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# Attentional bias in anxiety: A behavioral and ERP study

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## Abstract

Accumulating evidence suggests the existence of a processing bias in favor of threat-related stimulation in anxious individuals. Using behavioral and ERP measures, the present study investigated the deployment of attention to face stimuli with different emotion expressions in high-anxious and low-anxious participants. An attention-shifting paradigm was used in which faces with neutral, angry, fearful, sad, or happy expressions were presented singly at fixation. Participants had to fixate on the face cue and then discriminate a target shape that appeared randomly above, below, to the left, or right of the fixated face. The behavioral data show that high-anxious participants were slower to respond to targets regardless of the emotion expressed by the face cue. In contrast, the ERP data indicate that threat-related faces elicited faster latencies and greater amplitudes of early ERP components in high-anxious than in low-anxious individuals. The between-group pattern in ERP waveforms suggests that the slower reaction times in high-anxious participants might reflect increased attentional dwelling on the face cues, rather than a general slowing of response enacting.

*Keywords:* Anxiety; Attentional bias; Selective attention; ERP

## 1. Introduction

For behavior to be adaptive and guide attention to salient events, some degree of stimulus processing must take place preattentively. From this perspective, it is reasonable to expect that threat-related stimuli should be more likely to attract attention than other stimuli (e.g., Ohman, Flykt, & Esteves, 2001). Several authors have suggested that the attentional system of anxious individuals may be abnormally sensitive to threat-related stimuli in the environment, leading to an even more pronounced processing bias in favor of threat-related stimulation than is observed in non-anxious individuals. Such increased attentional bias towards threat is thought to play a prominent role in the etiology and maintenance of anxiety disorders. Support for this claim in both clinically anxious individuals (e.g., MacLeod, Mathews, & Tata, 1986; Mogg, Mathews, & Eysenck, 1992) and participants with high levels of self-reported anxiety (e.g., Broadbent & Broadbent, 1988; Eysenck, MacLeod, & Mathews, 1987) has come from a range of studies using a variety of selective attention tasks.

One such task is the modified emotional version of the Stroop color-naming task. Anxious individuals are typically slower to name the colors of threat-related words than of neutral words (e.g., Mogg, Kentish, & Bradley, 1993). The slower color-naming latencies to threat stimuli in anxious individuals are held to reflect selective allocation of processing resources to these stimuli (Mathews & MacLeod, 1985; Williams, Mathews, & MacLeod, 1996). This interpretation has been criticized, however, as such interference effects might reflect effortful avoidance rather than vigilance for threat stimuli (De-Ruiter & Brosschot, 1994), or competition at the response selection stage rather than at earlier attentional stages (MacLeod, 1991).

To obtain a more direct measure of attentional biases in anxious individuals, MacLeod et al. (1986) developed

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the probe detection task. In this task, two stimuli, one threat-related and one neutral, are shown briefly on each trial, and their offset is immediately followed by a small dot probe in the location just occupied by one of them. Participants are required to respond as fast as possible to the probe. Based on the attention literature (Navon & Margalit, 1983; Posner, Snyder, & Davidson, 1980), response latencies in this probe detection task are held to provide a "snap-shot" of the distribution of participants' attention, with faster responses to probes presented in the attended relative to the unattended location. Anxious individuals are faster to respond to probes that replace threat-related rather than neutral stimuli, whereas no such pattern is observed in non-anxious individuals (Fox, 1993; MacLeod et al., 1986; for review see Mogg & Bradley, 1998; Mogg, Bradley, & Williams, 1995).

Although this line of research has generally shown that anxious participants exhibit an attentional bias toward threat-related stimuli, the nature of this bias is not well understood. First, it is not clear whether the increased attentional bias observed in anxious individuals is tied to threat-related, to negatively valenced emotional stimuli, or to emotional stimuli in general. Indeed, some studies reported findings that are consistent with a bias towards both negative and positive faces relative to neutral faces (e.g., Bradley, Mogg, White, Groom, & de Bono, 1999). Others (e.g., Bradley, Mogg, Falla, & Hamilton, 1998; Mogg & Bradley, 1999) reported an attentional bias only to angry faces and not to happy faces but their stimuli did not include other negative faces. Finally, those studies that included a larger variety of negative facial expressions yielded contradictory findings (e.g., Bradley, Mogg, & Millar, 2000).

Second, there is no consensus as to what mechanisms underlie the attentional bias in anxious individuals. Some authors suggested that a hyper-vigilant (Eysenck, 1992) or orienting (Beck & Clark, 1997) mode in anxious individuals permits early detection of threatening stimuli, and support the view that these individuals' attention is automatically oriented towards threat. However, this view has been recently challenged in a series of studies by Fox and colleagues (Fox, Russo, Bowles, & Dutton, 2001). Relying on Posner and Peterson's (1990) distinction between separate components of attention, Fox et al. (2001) investigated whether the attentional bias in anxious participants reflects speeded engagement of attention with threat-related stimuli or a difficulty in disengaging attention from threat-related stimuli once such stimuli have been attended. Fox et al. (2001) used a variant of the spatial cuing paradigm developed by Posner and colleagues (e.g., Posner et al., 1980). In this task, a cue appears in one of two locations, and is followed by a target presented at the cued location on a majority of the trials (valid-cue condition) and at the alternative location on the remaining trials (invalid-cue condition). Performance in detecting or identifying the target is typically faster on validly cued than on invalidly cued trials. Speeding on validly cued trials has been attributed to the benefit of attentional engagement with the cued location. Slowing on invalidly cued trials has been associated with the cost arising from having to disengage attention from the cued location.

Fox et al. (2001) manipulated the emotional valence of the cue using neutral, positive, or threat-related stimuli (see Stormark, Nordby, & Hugdahl, 1995 for the original version of this manipulation). High-anxious participants took longer to respond to an invalidly cued target following a threat-related cue than following a neutral or a positive cue. No such pattern was found in low-anxious participants. Cue valence did not affect response latencies on validly cued trials in either group. The authors concluded that the attentional bias in anxious participants reflects increased attentional dwell time at the location of threat-related stimuli. This conclusion was reinforced by the finding that in an attention-shifting task, in which participants were requested to judge a peripheral target, anxious participants took longer to disengage their attention from centrally presented threat words than from either positive or neutral words. Again, no such pattern was found in non-anxious participants (Fox et al., 2001, Experiment 5).

Congruent findings were reported by Yiend and Mathews (2001) using a spatial cuing paradigm. They observed effects of cue valence (threat versus non-threat) on invalidly cued trials in anxious subjects but not in non-anxious subjects, and no such effect was apparent on validly cued trials. However, the expected standard validity effect was not obtained with non-threat cues, which casts doubts on the adequacy of the cuing procedure. Specifically, cue-to-target stimulus onset asynchronies (SOAs) were much longer than those typically used in Posner's spatial cuing task. Fox, Russo, and Dutton (2002) reported a similar effect but the delayed disengagement in anxious participants appeared to pertain to both angry and happy faces.

An additional prediction following from the disengagement account of the attentional bias in anxious subjects was tested using the inhibition of return (IoR) phenomenon. After attention has been disengaged from a cued location, the typical pattern of faster responses to validly cued targets is reversed, and reaction times become slower at the cued location relative to uncued locations. If anxious participants take longer to disengage from threat-related cues, IoR from such cues should also be reduced or delayed relative to non-anxious participants. This rationale yielded mixed results. Yiend and Mathews (2001) and Fox et al. (2002, Experiment 2) reported reduced IoR from threat cues relative to non-threat cues, but in both anxious and non-anxious participants. Fox et al. (2002, Experiment 3) observed the expected IoR reduction only in anxious participants but for angry faces and for jumbled faces relative to neutral faces.

Taken together, the reviewed findings are generally consistent with the notion that attention is normally captured by threat-related stimuli and that anxious participants tend to show difficulty in disengaging their attention from such stimuli. However, the extant data regarding the disengage component of attention in relation to anxiety is scarce and does not yield a clear-cut picture. Therefore, the main objective of the present study was to further investigate the time course of attention deployment to emotional stimuli in anxious versus non-anxious participants.

Fine-grained information about the temporal structure of attentional processes can be obtained through the use of event-related brain potentials (ERPs). Recording of ERPs to cue and target stimuli may provide useful data on both the timing and the neural substrates of spatial attention. Such physiological data may serve as converging operations that supplement behavioral data to advance our understanding of the mechanisms underlying attentional biases in anxiety. Several studies have used ERPs to gain more direct insight into the temporal characteristics of attentional processing during performance of selective attention tasks (e.g., Hillyard & Anllo-Vento, 1998). Electrophysiological investigations of spatial selective attention have identified specific indices of attention allocation.

Visuospatial orienting of attention is known to enhance the stimulus-evoked neural activity reflected in enhanced amplitude of the P1 (80–110 ms) and N1 (140–190 ms) components of the ERP (Hillyard et al., 1995). The processes indexed by P1 and N1 appear to be dissociable, with increased amplitude of occipital P1 reflecting allocation of attention to stimuli, and enhanced amplitude of N1 indicating discrimination of attended stimuli (Mangun, 1995; Mangun & Buck, 1998). This pattern of activity is held to support the idea that sensory visual processing of stimuli at an attended location is facilitated (Mangun & Hillyard, 1990). Accordingly, one may predict that increased allocation of attention to emotional information (e.g., threat-related facial expressions) in anxious individuals should be associated with attention-related increase in the amplitude of these early ERP components, or with faster P1 and N1 latencies, reflecting speeded capture of attention relative to non-anxious individuals. A similar attention-related interpretation of the P2 component was suggested by Carretie et al. (Carretie, Martin Loeches, Hinojosa, & Mercado, 2001; Carretie, Mercado, Tapia, & Hinojosa, 2001), who found increased P2 amplitude and faster P2 latency in response to negative- versus positive-arousing pictures.

Also of interest for the present study are ERP components related to the processing of targets in choice reaction tasks. A number of studies have provided evidence suggesting that the latency of the P3 component, a positive-going wave with a latency of 250 ms or more, reflects the time of stimulus evaluation in choice reaction tasks (Kutas, McCarthy, & Donchin, 1977; Magliero, Bashore, Coles, & Donchin, 1984; McCarthy & Donchin, 1981). Other studies suggest that the latency and amplitude of the P3 component depend not only on stimulus evaluation, but also on later cognitive processes, such as response selection (e.g., Falkenstein, Hohnsbein, & Hoormann, 1994; Verleger, 1997). Thus, if the observed behavioral bias toward threat-related stimuli in anxious individuals is the result of such later processes, as opposed to or in addition to differential processing of threat-related cues, this should be reflected in differences between anxious and non-anxious individuals in ERP components time-locked to target onset. In contrast, if the observed bias reflects increased dwelling time on threat cues only, no specific differences in ERP to targets should be expected.

Previous studies have also described the time course of ERP modulation by emotion expression. Discrimination between emotional and neutral faces was detected at around 250 ms after stimulus onset, and discrimination between fearful and other expressions at around 550 ms (Krolak-Salmon, Fischer, Vighetto, & Mauguiere, 2001; Sato, Kochiyama, Yoshikawa, & Matsumura, 2001). Other studies, however, provided evidence for ERP modulation by emotion in earlier components, starting between 100 and up to 200 ms after stimulus onset (Eimer & Holmes, 2002; Holmes, Vuilleumier, & Eimer, 2003; Pizzagalli, Regard, & Lehmann, 1999; Sato et al., 2001). These findings, which suggest rapid processing of facial emotional expression, are compatible with the notion that such stimuli are endowed with special significance for the organism (Vuilleumier, 2002).

In the present study, we used a variant of Fox et al.'s (2001, Experiment 5) attention shifting paradigm along with ERP recording. In the original paradigm words with neutral, positive, or threat-related valence were presented singly at fixation. The participants' task was to fixate on the word cue and then name a target letter that appeared randomly above, below, to the left, or right of the fixated word. We introduced three modifications to this procedure.

First, we used photographs of facial expressions rather than word stimuli. An angry or fearful facial expression is a natural sign of potential threat, whereas a threat-related word is an arbitrary symbol. Thus, threatening faces represent a more potent and ecologically valid type of threat (Bradley et al., 1997; Ekman, 1993; Izard, 1994). In addition, the use of pictures of facial expressions of emotion circumvents a potential confound between stimulus threat value and subjective frequency of usage. Namely, threat words are likely to have higher subjective frequency of usage the more anxious the individual (Mogg & Bradley, 1999).

Second, we used faces displaying a variety of expressions (angry, fearful, sad, happy, and neutral). The inclusion of fearful and sad faces should allow us to examine whether the increased attentional bias observed in anxious participants is tied to threat-related stimuli in particular or to negatively valenced emotional stimuli in general. To increase the ecological validity of the stimuli, all five facial expressions of emotion were randomly mixed within the same experimental blocks. We thereby attempted to create a more naturalistic context of face processing, characterized by a stream of constantly changing facial expressions, of either different individuals or the same person at different times.

Third, ERPs to both cues and targets were recorded in conjunction with behavioral measures, to unveil the time course of attentional deployment and the neural mechanisms underlying the attentional bias in anxious individuals. With ERP data, we expected to find different patterns of neural activity in response to the cue as a function of emotional expression. Moreover, we expected the ERP methodology to allow us to determine how early in processing anxious individuals differ from non-anxious individuals, and to describe the pattern of this time course for different facial expressions.

To summarize, the objective of the present study was twofold. First, we expected to replicate Fox et al.'s (2001) findings with more ecologically valid stimuli (i.e., faces as opposed to words). That is, we expected a larger attentional bias, reflected in longer RTs to threat versus non-threat stimuli in anxious relative to non-anxious participants. Second, we aimed at studying the chronometry and neural substrates of the hypothesized attentional bias using ERP methodology. Specifically, we expected to find between-group differences in the modulation by emotion of early ERP components to the cues. No such between group differences were expected for targets. Finally, although not the primary objective of our study, we hoped to shed further light on the time course of neural processing of facial expressions of emotion.

## 2. Materials and methods

### 2.1. Participants

Participants were selected out of a pool of sixty-six undergraduate students (54 females), mean age 23 years (range 18–33 years, *SD* = 2.87). All the participants had self-reported normal or corrected-to-normal eyesight. The participants were selected into two extreme groups on the basis of their response to Spielberger's Trait Anxiety Inventory (Spielberger, Gorsuch, Lushene, Vagg, & Jacobs, 1983), completed one week prior to the testing session. Those with scores in the top quartile of the distribution ($n = 13$, 2 males and 11 females) were allocated to the high trait-anxiety group, and those with scores in the bottom quartile of the distribution ($n = 11$, 3 males and 8 females) were allocated to the low trait-anxiety group. Participants also completed the Beck Depression Inventory (BDI, Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) and the Marlowe–Crowne Scale of Social Desirability (MC, Crowne & Marlowe, 1964). Table 1 presents means and *SD*s by group for the questionnaires completed. The groups differed significantly on trait anxiety, $t(22) = 14.90$, $p < .0001$. There was no difference between high- and low trait-anxious participants on state anxiety, $t(22) = 1.14$, $p > .10$ or on social desirability, $t(22) = 1.70$, $p > .10$. High trait-anxious participants reported higher level of depression than low trait-anxious participants, $t(22) = 3.37$, $p < .01$.

Table 1
Means and standard deviations of participants' characteristics for the high and low trait anxiety groups

| | Low trait anxiety ($n = 11$) | | High trait anxiety ($n = 13$) | |
|---|---|---|---|---|
| | Mean | *SD* | Mean | *SD* |
| Age | 23.7 | 3.2 | 22.7 | 1.9 |
| STAI—trait anxiety | 40.0 a | 1.8 | 52.2 b | 2.2 |
| STAI—state anxiety | 46.1 | 4.6 | 43.8 | 5.4 |
| Beck depression inventory | 22.6 a | 3.4 | 31.2 b | 8.0 |
| M–C social desirability scale | 15.1 | 2.6 | 13.5 | 2.2 |

Significant between groups differences are marked by different low case letters.

### 2.2. Attention shifting task—stimuli and procedure

Participants were seated in a comfortable chair in a dimly lit room at a distance of 80 cm from a computer screen. They were instructed to focus their gaze on the face stimuli to be presented in the center of the screen, and then to identify the shape of a target that would appear on each trial at one of four possible peripheral locations. They were required to press "A" on the response box with their left thumbs if the target was a square, and "B" with their right thumbs if it was a diamond. Half of the participants were assigned the reverse target-to-hand mapping for counterbalance. Participants were asked to refrain from making eye movements throughout the session. It was emphasized that they could perform the task without having to move their eyes.

Fig. 1 describes the sequence of events in the attention-shifting task. Each trial began with the presentation of a fixation display, a black 0.8 × 0.8 cm asterisk sign (*) in the center of an outline frame drawn with a black 1-pixel stroke (3.5 × 3.5 cm), which appeared on the screen for 1000 ms. Then, a face cue appeared inside the outline frame and remained on the screen until the end of the trial. The face stimuli were chromatic photographs of 10 different Caucasian individuals, five males and five females, selected from the *Japanese and caucasian facial*

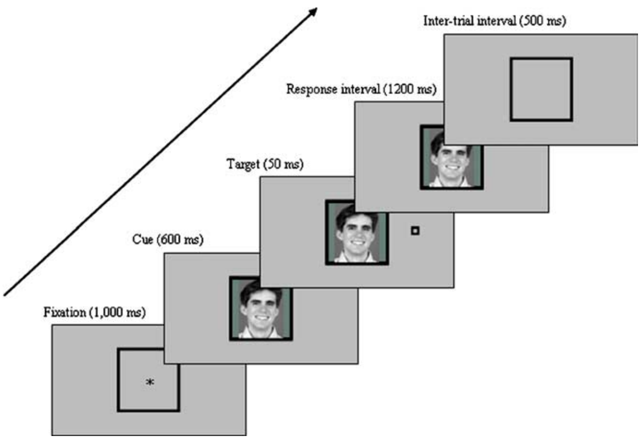

Fig. 1. Sequence of events in the attention shifting task.

*expressions of emotion* (JACFEE) set. Each face displayed either one of four different expressions of emotion: happiness, anger, sadness, and fear, or a neutral expression. These faces were all reliably categorized as happy, sad, angry, fearful, and neutral (see Matsumoto & Ekman, 1988). Six hundred milliseconds after face cue onset, a target appeared for 50 ms. The target was a black outline shape, either a square or a diamond (i.e., an identical square rotated by 90°), subtending $0.4 \times 0.4$ cm and drawn with a 2-pixel stroke. The target appeared at one of four possible locations, and was centered at 3.6 cm above, below, to the left, or to the right of the center of the computer screen. After the target disappeared the face cue remained on the screen for an additional 1200 ms, during which the subject had to respond. An inter-trial interval of 500 ms followed, during which only the outline frame was present on the screen. All stimuli were presented against a gray background.

Each participant was run on 48 practice trials, with displays consisting of two different neutral faces, one male and one female, and followed by 240 experimental trials divided into three blocks of 80 trials each. Participants were allowed a rest period after each block. In the experimental session, the 10 different faces were presented 24 times each, in random order. Target shapes and locations were equally probable and their presentation was randomized between trials. Target identification performance was measured using reaction times and accuracy.

### *2.3. EEG/ERP recording*

#### *2.3.1. EEG recording parameters and artifact scoring*

Continuous EEG from 20 scalp sites (Fp1, Fp2, F7, F3, Fz, F4, F8, T3, T4, T5, T6, C3, Cz, C4, P3, Pz, P4, O1, Oz, and O2, plus the left and right mastoids) was recorded while participants performed the attention-shifting task. EEG data was recorded using a stretch Lycra cap (Electro-Cap) with electrodes located according to the international 10/20 system (Jasper, 1958). All EEG channels were collected referenced to the chin. Vertical and horizontal EOG were recorded from above and below the left eye and at the right and left outer canthi, respectively. All electrode impedances were kept below $5\,\mathrm{k\Omega}$. EEG and EOG signals were amplified with Ceegraph IV bioamplifier from Biologic Systems, and were digitized onto a PC using a 16 bit A/D converter and Ceegraph IV data acquisition software. For both EEG and EOG sampling rate was 256 Hz with bioamplifier filter settings of. 1Hz high pass and 100 Hz low pass.

Further processing and analysis of the EEG signal was carried out offline using BPM software package from Orgil Company. Artifactual EEG ($\pm 100\,\mu\mathrm{V}$) was automatically removed from further analysis. Eye blinks that appeared in the EOG signal were regressed out of the EEG using a procedure based on methods described in the literature (e.g., Lins, Picton, Berg, & Scherg, 1993; Miller & Tomarken, 2001). Trials containing horizontal eye movements were eliminated from further analyses (also ensuring the removal of trials in which participants moved their eyes and did not follow the instructions for the attention task). Trials with incorrect responses or response latencies faster than 150 ms or exceeding 1500 ms were also removed from further analysis. Overall, 4.1 percent of the trials were removed due to artifacts in the EEG signal, with similar numbers of removed trials in the high anxious group and low anxious group, $ps > .50$. Before derivation of the ERPs, the EEG signal was subjected to low-pass digital filtering of 30 Hz.

#### *2.3.2. ERP measures and waveform scoring*

Because no important left-right lead effects emerged, and to simplify presentation, data from four midline electrode sites was selected for further statistical analysis: Fz, Cz, Pz, and Oz. The measured ERP variables were baseline-to-peak amplitudes and cue-to-peak and target-to-peak latencies. Latencies were calculated for every subject within latency windows that were determined after inspection of the relevant grand mean ERPs. Once selected, latency windows were the same for all subjects and conditions. The amplitude of each ERP component was measured relative to a 200 ms pre-cue or pre-target stimulus baseline, within latency windows centered on the peak latency of the grand mean ERPs.

#### *2.3.3. Cue-evoked ERP components*

Based on a review of the grand ERPs to cue stimuli three ERP components (P1, N1, and P2) were selected for analysis: (a) P1 (the first major positive voltage deflection in the ERP occurring 50–165 ms after the cue); (b) N1 (the following major negative voltage deflection occurring 90–215 ms after the cue). Attention-related enhancement of the P1/N1 complex over frontal, parietal, and occipital electrode sites has been interpreted as reflecting the facilitation of visual sensory-processing for stimuli at an attended location (Hillyard & Anllo-Vento, 1998); (c) P2 (the following major positive voltage deflection occurring 120–315 ms after the cue). It has been suggested that this ERP component over occipital sites may reflect a distributed network of visual processing areas that are sensitive to threat-related stimuli and might indicate more elaborate sustained perceptual processing (Schupp, Junghoefer, Weike, & Hamm, 2003; Schupp et al., 2004).

### *2.3.4. Target-evoked ERP components*

Three ERP components were chosen for analysis (P1, N1, and P3): (a) P1 (the first major positive voltage deflection in the ERP occurring 40–140 ms after target onset); (b) N1 (the following major negative voltage deflection occurring 100–200 ms after target onset); (c) P3 (the major positive deflection occurring 200–450 ms after target onset).

### *2.4. Statistical analyses*

Behavioral data were subjected to repeated measurement analysis of variance (ANOVAs), with emotion-expression (fear, angry, sad, happy, and neutral) as a within-subject factor and group (high-anxious versus low-anxious) as a between-subjects factor. Because depression (BDI scores) significantly correlated with trait anxiety, $r = .54$, $p < .01$, the BDI scores were entered into the analysis as a covariate factor.

ERP latency and amplitude data were subjected to separate repeated measures multivariate analyses of variance (MANOVAs) for each pre-selected ERP component. Emotion-expression (fear, angry, sad, happy, and neutral) and electrode site (Fz, Cz, Pz, and Oz) were within-subject factors and group (high-anxious versus low-anxious) was a between-subjects factor. BDI scores were again entered into the analyses as a covariate factor.

Follow-up ANOVAs and post hoc least square difference (LSD) contrasts were used to breakdown interaction effects and multi-category main effects. Whenever assumptions of sphericity in repeated measures analyses were violated, as assessed by Mauchly's (1940) test of sphericity, the Greenhouse–Geisser statistic (Greenhouse & Geisser, 1959) was used to adjust the degrees of freedom. The application of the Greenhouse–Geisser correction is indicated by the epsilon value ($\varepsilon$) reported in the results. The degrees of freedom indicated in the text are always those before the Greenhouse–Geisser correction.

## 3. Results

### *3.1. Behavioral measures*

Table 2
Mean response latencies (in ms) and standard deviations by emotion expression and trait anxiety groups

| Facial expression | Low trait anxiety ($n = 11$) | | High trait anxiety ($n = 13$) | |
|---|---|---|---|---|
| | Mean | *SD* | Mean | *SD* |
| Angry | 500.3 | 65.0 | 567.5 | 84.2 |
| Fearful | 509.6 | 65.0 | 569.3 | 82.0 |
| Happy | 498.6 | 56.4 | 558.7 | 66.6 |
| Neutral | 499.7 | 62.0 | 567.4 | 79.2 |
| Sad | 507.8 | 62.6 | 554.5 | 77.4 |

Table 2 presents means and standard deviations of RTs as a function of group and emotion expression. Analysis of the reaction time (RT) data revealed a main effect of group $F(1,21) = 4.24$, $p < .05$, such that high-anxious participants had longer RTs ($M = 565$ ms, $SD = 99.31$) relative to low-anxious participants ($M = 502$ ms, $SD = 108.41$). The main effect of emotion and emotion by group interaction were not significant.

Participants had relatively low error rates: mean percent of correct responses across groups and emotions was 97.5 ± .5%. There was not enough variability in error rates to conduct meaningful analyses, and error rates were therefore not inspected further.

### *3.2. ERPs*

For brevity reasons, only significant findings are reported. Grand-averaged ERPs to cues and targets by group are presented in Fig. 2. Grand-averaged ERPs to cue by emotion are presented in Fig. 3.

### *3.3. ERPs to cue stimuli*

Table 3 presents mean amplitudes and latencies of ERP components to the face cues by electrode site.

### *3.4. P1*

### *3.4.1. Amplitude*

A main effect of emotion was found, $F(4,84) = 6.04$, $\varepsilon = .90$, $p < .001$. P1 amplitude was lower in response to fearful ($M = .92\,\mu V$, $SD = 2.16$) than to all the other facial expressions of emotion ($M$s = 3.01, 2.17, 3.35, 2.48 µV, $SD$s = 2.01, 2.11, 2.20, 1.67, for neutral, sad, happy, and angry expressions, respectively). In addition, a main effect of electrode site was found that followed the pattern of: $Fz < Cz < Pz < Oz$, $F(3,63) = 93.24$, $p < .001$.

### *3.4.2. Latency*

An electrode by group interaction was found, $F(3,63) = 7.63$, $p < .001$. To breakdown this interaction, separate repeated measures ANOVAs were computed to assess group effects separately for each electrode. High-anxious participants displayed faster P1 latency ($M$s = 78 and 98 ms, $SD$s = 17.02 and 20.82) compared with low-anxious participants ($M$s = 90 and 117 ms, $SD$s = 15.38 and 19.15) over Pz and Oz electrode sites, respectively, $F$s$(1,21) = 5.84$ and 6.19, respectively, $p$s < .05.

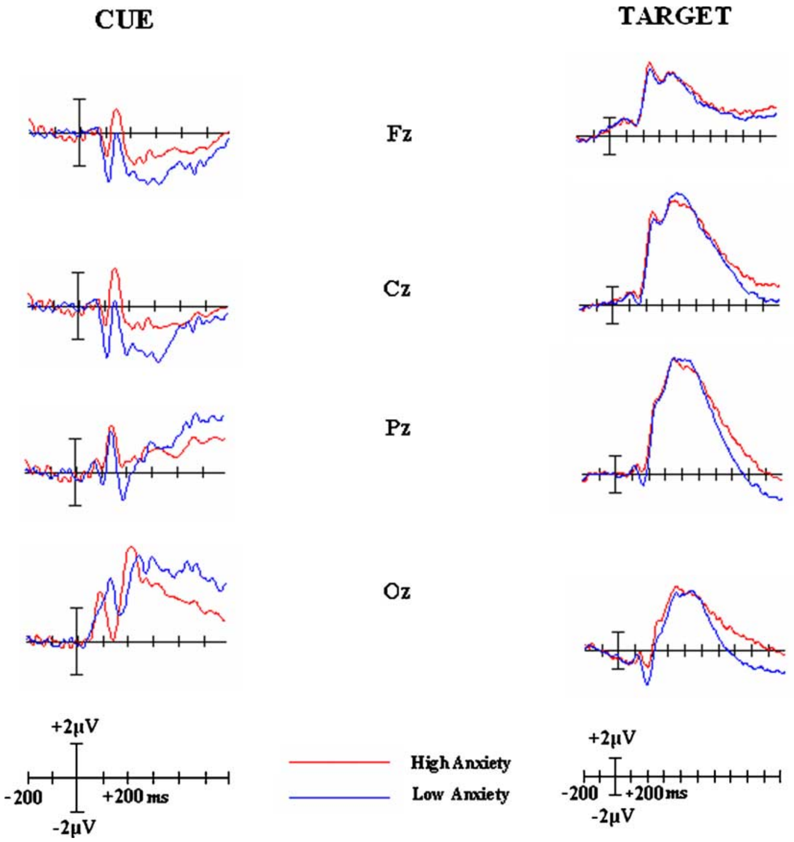

Fig. 2. Grand-average ERP's to cue-stimuli (left) and target-stimuli (right) from central scalp sites. The time scale is marked in intervals of 100 ms, starting 200 ms prestimulus onset.

### 3.5. N1

#### 3.5.1. Amplitude

A main effect of emotion was found, $F(4,84) = 3.84$, $\varepsilon = .82$, $p < .01$. Fearful facial expressions evoked significantly greater negativity ($M = -3.56\,\mu V$, $SD = 2.11$) than neutral, happy, and angry expressions ($M\text{s} = -2.08, -1.94, -1.76\,\mu V$, $SD\text{s} = 1.71, 2.16, 1.76$, respectively). In addition, a main effect of electrode site was found, $F(3,63) = 5.02$, $p < .05$, such that N1 negativity at Fz was greater than at Pz and N1 negativity at Cz was greater than at Pz and Oz.

#### 3.5.2. Latency

An electrode by group interaction was found, $F(3,63) = 6.18$, $p < .001$. Further analyses revealed that high-anxious participants displayed faster N1 latency ($M = 145$ ms, $SD = 22.18$) than low-anxious participants ($M = 168$ ms, $SD = 24.19$) over Oz, $F(1,21) = 10.42$, $p < .01$. No such between-groups effects were found over Fz, Cz, or Pz electrode sites.

### 3.6. P2

#### 3.6.1. Amplitude

An emotion by group by electrode interaction was found, $F(12,252) = 3.02$, $p < .001$. Separate follow-up ANOVAs for each electrode site revealed a significant emotion by group interaction over the Cz electrode site, $F(4,84) = 2.38$, $p < .05$, such that compared with low-anxious participants ($M = 1.80$, $SD = 4.69$), high-anxious participants had greater P2 amplitudes ($M = 3.96$, $SD = 4.30$), but only to angry faces, $t(22) = 2.89$, $p < .01$. Fig. 4 presents grand-averaged ERPs to the five emotion expressions by group at Cz electrode site.

#### 3.6.2. Latency

An electrode by group interaction was found, $F(3,63) = 4.49$, $p < .01$. To clarify this interaction, separate repeated measures ANOVAs were computed for each electrode site. High-anxious participants displayed faster P2 latency ($M = 229.24$ ms, $SD = 31.26$) than low-anxious participants ($M = 251.32$ ms, $SD = 32.43$) over Oz, $F(1,21) = 4.74$, $p < .05$. No such between-groups effects were found over Fz, Cz, or Pz electrode sites. In addition, a P2 latency was longer over Oz compared with Fz, Cz, and Pz, $F(3,63) = 26.34$, $p < .001$.

In summary, early ERP components (P1 and N1) to cue stimuli reveal that amplitudes are modulated by emotion expression, with fear showing a distinctive pattern, whereas ERP latencies are modulated by anxiety level, with high-anxious participants displaying faster latencies than low-anxious participants over the

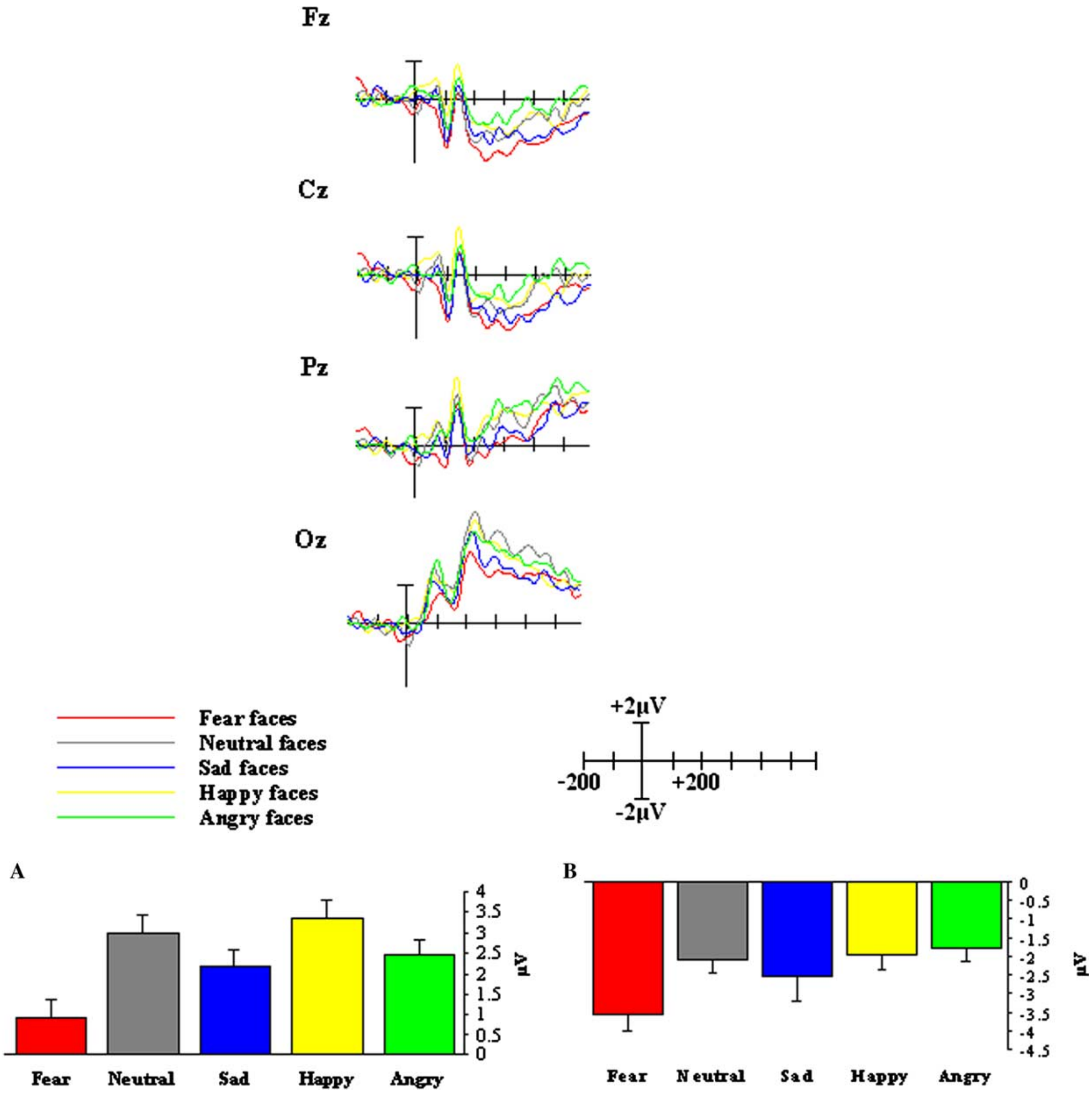

Fig. 3. Grand averaged ERPs to five emotion expressions. The time scale is marked in intervals of 100 ms, starting 200 ms pre-stimulus onset. (A) mean amplitudes of the P1 component to the different facial expressions, showing a smaller amplitude to fearful versus neutral and happy expressions; (B) mean amplitudes of the N1 component to the five facial expressions, with greater negativity for fearful versus neutral faces. Standard errors are marked.

occipital region. The expected emotion by group interaction was found only for the P2 component, with high-anxious participants showing higher amplitude for angry faces than low-anxious participants at the vertex.

### *3.7. ERPs to target stimuli*

Visual inspection of the grand ERPs to targets indicates no between-groups difference in the characteristics of the P1, N1, and P3 components. This observation was backed up by separate statistical analyses for each component that revealed no significant main or interaction effects involving group or emotion expression.

## 4. Discussion

Following Fox et al. (2001, Experiment 5) we expected high-anxious participants to respond to targets more slowly following threat-related versus non-threat stimuli. This prediction was not confirmed at the behavioral level, as high-anxious participants displayed slower RTs than low-anxious participants regardless of facial expression.

Unlike the behavioral data, the ERP data provided some indication that processing of threat-related stimuli is modulated by trait-anxiety level. Significant group differences were found in processing of angry faces but not of neutral faces or faces displaying other expressions

Table 3
Mean amplitudes (in μV) and latencies (in ms) of ERP components to the face cues by electrode site

| | P1 | N1 | P2 |
|---|---|---|---|
| *Amplitude (μV)* | | | |
| Fz | 1.02 (.89) | −3.11 (1.22) | 2.06 (2.28) |
| Cz | 1.35 (1.13) | −3.17 (1.32) | 2.97 (3.21) |
| Pz | 2.04 (1.29) | −1.71 (1.52) | 4.24 (3.37) |
| Oz | 5.08 (2.05) | −1.50 (3.84) | 7.79 (3.66) |
| *Latency (ms)* | | | |
| Fz | 80.57 (7.58) | 116.18 (8.73) | 155.70 (15.09) |
| Cz | 82.19 (8.34) | 117.06 (10.66) | 155.99 (16.37) |
| Pz | 84.24 (11.06) | 116.93 (12.85) | 156.25 (17.69) |
| Oz | 106.71 (16.82) | 155.57 (20.04) | 240.59 (25.42) |

Standard deviations are in parentheses.

of emotion. Specifically, high-anxious participants showed higher amplitudes of the P2 ERP component to angry faces at all analyzed electrode sites. These findings may be cautiously interpreted as suggesting that threat-related stimuli (angry faces) elicit greater mobilization of attentional resources in high-anxious than in low-anxious participants. The fact that the expected interaction between anxiety level and response to emotion expressions was detected only in the ERP data suggests that the ERP methodology may provide a more sensitive measure of the threat-related attentional bias in anxiety.

A prominent finding of the present study is the robust main effect of anxiety group, by which high-anxious participants were slower to respond to targets regardless of the emotion expressed by the cue. A similar group effect has been reported in some studies (e.g., Taghavi, Dalgleish, Moradi, Neshat Doost, & Yule, 2003; Yiend & Mathews, 2001), while in other studies (e.g., Fox et al., 2002) a similar trend is clearly apparent in the raw data but was not tested for significance because only attentional bias scores were analyzed.

The between-group pattern in ERP waveforms suggests that the slower RTs in high-anxious participants may reflect increased processing of the cue, rather than a general slowing of response enacting. Specifically, the ERP waveforms displayed by the two anxiety groups started to diverge as early as 50 ms after cue onset. Indeed, P1 and N1 latencies to cue were significantly faster in the high-anxious group than in the low-anxious group. No such between-groups differences were observed in ERP waveforms to targets. This pattern of results may suggest that in high-anxious participants processing of the centrally presented faces interfered with speed of target discrimination, which is consistent with the findings of recent studies showing that allocating attention to an object may produce long-lasting interference on identification of subsequent objects

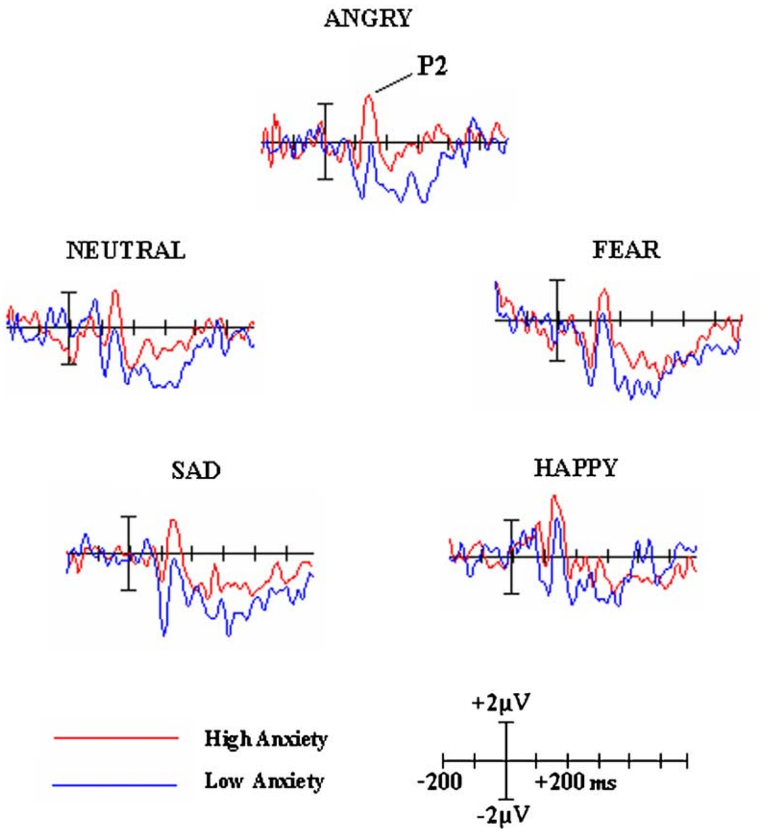

Fig. 4. Grand average ERPs to the five facial expressions by group at Cz electrode site. The time scale is marked in intervals of 100 ms, starting at 200 ms prestimulus onset.

(Muller, Teder-Salejarvi, & Hillyard, 1998; Ward, Duncan, & Shapiro, 1996). In other words, attended objects that appear within several hundred ms of each other share some form of visual processing resources (see for discussion Isreal, Wickens, Chesney, & Donchin, 1980; Wickens, Kramer, Vanasse, & Donchin, 1983). In the same vein, Bradley, Cuthbert, and Lang (1996) found that reaction times to acoustic word probes were slower during affective picture processing than during processing of neutral pictures. Within the theoretical framework proposed by Fox et al. (2001), high trait anxiety may be associated with rapid orienting of processing resources to faces, which may be followed by a difficulty to disengage from them.

What discrepancies might explain our failure to replicate Fox et al.'s (2001) finding of slower RTs to threat-related stimuli in high-anxious participants? One possibility is that some aspects of our study may have brought the high-anxious group to a ceiling level of state anxiety, which may have washed out the expected group-specific differences in response to threat-related stimuli. One such aspect may have been the use of EEG/ERP recordings in the present study. EEG recording necessitates mildly unpleasant preparation procedures (Blackhart, Kline, Donohue, Larowe, & Joiner, 2002) that may have induced an elevated anxious state in the high trait-anxious relative to the low trait-anxious group, leading to a ceiling effect of slow RTs in this group to all the emotion expressions. Since we did not measure state-anxiety after the EEG preparation, this possibility cannot be resolved without further experimentation.

There are two additional differences between our study and Fox et al.'s, which in our opinion are less likely to account for the result discrepancy. First, we examined the influence of trait anxiety on attentional bias, while Fox et al., focused on the effects of state anxiety. However, since the attentional bias has been repeatedly demonstrated using groups that differed in trait-anxiety levels an explanation along these lines seems unwarranted. Second, we employed faces as stimuli, whereas (Fox et al., 2001) used words. However, faces are considered to be more potent and ecologically valid stimuli than words (e.g., Fox et al., 2001; Mogg & Bradley, 1999). Therefore, this factor is unlikely to have played a role either.

Our ERP data also provide interesting findings pertaining to the time course of facial emotion processing. In line with earlier studies showing evidence for ERP modulation by emotion in early components, from 100 and up to 200 ms after stimulus onset (Eimer & Holmes, 2002; Holmes et al., 2003; Junghoefer, Bradley, Elbert, & Lang, 2001; Pizzagalli et al., 1999; Sato et al., 2001), we found the P1 component to differ for fearful faces relative to neutral, happy, angry, and sad faces, and the N1 component to differ for fearful faces relative to neutral, happy, and angry faces.

Moreover, the ERP modulation by emotion observed in the present study occurred despite the fact that facial emotions were task irrelevant. Earlier studies by Eimer and colleagues (Eimer, Holmes, & McGlone, 2003; Holmes et al., 2003) showed that early ERPs were modulated by emotion (fearful versus neutral faces) when participants had to judge whether two faces or two houses were physically identical or different, such that facial expression was task irrelevant. In the present study, however, not only was facial expression irrelevant to the task but so was the facial stimulus itself, since participants were not required to carry out any task regarding the centrally presented faces.

In conclusion, the present study provides evidence for anxiety-modulated facial processing. This effect was not emotion-specific at the behavioral level, thus failing to replicate Fox et al.'s finding (2001, Experiment 5). However, our ERP data support the idea that threat-related faces elicit faster and more intense processing in high-anxious than in low-anxious individuals. As such, the present study underscores the usefulness of the ERP methodology, as a sensitive measure for the study of attentional bias in anxiety and its chronometry.

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