review Board, and subjects received course credit for participation.

Stimuli and task

The stimuli were 50 neutral and 50 threatening images selected from the IAPS images[1]. Neutral images included pictures of buildings, household objects and people with neutral facial expressions. Threatening images included pictures of animals attacking the viewer, assault, abduction scenes and pictures of guns.

Subjects performed a dot-probe task. Example trial sequences are presented in Figure 1. Stimuli were presented on a black background using an LCD monitor viewed at a distance of ~60 cm. On each trial, a pair of IAPS images (each image subtending ~7×9 degrees of visual angle) was presented for 400–600 ms (rectangular distribution; average of 500 ms), one image to the left and one image to the right of a continuously visible central white fixation cross. Immediately following the offset of the images, a target composed of either two horizontally or vertically arranged dots (each dot subtending ~0.5×0.5 degrees of visual angle) was presented for 400 ms centered in the location of one of the previously presented images. Subjects made a key press using the index or middle finger of the right hand to indicate whether the target item was a pair of horizontally or vertically arranged dots; the mapping of targets and response buttons was counterbalanced across subjects. Subjects were given a window of 1500 ms from the onset of the target to respond; the response window ended when a response was made. Immediately following the response, a jittered intertrial interval of 750–1250 ms (rectangular distribution) was presented. Subjects were told that the images were irrelevant to the task and were instructed to respond as quickly and accurately as possible while maintaining central fixation.

Subjects completed a total of 500 trials. All trial types were randomly intermixed. On 400 trials, one threatening image and one neutral image ('mixed-emotion' trials) were presented (i.e., typical trials in a dot-probe task). The mixed-emotion trials allowed us to assess the

1 Threatening IAPS images were—1050, 1120, 1201, 1270, 1274, 1300, 1304, 1930, 1932, 2120, 2811, 3010, 3015, 3030, 3051, 3060, 3068, 3069, 3080, 3100, 3102, 3120, 3140, 3225, 3230, 3250, 3261, 3400, 3530, 6242, 6312, 6313, 6315, 6350, 6360, 6370, 6510, 6530, 6540, 6550, 6560, 9042, 9253, 9265, 9405, 9413, 9414, 9490, 9635.1, 9940. Neutral IAPS images were—1390, 1450, 1650, 1670, 1810, 2038, 2102, 2191, 2357, 2383, 2393, 2396, 2397, 2446, 5500, 5510, 5530, 7000, 7002, 7004, 7009, 7010, 7020, 7026, 7030, 7034, 7036, 7037, 7040, 7041, 7050, 7057, 7060, 7080, 7110, 7130, 7175, 7234, 7491, 7493, 7496, 7500, 7501, 7546, 7547, 7560, 7595, 7620, 7710, 7920.

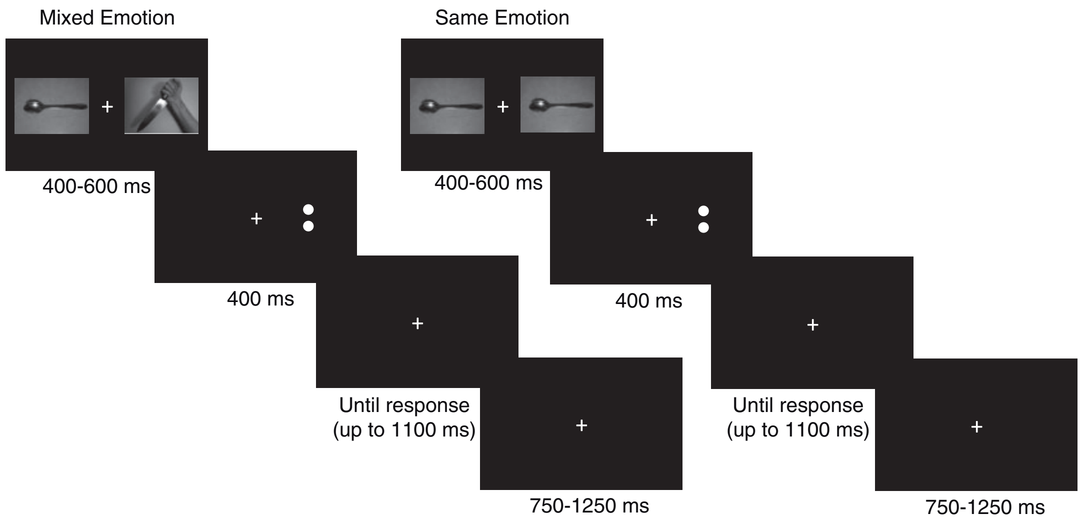

Fig. 1 Example trial sequences in the dot-probe task (target dots are enlarged for illustrative purposes).

typical behavioral measures in a dot-probe task and to isolate the N2pc and LPP. There were also 100 'same-emotion' trials, including 50 trials on which two neutral images were presented and 50 trials on which two threatening images were presented. These same-emotion trials allowed us to assess behavioral measures and the LPP for purely threatening and purely neutral trials, as in typical LPP studies (note that it is not possible to isolate the N2pc on same-emotion trials, which included identical images to the left and right side of fixation). A greater number of mixed-emotion trials were included than same-emotion trials to more closely replicate previous dot-probe tasks (which typically included only mixed-emotion trials), and to replicate the number of trials typically included in studies of the N2pc and LPP.

For mixed-emotion trials, targets replaced threatening images on half of the trials and neutral images on the other half. This resulted in the following distribution of trial types across the experiment: 50 same-emotion trials on which targets replaced neutral images; 50 same-emotion trials on which targets replaced threatening images; 200 mixed-emotion trials on which targets replaced threatening images, referred to as 'threat-congruent'; and 200 mixed-emotion trials on which targets replaced neutral images, referred to as 'threat-incongruent'. For the mixed-emotion trials, threatening images were presented an equal number of times to the left and right of fixation. Target type (a horizontally or vertically arranged pair of dots) was fully counterbalanced for each trial type, and targets were presented an equal number of times to the left and to the right of fixation. Each image was presented nine times, and all images were presented once before an image was repeated. Short self-paced breaks were provided every 100 trials.

Recording and data processing procedures

Continuous EEG was recorded using a Biosemi ActiveTwo recording system (Biosemi B.V., Amsterdam, the Netherlands). The electrodes were mounted in an elastic cap using a subset of the International 10/20 System sites (standard 32 channel sites and sites FCz and Iz). The common mode sense (CMS) electrode was located at site C1, with a driven right leg (DRL) electrode located at site C2. The horizontal electrooculogram (EOG) was recorded from electrodes placed lateral to the external canthi and was used to detect horizontal eye movements; the vertical EOG was recorded from electrodes placed above and below the right eye and was used to detect eyeblinks and vertical eye movements. The EEG and EOG were low-pass filtered using a fifth order sinc filter with a half-power cutoff at 204.8 Hz and then digitized at 1024 Hz with 24 bits of resolution. The single-ended EEG signals were converted to differential signals offline, referenced to the average of the left and right mastoids.

Signal processing and analysis of the EEG data was performed using Brain Vision Analyzer software (Brain Products, Gilching, Germany). The EEG was high-pass filtered with a cutoff of 0.1 Hz (noncausal Butterworth impulse response function, half-power cutoff, 12 dB/oct roll-off) and low-pass filtered with a cutoff of 30 Hz (noncausal Butterworth impulse response function, half-power cutoff, 24 dB/oct roll-off). The EEG data were segmented for each trial beginning 200 ms prior to the onset of the images and continuing for 600 ms after image onset (i.e., for a total duration of 800 ms). Baseline correction was performed using the 200 ms prior to the onset of the images. Ocular correction of the EEG data was performed using the method developed by Miller *et al.* (1988a), to remove eyeblinks, vertical and horizontal eye movements. Additional artifacts were rejected based on the following criteria: a voltage step of >50.0 μV between sample points, a voltage difference of 300.0 μV within a trial and a maximum voltage difference of <0.50 μV within 100-ms intervals. Trials were also visually inspected for any remaining artifacts, and data from individual channels containing artifacts were rejected on a trial-by-trial basis. Trials with incorrect behavioral responses were excluded from all analyses.

Behavior

RT was measured per condition as the time it took subjects to respond following the onset of the target item for trials with correct responses only. Accuracy was calculated as the percentage of correct trials per condition. Pearson's correlations were used to examine the relationship among measures; split-half reliability analyses were conducted by correlating the average of odd and even trials, corrected using the Spearman–Brown formula (Anastasia and Urbina, 1997).

N2pc

To determine whether attention was preferentially allocated to the threatening image on mixed-emotion trials, we isolated the N2pc time-locked to the onset of the threatening–neutral image pairs at posterior electrode sites (P7 and P8, where the N2pc is typically maximal; Luck, 2012), relative to the location of the threatening image. Specifically, we first created separate waveforms for the hemisphere that was contralateral to the threatening image (i.e., left hemisphere for right-side threatening images, and right hemisphere for left-side threatening images) and the hemisphere that was ipsilateral to the threatening image (i.e., right hemisphere for right-side threatening images, and left hemisphere for left-side threatening images). We then created a contralateral-minus-ipsilateral difference waveform, and the N2pc was measured from the resulting difference wave in each subject. The mean amplitude of the N2pc was measured using a time window of 175–225 ms following the onset of the image pairs. To determine the time by which attention had been preferentially allocated to the threatening image, we also measured the onset latency of the N2pc. Onset latency was defined as the time point at which the voltage reached 50% of the peak amplitude in the 175–225 ms time window, which is thought to be the optimal measure of the onset time of ERP components under many conditions (see Miller *et al*., 1998b; Kiesel *et al*., 2008). Note that the N2pc analyses were all conducted on the mixed-emotion trials, as it is not possible to use the N2pc to examine the allocation of attention on the same-emotion trials, which included identical images to the left and right side of fixation (the same-emotion trials were used for the LPP; see below).

LPP

To examine sustained engagement with the images, we isolated the LPP separately for threatening image pairs, neutral image pairs and threatening–neutral image pairs at a posterior-midline electrode site (Pz, where the LPP is typically maximal; Dunning and Hajcak, 2009). By comparing the LPP among threatening image pairs, neutral image pairs and threatening–neutral image pairs, we were able to assess whether sustained engagement on mixed-emotion trials was more similar to neutral–neutral trials, threatening–threatening trials or intermediate between these conditions. The mean amplitude of the LPP was measured in each condition using a time window of 300–600 ms after the onset of the image pairs, as in previous studies (Dennis and Hajcak, 2009). This time window is subsequent to the time of the N2pc (175–225 ms), which allowed us to examine sustained engagement with the images subsequent to an initial shift of attention. Although the time window of the LPP overlaps with the presentation of the probe stimulus on some trials (400–600 ms following the onset of the IAPS images), there are two reasons this overlap is unlikely to have impacted the LPP. First, probe presentation was counterbalanced across all factors in the task and was equivalent in the three conditions, equating any overlap among the conditions used to compare the LPP. Second, the 200-ms jitter in the onset time of the probe stimulus (which onset between 400–600 ms after image onset) should have been sufficient to eliminate the probe-elicited ERP from the average ERP time-locked to the IAPS images (see Woldorff, 1993; Luck, 2005).

RESULTS

Behavior

Mean RTs and mean accuracy (percent correct) are shown in Table 1. Consistent with prior work, no significant RT difference was found for mixed-emotion trials between targets that replaced threatening images (threat-congruent trials) and targets that replaced neutral images [threat-incongruent trials; $t(29) = 0.59$, $P > 0.56$]. In contrast, RT differed across the three trial types used in the present study (neutral–neutral, mixed-emotion, threatening–threatening), leading to a significant main effect of condition [$F(2,58) = 16.74$, $P < 0.001$, $\eta^2 = 0.36$]. Follow-up analyses revealed that response times were significantly increased following mixed-emotion image pairs compared with neutral image pairs [$t(29) = 2.37$, $P < 0.05$, $\eta^2 = 0.16$], and significantly increased following threatening image pairs compared with mixed-emotion image pairs [$t(29) = 3.64$, $P < 0.01$, $\eta^2 = 0.31$], with each additional threatening image in the display resulting in a RT increase of ~15 ms.

Participants were just as accurate on mixed-emotion trials for targets that replaced threatening compared with neutral images [$t(29) = 1.46$, $P > 0.15$]. No significant difference in accuracy was found across the three emotion trial types [$F(2,58) = 0.10$, $P > 0.90$].

Table 1 Behavioral results for each trial type (standard deviations in parentheses)

Trial type	Accuracy (% correct)	Mean RT (ms)
Threatening–neutral		
Threat-congruent	90.98 (5.08)	629.99 (101.40)
Threat-incongruent	90.18 (6.16)	627.41 (112.23)
Threatening–threatening	90.40 (5.16)	645.85 (107.34)
Neutral–neutral	90.73 (5.79)	615.80 (98.72)

Table 2 N2pc and LPP measures (standard deviations in parentheses)

	N2pc		LPP
Image pairs	Mean amplitude (μV)	Onset latency (ms)	Mean amplitude (μV)
Threatening–neutral	−.85 (.90)	185.97 (20.10)	−3.48 (4.09)
Threatening–threatening			−1.28 (5.79)
Neutral–neutral			−4.06 (4.09)

ERP waveforms

N2pc and LPP measures are summarized in Table 2.

N2pc

Grand-average ERP waveforms time-locked to the onset of the IAPS images on mixed-emotion trials and collapsed across the P7 and P8 electrode sites are presented in Figure 2, overlaying the waveforms contralateral to the threatening image (black line), ipsilateral to the threatening image (gray line) and the contralateral-minus-ipsilateral difference wave (dotted line). Analyses revealed a significant N2pc in the contralateral-minus-ipsilateral difference waveform [$t(29) = 5.14$, $P < 0.001$, $\eta^2 = 0.48$], reflecting a shift of covert visual attention in the direction of the threatening image on the mixed-emotion trials. An analysis of the onset latency of the N2pc revealed that this shift of covert attention to the threatening image occurred by 186 ms after the onset of the threatening–neutral image pair.

LPP

Grand-average ERP waveforms time-locked to the onset of the IAPS images on same-emotion and mixed-emotion trials at electrode site Pz are presented in Figure 3, overlaying threatening image pairs (black line), neutral image pairs (gray line) and threatening–neutral image pairs (dotted line). There was a significant main effect of condition on the LPP [$F(2,58) = 13.17$, $P < 0.01$, $\eta^2 = 0.31$], such that threatening image pairs elicited a larger LPP compared with neutral image pairs and mixed-emotion image pairs [$t(29) = 3.85$, $P < 0.001$, $\eta^2 = 0.34$, and $t(29) = 4.22$, $P < 0.001$, $\eta^2 = 0.38$, respectively]. The LPP elicited by mixed-emotion image pairs did not, however, differ from that elicited by neutral–neutral image pairs [$t(29) = 1.33$, $P > 0.19$], indicating that the threatening–neutral image pairs (from which RT measures of threat bias were derived) did not elicit an enhanced LPP.

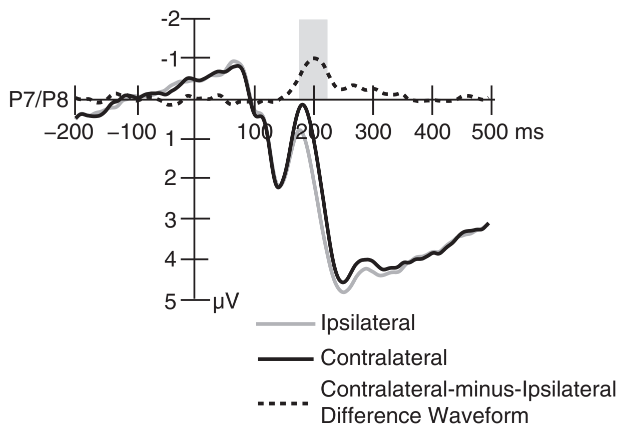

Fig. 2 Grand-average ERP waveforms time-locked to the onset of the images for the mixed-emotion (threatening–neutral) image pairs collapsed across the P7 and P8 electrode sites. The waveforms shown are contralateral to the location of the threatening image (black line), ipsilateral to the location of the threatening image (gray line) and the contralateral-minus-ipsilateral difference waveform (dotted line). The shaded region indicates the time window used for measurement of the N2pc.

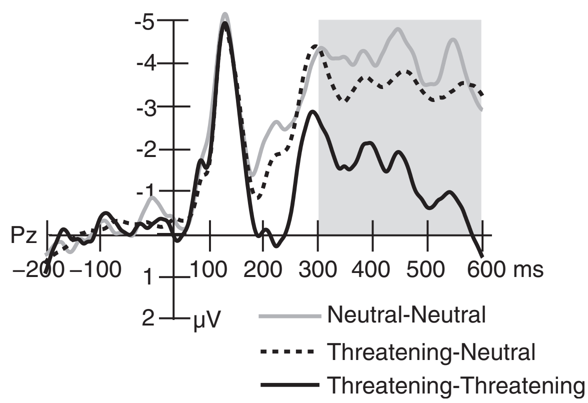

Fig. 3 Grand-average ERP waveforms time-locked to the onset of the images at electrode site Pz for the threatening–threatening image pairs (black line), neutral–neutral image pairs (gray line) and threatening–neutral image pairs (dotted line). The shaded region indicates the time window used for measurement of the LPP.

Correlations

To determine whether the significant shift of attention to the threatening image on mixed-emotion trials was related to the behavioral response to the target item, we correlated the difference in RT on threat-incongruent and threat-congruent trials separately with the amplitude and the onset time of the N2pc. RT was not related to the amplitude ($r = -.11$, $P > 0.58$) or the onset time ($r = 0.27$, $P > 0.15$) of the N2pc. To determine whether behavioral performance was related to sustained engagement with the emotional images, we also examined correlations between RT and the LPP separately for each condition (neutral–neutral, mixed-emotion, threatening–threatening); none of the correlations reached significance (all Ps > 0.29).

Internal reliability

The traditional behavioral measure of attentional bias to threat (the RT difference between threat-incongruent and threat-congruent trials) was not significantly correlated between even- and odd-numbered trials ($r = 0.35$, $P > 0.25$). In contrast, the amplitude of the N2pc and the onset latency of the N2pc between even- and odd-numbered trials were both highly correlated ($r = 0.75$, $P < 0.001$, and $r = 0.70$, $P = 0.002$, respectively), indicating that the N2pc was internally reliable. Both the RT and LPP difference between threatening and neutral image pairs were not reliable ($r = 0.16$, $P > 0.64$, and $r = 0.27$, $P > 0.40$, respectively).

DISCUSSION

The present study used ERPs and behavioral measures to examine the time course of attention to threat in unselected individuals in the dot-probe task. In line with previous studies, we found no behavioral evidence of an attentional bias to threat in this sample using traditional RT and accuracy measures. In contrast, neural measures were able to detect an initial shift of attention to the threat-related image, reflected by an N2pc to the threatening image directly following the onset of the image pair. In addition, our analyses showed that this shift of attention occurred rapidly—by 186 ms after the onset of the images. We also examined whether the threatening images in the present task elicited sustained engagement by measuring the LPP, which occurred subsequent to the N2pc. These results showed that the LPP to the mixed-emotion image pairs did not differ from the LPP to neutral image pairs, indicating that the threatening images on these trials did not elicit sustained engagement, despite the initial shift of attention to threat reflected by the N2pc. In contrast, we did find a significantly increased LPP for threatening image pairs compared with neutral and threatening–neutral image pairs, indicating that it was possible to elicit an enhanced LPP in the present study.

The presence of an N2pc to emotional stimuli that was not accompanied by a corresponding behavioral effect has been shown in two previous studies (Fenker *et al.*, 2009; Ikeda *et al.*, 2013), indicating that it is possible to observe a shift of attention to an emotional stimulus in the absence of modulation of behavior. In addition, one of these studies investigated behavior, the N2pc and the LPP and found results similar to the present study (e.g. an N2pc that was not followed by an LPP or a behavioral effect; Ikeda *et al.*, 2013).

It is important to ask why the behavioral measures in this task were unable to capture the attentional bias for threat-related stimuli revealed by the N2pc. One likely explanation is that the N2pc is a direct measure of attention to the onset of the threatening image, whereas the behavioral measures are in response to separate target stimuli that are presented hundreds of milliseconds after the initial onset of the threatening image. Therefore, it is possible that attention was withdrawn from the location of the threatening image by the time the behavioral response was executed (Müller and Rabbit, 1989). This idea is supported by the absence of sustained engagement with the threatening image on the mixed-emotion trials, as reflected by the LPP. Given that the target stimulus was presented during the time of the LPP, the absence of an LPP during this time window indicates that attention may no longer have been present at the location of the threatening image when the target item was presented. Indeed, affective modulation of the LPP is highly dependent on the allocation of spatial attention (Dunning and Hajcak, 2009; Hajcak *et al.*, 2009, 2013; MacNamara and Hajcak, 2009).

To further examine the measures used in the present study, we assessed the internal (i.e., split-half) reliability of each measure. For the RT measure of attentional bias traditionally used in the dot-probe task, we found poor reliability, consistent with previous studies (Schmukle, 2005; Staugaard, 2009; Waechter *et al.*, 2014). This is important, because a measure cannot be valid if it is not reliable. This poor reliability may in part explain why an attentional bias to threat has not typically been observed in unselected individuals in the dot-probe task, as poor internal consistency makes effects harder to find (Henson, 2001). In contrast to RT, the N2pc in our sample was internally reliable both in terms of amplitude and onset latency measures, indicating that the N2pc may be a more valid measure of attentional bias to threat.

In summary, the results of the present study show that unselected individuals do initially and rapidly shift attention to threat-related images in the dot-probe task, and that the N2pc reliably captures this shift of attention. However, the initial shift of attention to threatening images is not accompanied by sustained engagement with threatening images or by behavioral evidence of an attentional bias. In addition, the behavioral measure traditionally used in the dot-probe task showed poor internal reliability, and further analyses illustrated that response times overall were increased in the presence of threat-related information in this task. Together, these results may explain why previous dot-probe studies in unselected individuals have been unable to find evidence of an attentional bias to threat. Moreover, these results indicate that neural measures such as the N2pc provide important information about the processing of threatening images that is not captured by behavioral measures in this task.

These results also have implications for the study of attentional bias to threat in anxiety. Specifically, in contrast to studies in unselected individuals, the dot-probe task has revealed attentional biases in clinically and non-clinically anxious individuals, and therefore it has become an important tool in the study of abnormal attention to emotional stimuli in anxiety. However, the majority of these studies rely on RT, which might be insensitive to threat-related biases (observed here with ERPs) and may have poor internal reliability. Thus, the ability of this behavioral measure to elucidate typical versus pathological responses to threat and reveal individual differences in threat bias may be quite limited. It remains for future research on attentional bias to threat in anxiety to determine whether neural measures such as the N2pc might better characterize abnormal allocation of attention to threat-related stimuli in anxious individuals. In addition, the N2pc may be useful for clarifying the mechanisms behind attentional bias modification treatment programs, which have been used to modulate the allocation of attention to threat in anxiety (Hakamata *et al.*, 2010).

Conflict of Interest

None declared.

REFERENCES

Anastasia, A., Urbina, S. (1997). *Psychological Testing*. Upper Saddle River, NJ: Prentice Hall.

Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M.J., van IJzendoorn, M.H. (2007). Threat-related attentional bias in anxious and nonanxious individuals: a meta-analytic study. *Psychological Bulletin*, *133*(1), 1–24.

Britton, J.C., Taylor, S.F., Sudheimer, K.D., Liberzon, I. (2006). Facial expressions and complex IAPS pictures: common and differential networks. *Neuroimage*, *31*, 906–19.

Brosch, T., Pourtois, G., Sander, D., Vuilleumier, P. (2011). Additive effects of emotional, endogenous, and exogenous attention: behavioral and electrophysiological evidence. *Neuropsychologia*, *49*, 1779–87.

Buodo, G., Sarlo, M., Munafo, M. (2010). The neural correlates of attentional bias in blood phobia as revealed by the N2pc. *Social Cognitive and Affective Neuroscience*, *5*(1), 29–38.

Dennis, T.A., Hajcak, G. (2009). The late positive potential: a neurophysiological marker for emotion regulation in children. *Journal of Child Psychology and Psychiatry, and Allied Disciplines*, *50*(11), 1373–83.

Dunning, J.P., Hajcak, G. (2009). See no evil: directing visual attention within unpleasant images modulates the electrocortical response. *Psychophysiology*, *46*(1), 28–33.

Eimer, M., Kiss, M. (2007). Attentional capture by task-irrelevant fearful faces is revealed by the N2pc component. *Biological Psychology*, *74*(1), 108–12.

Fenker, D.B., Heipertz, D., Boehler, C.N., et al. (2009). Mandatory processing of irrelevant fearful face features in visual search. *Journal of Cognitive Neuroscience*, *22*(12), 2926–38.

Flykt, A., Caldara, R. (2006). Tracking fear in snake and spider fearful participants during visual search: a multi-response domain study. *Cognition and Emotion*, *20*(8), 1075–91.

Fox, E., Derakshan, N., Shoker, L. (2008). Trait anxiety modulates the electrophysiological indices of rapid spatial orienting towards angry faces. *Neuroreport*, *19*(3), 259–63.

Hajcak, G., Dunning, J.P., Foti, D. (2009). Motivated and controlled attention to emotion: time-course of the late positive potential. *Clinical Neurophysiology: Official Journal of the International Federation of Clinical Neurophysiology*, *120*(3), 505–10.

Hajcak, G., MacNamara, A., Foti, D., Ferri, J., Keil, A. (2013). The dynamic allocation of attention to emotion: simultaneous and independent evidence from the late positive potential and steady state visual evoked potentials. *Biological Psychology*, *92*, 447–55.

Hajcak, G., Olvet, D.M. (2008). The persistence of attention to emotion: brain potentials during and after picture presentation. *Emotion*, *8*(2), 250–5.

Hajcak, G., Weinberg, A., MacNamara, A., Foti, D. (2012). ERPs and the study of emotion. In: Luck, S.J., Kappenman, E.S., editors. *Oxford Handbook of Event-Related Potential Components*. New York: Oxford University Press, pp. 441–72.

Hakamata, Y., Lissek, S., Bar-Haim, Y., et al. (2010). Attention bias modification treatment: a meta-analysis twoards the establishment of novel treatment for anxiety. *Biological Psychiatry*, *68*, 982–90.

Henson, R.K. (2001). Understanding internal consistency reliability estimates: a conceptual primer on coefficient alpha. *Measurement and Evaluation in Counseling and Development*, *34*, 177–89.

Hillyard, S.A., Vogel, E.K., Luck, S.J. (1998). Sensory gain control (amplification) as a mechanism of selective attention: electrophysiological and neuroimaging evidence. *Philosophical Transactions of the Royal Society: Biological Sciences*, *353*, 1257–70.

Ikeda, K., Sugiura, A., Hasegawa, T. (2013). Fearful faces grab attention in the absence of late affective cortical responses. *Psychophysiology*, *50*, 60–9.

Kiesel, A., Miller, J., Jolicoeur, P., Brisson, B. (2008). Measurement of ERP latency differences: a comparison of single-participant and jackknife-based scoring methods. *Psychophysiology*, *45*, 250–74.

Koster, E.H., Crombez, G., Verschuere, B., De Houwer, J. (2004). Selective attention to threat in the dot probe paradigm: differentiating vigilance and difficulty to disengage. *Behaviour Research and Therapy*, *42*(10), 1183–92.

Lang, P.J., Bradley, M.M., Cuthbert, B.N. (2008). International affective picture system (IAPS): affective ratings of pictures and instruction manual. *Technical Report A-8*. Gainesville, FL: University of Florida.

Luck, S.J. (2005). *An Introduction to the Event-Related Potential Technique*. Cambridge, MA: MIT Press.

Luck, S.J. (2012). Electrophysiological correlates of the focusing of attention within complex visual scenes: N2pc and related ERP components. In: Luck, S.J., Kappenman, E.S., editors. *Oxford Handbook of Event-Related Potential Components*. New York: Oxford University Press, pp. 329–60.

MacLeod, C., Mathews, A., Tata, P. (1986). Attentional bias in emotional disorders. *Journal of Abnormal Psychology*, *95*(1), 15–20.

MacLeod, C.M. (1991). Half a century of research on the Stroop effect: an integrative review. *Psychological Bulletin*, *109*, 163–203.

MacNamara, A., Hajcak, G. (2009). Anxiety and spatial attention moderate the electrocortical response to aversive pictures. *Neuropsychologia*, *47*(13), 2975–80.

MacNamara, A., Kappenman, E.S., Black, S.R., Bress, J.N., Hajcak, G. (2013). Integrating behavioral and electrocortical measures of attentional bias toward threat. In: Barrett, K.C., Fox, N.A., Morgan, G.A., Fidler, D., Daunhauer, L., editors. *Handbook of Self-Regulatory Processes in Development: New Directions and International Perspectives*. New York: Psychology Press, pp. 215–46.

Miller, G.A., Gratton, G., Yee, C.M. (1988a). Generalized implementation of an eye movement correction procedure. *Psychophysiology*, *25*, 241–3.

Miller, J., Patterson, T., Ulrich, R. (1998b). Jackknife-based method for measuring LRP onset latency differences. *Psychophysiology*, *35*, 99–115.

Mogg, K., Bradley, B.P. (1999). Some methodological issues in assessing attentional biases for threatening faces in anxiety: a replication study using a modified version of the probe detection task. *Behaviour Research and Therapy*, *37*(6), 595–604.

Mogg, K., Bradley, B.P., de Bono, J., Painter, M. (1997). Time course of attentional bias for threat information in non-clinical anxiety. *Behaviour Research and Therapy*, *35*(4), 297–303.

Mogg, K., Bradley, B.P., Williams, R., Mathews, A. (1993). Subliminal processing of emotional information in anxiety and depression. *Journal of Abnormal Psychology*, *102*(2), 304–11.

Mogg, K., Kentish, J., Bradley, B.P. (1993). Effects of anxiety and awareness on colour-identification latencies for emotional words. *Behaviour Research and Therapy*, *31*(6), 559–67.

Müller, H.J., Rabbit, P.M.A. (1989). Reflexive and voluntary orienting of visual attention: time course of activation and resistance to interruption. *Journal of Experimental Psychology: Human Perception and Performance*, *15*, 315–30.

Öhman, A., Flykt, A., Esteves, F. (2001a). Emotion drives attention: detecting the snake in the grass. *Journal of experimental psychology: General*, *130*(3), 466–78.

Öhman, A., Lundqvist, D., Esteves, F. (2001b). The face in the crowd revisited: a threat advantage with schematic stimuli. *Journal of personality and social psychology*, *80*(3), 381–96.

Rinck, M., Becker, E.S., Kellermann, J., Roth, W.T. (2003). Selective attention in anxiety: distraction and enhancement in visual search. *Depression and Anxiety*, *18*(1), 18–28.

Salemink, E., van den Hout, M.A., Kindt, M. (2007). Selective attention and threat: quick orienting versus slow disengagement and two versions of the dot probe task. *Behaviour Research and Therapy*, *45*, 607–15.

Schmukle, S.C. (2005). Unreliability of the dot probe task. *European Journal of Personality*, *19*, 595–605.

Shaw, K., Lien, M., Ruthruff, E., Allen, P.A. (2011). Electrophysiological evidence of emotin perception without central attention. *Journal of Cognitive Psychology*, *23*, 695–708.

Staugaard, S.R. (2009). Reliability of two versions of the dot-probe task using photographic faces. *Psychology Science Quarterly*, *51*(3), 339–50.

Waechter, S., Nelson, A.L., Wright, C., Hyatt, A., Oakman, J. (2014). Measuring attentional bias to threat: reliability of dot probe and eye movement indices. *Cognitive Therapy and Research*, *38*(3), 313–33.

Woldorff, M. (1993). Distortion of ERP averages due to overlap from temporally adjacent ERPs: Analysis and correction. *Psychophysiology*, *30*, 98–119.