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Face processing biases in social anxiety: An electrophysiological study

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Abstract

Studies of information processing biases in social anxiety suggest abnormal processing of negative and positive social stimuli. To further investigate these biases, behavioral performance and event-related brain potentials (ERPs) were measured, while high- and low-socially anxious individuals performed a modified version of the Erikson flanker task comprised of negative and positive facial expressions. While no group differences emerged on behavioral measures, ERP results revealed the presence of a negative face bias in socially anxious subjects as indexed by the parietally maximal attention- and memory-related P3/late positive potential. Additionally, non-anxious subjects evidenced the presence of a positive face bias as reflected in the centrally maximal early attention- and emotion-modulated P2 and the frontally maximal response monitoring-related correct response negativity. These results demonstrate the sensitivity of different processing stages to different biases in high- versus low-socially anxious individuals that may prove important in advancing models of anxious pathology.

Keywords: Social anxiety; Information processing biases; Event-related potentials; Attention; Response monitoring

Current accounts of social anxiety suggest that it is characterized by abnormal processing of social threat information (see Heinrichs and Hofmann, 2001 for a review) as well as social safety and acceptance signals (see Kashdan, 2007 for a review). These two abnormalities or unique tendencies – typically referred to as 'biases' – in information processing manifest such that socially anxious individuals display a bias toward negative social stimuli (e.g., angry faces) whereas they *fail* to show the normal bias toward positive social stimuli (e.g., praising words). Better understanding the nature of information processing biases in social anxiety is essential to elucidating its conceptualization and treatment.

Several lines of research support the idea that social anxiety is characterized by a bias towards social threat information. These studies show that while socially anxious individuals demonstrate preferential processing of (i.e., a bias toward) social threat, normal controls do not seem to show any bias at all (cf. Bar-Haim et al., 2007). For instance, behavioral studies have demonstrated facilitated response times (RT) to task-relevant stimuli that replace negative faces in dot probe tasks (Mogg and Bradley, 2002; Mogg et al., 2004), faster detection of negative faces during visual search (Eastwood et al., 2005) and pop out (Gilboa-Schechtman et al., 1999), as well as slower disengagement from threat words in a Posner task (e.g., Amir et al., 2003) in socially anxious subjects. Further support for this notion comes from functional neuroimaging studies that have demonstrated hyperactive amygdala, extrastriate visual cortex and insula activation to negatively valenced facial stimuli in socially anxious subjects (Stein et al., 2002; Straube et al., 2005).

Evidence for socially anxious individuals' failure to show a bias towards positive social stimuli is less robust, but still spans a number of different paradigms. Whereas the negative bias reviewed above is evident in *the presence of* preferential processing of threat information in socially anxious subjects and *the lack of* preferential processing in normal controls, the lack of positive bias is evident in *the lack of* preferential processing of positive social information in socially anxious subjects and *the presence of* preferential processing of positive social stimuli in normal controls. Socially anxious individuals, for example, fail to evince the faster RT advantage to words that complete ambiguous passages in a positive manner (Hirsch and Mathews, 2000), to positive words that are associated with self-referential words (Tanner et al., 2006), to positive faces (Silvia

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et al., 2006) that normal controls do. Additionally, socially anxious subjects fail to show the bias to associate positive outcomes with positive facial expressions that normal controls do (Garner et al., 2006).

Thus, the behavioral and neuroimaging data reviewed above suggest that socially anxious subjects show a bias toward threat information, while normal controls do not, and normal controls show a bias toward positive information, while socially anxious subjects do not. However, it is unclear whether both biases can occur in a given experiment, as it seems that when a negative bias is shown, a lack of positive bias is not, and vice versa. One possible reason why the studies reviewed above demonstrate different biases is because the experimental paradigms employed might, in fact, tap into different processes. Another possible reason why studies show different biases is because of the measures typically employed, namely RT and hemodynamic activity. Both RT and hemodynamic activity reflect an amalgam of processes and might therefore be less sensitive to detecting multiple biases or biases reflected in multiple processes in the context of a given experiment.

Event-related brain potentials (ERPs), on the other hand, are electrophysiological signals that allow for the examination of the sequence of constituent operations involved in processing and acting on incoming information on the order of milliseconds. Specifically, the ERP waveform represents multiple neural processes by discrete changes in voltage observed at the scalp – i.e., components – that offers several opportunities at detecting processing biases. Therefore, ERPs might be more sensitive to detecting the presence of biases. Consistent with this notion, several studies have demonstrated ERP differences between negative affective (anxious and depressed) and control groups in the face of comparable behavioral performance (Fallgatter et al., 2004; Hajcak et al., 2003, 2004a,b; Hajcak and Simons, 2002; Shestyuk et al., 2005). To our knowledge, only two recent studies have examined ERP correlates of information processing biases in social anxiety, however. First, Kolassa and Miltner (2006) reported somewhat larger occipito-temporal N170s to angry faces in socially anxious patients during an emotion identification task. More recently, Rossingol et al. (2007) found that high-socially anxious subjects evinced abnormal processing of anger and disgust faces as reflected in the N2b component (with 10 subjects in each group). Although preliminary, these studies suggest that ERPs can detect biases in the processing of facial expressions in social anxiety.

In the current study, we intended to extend these recent findings by examining modulations of stimulus- *and* response-locked ERPs to negative *and* positive face categorization. We chose facial stimuli because the core feature of social anxiety is fear of negative social evaluation and rejection, and faces convey significant social information (cf. Adolphs, 2002; Bradley et al., 1997; Ekman, 1993; Izard, 1971; Ohman et al., 2001). Additionally, we used negative *and* positive facial expressions, as it allowed us to examine biases in the processing of negative and positive social information that *both* appear to differentiate socially anxious from non-anxious subjects. By measuring both stimulus- and response-locked ERPs, we were able to examine whether socially anxious or non-anxious subjects showed (or lacked) a negative or positive bias at multiple points during information processing. Specifically, we examined the fronto-central P2 and N2 and parietal P3 of the stimulus-locked ERP and the fronto-central correct response negativity (CRN) of the response-locked ERP.

Electrophysiological activity in the time window of the P2 and N2 seems to be a good candidate for studying information processing biases in social anxiety, as a recent review of the literature by Eimer and Holmes (2007) showed that emotional facial expressions elicit an enhanced fronto-central positive shift beginning around 150–200 ms post-stimulus. Eimer and Holmes suggested that the fronto-central modulations by facial expressions may reflect rapid representation of emotional significance in prefrontal regions. Additionally, the previously mentioned reports by Kolassa and Miltner (2006) and Rossingol et al. (2007) suggest that ERPs in this time window can detect information processing biases in social anxiety.

Following the above-mentioned processes, the brain engages in more detailed analysis of visual information as reflected by the P3/late positive potential (LPP). The P3/LPP is a positive ERP component observed at parietal recording sites between 200 and 800 ms post-stimulus. The P3/LPP also seems to be a good candidate for studying information processing biases in social anxiety, as a large body of literature indicates that it is a neural index of attentional, perceptual and memory updating processes facilitated by motivationally relevant stimuli (Donchin, 1981; Donchin and Coles, 1988; Nieuwenhuis et al., 2005; Schupp et al., 2000). The P3/LPP was also shown to be responsive to emotional facial expressions in Eimer and Holmes's (2007) review. In addition, the P3/LPP has been reliably responsive to fear-relevant stimuli in PTSD patients (Attias et al., 1996), panic patients (Pauli et al., 1997), spider phobic patients (Kolassa et al., 2005) and animal phobic students (Miltner et al., 2005). At the same time, a reduction in the P3/LPP to flanker stimuli (i.e., fear-irrelevant, task-relevant stimuli) was found when spider phobic subjects were exposed to a spider challenge (i.e., a fear-relevant, task-irrelevant stimulus; Moser et al., 2005). Taken together, it seems that the P3/LPP is a rather robust measure of emotional processing and information processing biases in anxiety.

Response-locked ERPs reflect processes that occur around response execution that are essential to the monitoring and control of behavior. ERPs therefore allow for the differentiation of stimulus- and response-related processes that are confounded in RT measures. The CRN is one such ERP that indexes response-related processes and is typically observed as a negative deflection that peaks at fronto-central recording sites approximately 50–100 ms after a correct response is made in a two-choice speeded reaction time task (Bartholow et al., 2005; Vidal et al., 2000, 2003). More specifically, the CRN is part of a class of mediofrontal negativities believed to reflect action monitoring activity of the anterior cingulate cortex (ACC; Bartholow et al., 2005; Vidal et al., 2000, 2003). The CRN has been shown to be sensitive to response and strategy conflict (Bartholow et al., 2005), as well as the combination of cognitive conflict and affective context (Simon-Thomas and Knight, 2005). Based on such studies, it has been suggested that the CRN, and more generally activity of the ACC, is responsible for signaling other frontal brain structures such as the prefrontal cortex (PFC) that processing conflict has occurred and that increased cognitive control (e.g., a change in processing approach) is needed on subsequent trials to maximize performance goals (Bartholow et al., 2005; Bush et al., 2000; Simon-Thomas and Knight, 2005). As models of selective attention (e.g., Desimone and Duncan, 1995) and anxiety (e.g., Mathews and Mackintosh, 1998) posit that resource competition is a necessary condition for observing information processing biases, the CRN is an ideal measure because of the information it reflects about the demands on the frontal system imposed by cognitive and affective load.

The current study, then, involved measuring the P2, N2 and P3/LPP of the stimulus-locked ERP and the CRN of the response-locked ERP, while high- and low-socially anxious individuals performed a modified version of the Eriksen flanker task (Eriksen and Eriksen, 1974) comprised of faces expressing negative (anger and disgust) and positive (happiness and surprise) emotions (hereafter the face flanker task). The face flanker task requires subjects to categorize the emotion of a centrally presented face while ignoring flanking distractor faces. Based on current conceptualizations and previous research, we hypothesized that socially anxious subjects would show a negative bias while controls would not (i.e., a negative bias in social anxiety), and controls would show a positive bias while socially anxious subjects would not (i.e., a lack of positive bias in social anxiety). The extant literature, however, does not support particularly strong predictions about exactly which ERPs should reflect these biases. With regard to the early ERPs – the P2 and N2 – previous results suggesting that early attentional and perceptual processes reflect a negative bias in social anxiety (Kolassa and Miltner, 2006; Rossingol et al., 2007) are not particularly strong. Thus, it seemed unclear whether these ERPs would demonstrate reliable biases in the high- and low-anxious subjects. On the other hand, a number of previous ERP studies have shown that the P3/LPP is larger to threat-relevant stimuli in anxiety (e.g., Attias et al., 1996). We therefore felt confident predicting that the P3/LPP would demonstrate a negative bias in the high-socially anxious group and not in the low-socially anxious subjects. Likewise, as several studies of ERP modulations to affective pictures in unselected populations have shown that the P3/LPP is equally large to negative and positive images (e.g., Schupp et al., 2000), we predicted that the low-anxious group would show no bias in P3/LPP. Last, as no previous studies have used the CRN as a measure of information processing biases to emotional stimuli in anxious populations, it was again unclear what to expect. However, given that the face flanker task employed in the current study is most similar to the task used in the Silvia et al. (2006) study such that both are emotion categorization tasks, and Silvia et al. found a lack of positive bias in socially anxious subjects as reflected in RT, we hypothesized that the CRN would similarly reflect a lack of positive bias as it is an index of response-related processes. Specifically, we predicted that the low-anxious subjects would show a positive bias while the high-anxious subjects would show no bias.

1. Method

1.1. Participants

Participants were recruited through the University of Delaware Psychology Department subject pool. Over 1000 undergraduate students completed the Social Phobia Inventory (SPIN; Connor et al., 2000) at a preliminary testing session as partial fulfillment of course requirements. The SPIN is a self-report measure of social phobia comprised of 17 questions that are rated on a Likert scale ranging from 0 (not at all) to 4 (extremely). Higher scores indicate more severe symptoms of social phobia. Following the preliminary testing session, participants were rank-ordered on the basis of their score on the SPIN. Twenty-one students (15 females) from the top 10% of the SPIN distribution comprised the high-socially anxious (High-SA) group and 21 students (11 females) from the bottom 10% of the SPIN distribution comprised the low-socially anxious (Low-SA) group. The groups did not differ with respect to gender ratio, χ^2 (1, $N = 42) = 1.62$, $p > 0.20$.

Retesting at the experimental session revealed that the high-socially anxious group remained significantly higher on the SPIN ($M = 38.19$, S.D. = 7.87) than the low-socially anxious group ($M = 4.48$, S.D. = 4.34; $t(40) = 17.20$, $p < 0.001$). Although it was not formally established that the college students in the current study met diagnostic criteria for social anxiety disorder, their scores on the SPIN are highly comparable to patients with clinical social anxiety reported previously (range 32.6–43 in Connor et al., 2000; Randall et al., 2001; Stein et al., 2001) and well above the established cut score of 19 for the measure (Connor et al., 2000). In addition to the SPIN, subjects completed the 21-Item Depression Anxiety Stress Scale (DASS-21; Lovibond and Lovibond, 1995) at the experimental session. The DASS-21 is a self-report measure comprised of three seven-item subscales, including the depression (DASS-D), anxiety (DASS-A) and stress reactivity (DASS-S) subscales that are rated on a Likert scale ranging from 0 (did not apply to me at all) to 3 (applied to me very much). Higher scores on all subscales indicate more severe symptoms. DASS-21 subscale scores are doubled so that they are comparable to the full 42-item subscale scores (Lovibond and Lovibond, 1995). The high-socially anxious group scored significantly higher on all three subscales of the DASS-21: DASS-D (high-socially anxious group $M = 12.10$, S.D. = 8.52; low-socially anxious group $M = 2.29$, S.D. = 2.85; $t(40) = 5.00$, $p < 0.001$); DASS-A (high-socially anxious group $M = 10.67$, S.D. = 8.59; low-socially anxious group $M = 2.29$, S.D. = 3.59; $t(40) = 4.13$, $p < 0.001$); DASS-S (high-socially anxious group $M = 18.67$, S.D. = 9.00; low-socially anxious group $M = 5.24$, S.D. = 5.64; $t(40) = 5.80$, $p < 0.001$). The DASS-21 subscale scores reported here for the high-socially anxious group are highly comparable to those previously reported for a group of socially anxious patients (see Antony et al., 1998); in addition, the low-socially anxious group's scores are very similar to those previously reported for a non-clinical group of healthy community volunteers (Antony et al., 1998).

1.2. Stimuli and task

The stimulus set comprised 60 pictures of 30 male and female models each posing anger, disgust, happy and surprise facial expressions taken from Perez-Lopez and Woody's (2001) set of 184 photographs. Perez-Lopez and Woody collapsed the happy and surprise faces into one category that they called 'reassuring' and the anger and disgust faces into another category that they called 'threatening'—throughout the remainder of this paper we will maintain usage of these labels. This stimulus set was chosen because it had independent ratings previously reported for it, it was successful in demonstrating information processing biases in social anxiety in the original study by Perez-Lopez and Woody, and included anger and disgust facial expression that have both been posited to play a prominent role in communicating social rejection that is the core fear of socially anxious individuals (e.g., Amir et al., 2005). In their original study, Perez-Lopez and Woddy (2001) had subjects rate all 184 pictures on a scale ranging from −5 (extremely threatening) to +5 (extremely reassuring) and reported an average rating of −1.94 for the threatening faces and 2.97 for the reassuring faces. In a rating session that followed the current experiment, participants (19 low-socially anxious and 20 high-socially anxious) rated the 60 pictures using an electronic version of the self-assessment manikin (SAM; Bradley and Lang, 1994). The SAM is a language-free measure that assesses the valence and arousal dimensions of emotional stimuli on a 1 (very unpleasant; low arousing) to 9 (very pleasant; highly arousing) scale. An analysis of the valence ratings revealed a significant main effect of face type ($F(1, 37) = 169.52$, $p < 0.001$), no main effect for group ($F(1, 37) < 1$) and no interaction between group and face type ($F(1, 37) = 1.92$, $p > 0.17$) indicating that both groups rated the threatening faces as more unpleasant (low-socially anxious M rating for threatening faces = 3.65; low-socially anxious M rating for reassuring faces = 6.74; high-socially anxious M rating for threatening faces = 3.35; high-socially anxious M rating for reassuring faces = 7.18). An analysis of the arousal ratings revealed no main effects or interactions ($ps > 0.15$) indicating that both groups rated the threatening and reassuring faces as equally arousing (low-socially anxious M rating for threatening faces = 2.3; low-socially anxious M rating for reassuring faces = 2.52; high-socially anxious M rating for threatening faces = 2.46; high-socially anxious M rating for reassuring faces = 2.52).

A modified version of the Eriksen Flanker task (Eriksen and Eriksen, 1974) using the facial stimuli described above was administered on a Pentium III class computer, using Presentation software (Neurobehavioral Systems, Inc.) to control the presentation and timing of all stimuli, the determination of response accuracy and the measurement of reaction times. The classic flanker task requires participants to respond to a central target, such as the letter *H*, while ignoring flanking stimuli that are either associated with the same response (congruent stimuli, e.g., *HHHHH*) or an alternate response (incongruent stimuli, e.g., *SSHSS*). Fig. 1 shows that each face flanker stimulus was comprised of three emotional faces oriented horizontally. The three emotional expressions presented were always posed by the same male or female model. The figure also shows examples of congruent (all three express the same emotion) and incongruent (the center face expresses one emotion and the two flanking faces express another) threatening target stimuli (top two, respectively), and congruent and incongruent reassuring target stimuli (bottom two, respectively).

During the task, subjects were randomly presented with the different face flanker stimuli such that there were an equal number of threatening congruent, threatening incongruent, reassuring congruent and reassuring incongruent trials. A fixation mark (+) was always presented at the center of the screen during the interstimulus interval to help participants remain focused throughout the task. Sets of faces replaced the fixation cross in the center of the computer screen for 500 ms against a black background at random intervals between 1800 and 2400 ms. At a viewing distance of roughly 65 cm, each set of faces occupied 2.3° of visual angle vertically and 8° horizontally. Subjects were instructed to categorize the emotion of the center face as either negative or positive by pressing the left or right mouse button. Assignment of target face emotion to response button was counterbalanced across subjects.

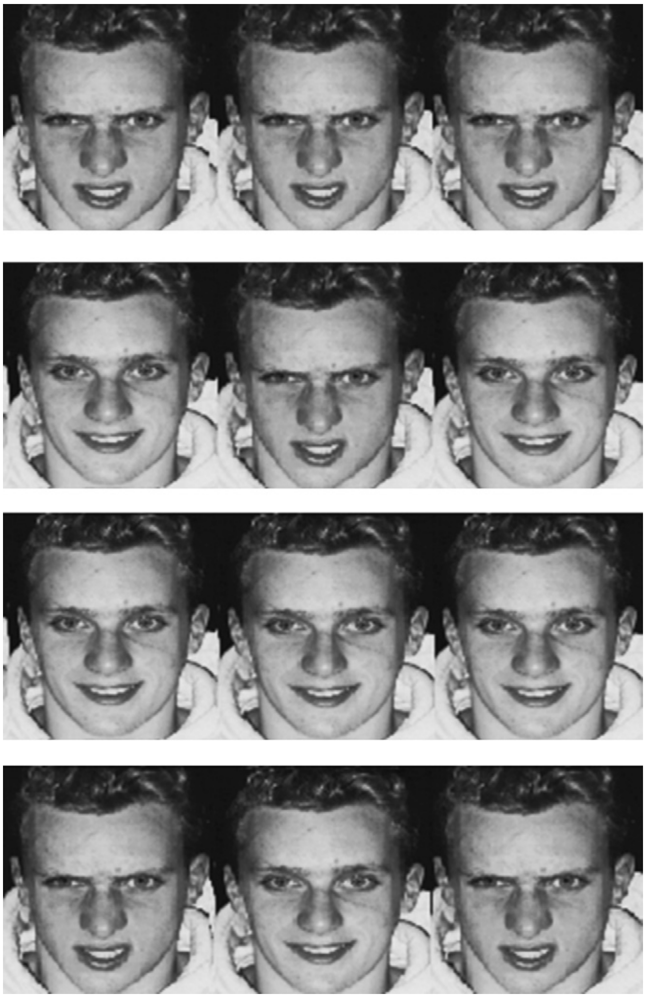

Fig. 1. Examples of congruent and incongruent threatening target face flanker stimuli (top two) and congruent and incongruent reassuring target face flanker stimuli (bottom two).

1.3. Task procedures

After participants received a general description of the experiment, sensor electrodes were attached and participants were given detailed task instructions. Each participant was seated approximately 0.5 m directly in front of the computer monitor and given two blocks of 24 practice trials. In the first practice block, participants were simply instructed to categorize the emotion of the center face by clicking the left or the right mouse button. The instructions for the second practice block were modified such that participants were asked to focus on being fast and accurate while responding to the emotion of the center face. Following the practice blocks, participants received 12 blocks of 48 trials (576 total trials) wherein both speed and accuracy were emphasized. Face flanker stimuli were random within each block.

1.4. Psychophysiological recording, data reduction and analysis

The electroencephalogram (EEG) was recorded from the frontal (Fz), fronto-central (FCz), central (Cz) and parietal (Pz) recording sites using an ECI electrocap. In addition, tin disc electrodes were placed on the left and right mastoids (M1 and M2, respectively). During the recording, all activity was referenced to Cz. The electro-oculogram (EOG) generated from blinks and vertical eye-movements was also recorded using Med-Associates miniature electrodes placed approximately 1 cm above and below the subject's right eye. The right earlobe served as a ground site. All EEG/EOG electrode impedances were kept below 10 kΩ and the data from all channels were recorded by a Grass Model 78D polygraph with Grass Model 7P511J preamplifiers (bandpass = 0.1–100 Hz).

All bioelectric signals were digitized on a laboratory microcomputer using VPM software (Cook, 1999). The EEG was sampled at 200 Hz. Data collection began 200 ms prior to the onset of the imperative stimulus and continued for 2000 ms. Off-line, the EEG for each trial was corrected for vertical EOG artifacts using the method developed by Gratton et al. (1983) and Miller et al. (1988) and then re-referenced to the average activity of the mastoid electrodes. Trials were rejected and not counted in subsequent analysis if there was excessive physiological artifact (i.e., 25 ms of invariant analog data on any channel or A/D values on any channel that equaled the converters minimum or maximum values; M trials rejected due to artifact = 22.07), or if the reaction time fell outside of a 200–1200 ms window (M trials rejected for RT = 9.29). Single trial EEG data were lowpass filtered at 20 Hz with a 51-weight FIR digital filter as per Cook and Miller (1992). Finally, the EEG for each trial was time-locked to either stimulus-onset or reaction time and averaged across threatening and reassuring congruent and incongruent face flanker trials to yield ERPs for each electrode site.

Average activity in the 75 ms pre-stimulus window served as the baseline for all stimulus-locked ERPs. To reduce the confounding effects of component overlap, each ERP was scored as the peak amplitude at the site where it reached its respective maximum (cf. Luck, 2005). The P2 was defined at Cz as the peak activity between 150 and 200 ms post-stimulus, the N2 was defined at Fz as the peak activity between 200 and 350 ms post-stimulus, and the P3/LPP was defined at Pz as the peak activity between 450 and 650 ms post-stimulus.

Average activity from 50 to 150 ms pre-response served as the baseline for the response-locked ERPs. Visual inspection of the response-locked ERPs revealed a negative deflection occurring approximately 50 ms after response execution that was identified as the CRN. The CRN was scored peak-to-peak at FCz, where it was maximal, as the difference between the most negative peak occurring in the 0–100 ms post-response window and the most positive peak occurring between this most negative peak and 50 ms pre-response. The peak-to-peak measure was chosen in order to reduce the effects of P3/LPP overlap with the CRN that could obscure or distort experimental effects (Hajcak et al., 2004a,b; see Nieuwenhuis et al., 2001 for similar methods).

Repeated measures analyses of variance (ANOVAs) were performed on behavioral and ERP measures. Partial eta squared (η_p^2) values are reported to demonstrate the size of effects in ANOVA models, where 0.05 represents a small effect, 0.1 represents a medium effect and 0.2 represents a large effect (Cohen, 1973). Cohen's *d* is reported for post hoc *t*-tests, where 0.2 represents a small effect, 0.5 represents a medium effect and 0.8 represents a large effect size (Cohen, 1988). Reaction time and ERP measures were evaluated on correct trials only (*M* % of trials used in analyses = 86.71%).

2. Results

2.1. Behavioral measures

Accuracy and RT data on threatening and reassuring congruent and incongruent face flanker trials for the high- and low-socially anxious groups are presented in Table 1. Visual inspection of Table 1 reveals that participants were able to perform the task well, achieving approximately 90% accuracy on all trial types. A 2 (Group) × 2 (Target Face Valence) × 2 (Congruence) ANOVA conducted on percentage correct revealed no significant main or interaction effects (all $p\text{s} > 0.15$, $\eta_p^2\text{s} < 0.06$). Thus, regardless of group status, participants appeared to be equally accurate on all types of face flanker trials. In terms of RT, the ANOVA indicated that participants were faster on trials in which reassuring faces were the target (i.e., reassuring congruent and incongruent trials; $F(1, 40) = 20.80$, $p < 0.001$, $\eta_p^2 = 0.34$). This pattern of faster RTs to reassuring than threatening target faces, indeed, held for both groups: Target Face Valence effect in the low-socially anxious group ($F(20) = 18.55$, $p < 0.001$, $\eta_p^2 = 0.48$); Target Face Valence effect in the high-socially anxious group ($F(20) = 4.82$, $p = 0.04$, $\eta_p^2 = 0.19$). Consistent with other studies using flanker tasks, participants in both groups were also faster on congruent trials than incongruent trials ($F(1, 40) = 10.79$, $p = 0.002$, $\eta_p^2 = 0.21$). No other main or interaction effects for RT were significant, including those involving group status (all $p\text{s} > 0.17$, $\eta_p^2\text{s} < 0.05$).

Table 1
Means (standard deviation) for accuracy and RT (ms) measures

Measure	High-SA	Low-SA
Threatening congruent percent correct	89.54 (6.61)	92.14 (5.78)
Threatening incongruent percent correct	90.01 (7.13)	92.63 (4.95)
Reassuring congruent percent correct	90.44 (4.92)	90.72 (6.39)
Reassuring incongruent percent correct	89.67 (5.50)	90.01 (6.97)
Threatening congruent RT	551.69 (73.74)	568.26 (102.65)
Threatening incongruent RT	554.44 (73.25)	574.02 (102.50)
Reassuring congruent RT	534.92 (81.98)	541.65 (94.62)
Reassuring incongruent RT	542.64 (79.38)	547.18 (88.71)

2.2. ERPs

2.2.1. Stimulus-locked results

If social anxiety is characterized by a bias toward negative social stimuli, then the P2, N2 and P3/LPP should be enhanced for trials in which threatening facial expressions were the targets in the socially anxious group. Based on previous research, this prediction is strongest for the P3/LPP. Similarly, concerning the effect of flanker congruence, it is possible that incongruent reassuring target trials would demonstrate larger stimulus-locked ERPs than congruent reassuring target trials in the socially anxious group because the threatening flanking faces in the incongruent condition would draw additional resources away from the reassuring target faces.

Inconsistent with the hypothesis concerning flanker congruence, analyses involving stimulus-locked components failed to yield any significant interactions involving the Group and Congruence factors ($p\text{s} > 0.19$, $\eta_p^2\text{s} < 0.05$); interactions involving Congruence only approached significance ($p = 0.064$, $\eta_p^2 = 0.08$) in one ANOVA – indicating an interaction between Valence and Congruence at the N2 time window – that had little relevance to the primary aims of the current study. Therefore, we collapsed across the Congruence factor in all subsequent analyses. Stimulus-locked grand average ERP waveforms at Fz, FCz, Cz and Pz are presented in Fig. 2. Mean amplitudes for the stimulus-locked P2, N2 and P3/LPP are presented in Table 2.

A 2 (Group) × 2 (Target Face Valence) ANOVA conducted on P2 magnitude yielded a significant main effect of Target Face Valence ($F(1, 40) = 8.55$, $p = 0.006$, $\eta_p^2 = 0.18$) indicating that reassuring target faces elicited larger P2s than threatening target faces (see Table 2). The main effect of group ($F(1, 40) < 1$) was not significant. The interaction between Target Face Valence and Group approached significance ($F(1, 40) = 3.56$, $p = 0.066$, $\eta_p^2 = 0.08$), however. Given the fact that the low-socially anxious group seemed to be driving the overall main effect (see Table 2 and Fig. 2), we decided to follow-up this near significant interaction. These analyses revealed that, indeed, the low-socially anxious subjects evinced larger P2s to reassuring target faces than threatening target faces ($t(20) = 3.12$, $p = 0.005$, $d = 0.68$), whereas the high-socially anxious subjects showed no difference in P2 magnitude to the two types of target faces ($t(20) < 1$).

A 2 (Group) × 2 (Target Face Valence) ANOVA conducted on N2 magnitude yielded a significant main effect of Target Face Valence ($F(1, 40) = 4.53$, $p = 0.04$, $\eta_p^2 = 0.10$) indicating that reassuring target faces continued to elicit greater positivity as threatening target faces elicited a relatively larger N2 (see Table 2). There was, however, no significant main effect of group and no significant interaction between Target Face Valence and Group ($F\text{s}(1, 40) < 1$).

Contrary to previous findings, the analyses involving early ERPs failed to show any evidence of an early negative bias in the high-socially anxious group, but rather indicated that the

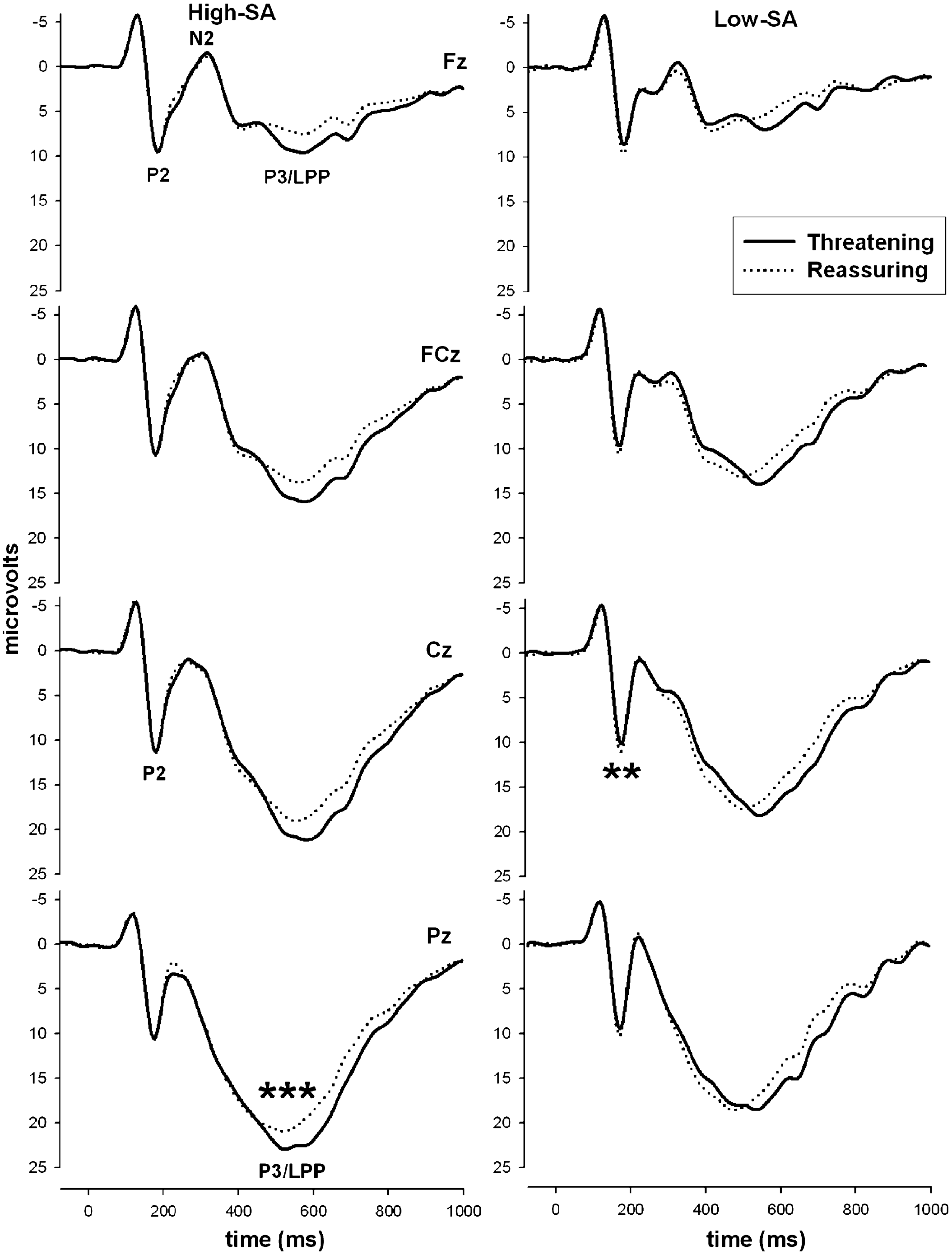

Fig. 2. Stimulus-locked grand average ERP waveforms at Fz, FCz, Cz and Pz for threatening and reassuring target trials for the high-socially anxious (High-SA) and low-socially anxious (Low-SA) groups. All components are labeled in the upper left panel of the figure. The site of maximum for each component is indicated by the bold labels. Asterisks (**) indicates within-group difference $p < 0.01$, (***) indicates within-group difference $p < 0.001$.

low-socially anxious group tended to show a positive bias that the high-socially anxious group lacked.

A 2 (Group) × 2 (Target Face Valence) ANOVA conducted on P3/LPP magnitude yielded a significant main effect of Target Face Valence ($F(1, 40) = 12.49$, $p = 0.001$, $\eta_p^2 = 0.24$) indicating that threatening target faces elicited larger P3/LPPs than reassuring target faces. There was also a marginally significant main effect of Group ($F(1, 40) = 3.72$, $p = 0.061$, $\eta_p^2 = 0.09$). Importantly, however, there was a significant interaction observed between Target Face Valence and Group ($F(1, 40) = 5.36$, $p = 0.026$, $\eta_p^2 = 0.12$). Investigation of the Target Face Valence effect in each group revealed that high-socially anxious subjects evidenced enhanced P3/LPPs to threatening target faces ($t(20) = 4.42$, $p < 0.001$, $d = 0.96$) whereas low-anxious participants showed no difference in P3/LPP magnitude to the two target faces ($t(20) < 1$). Thus, the P3/LPP analysis revealed the presence of a negative bias in the high-anxious subjects, but not in the low-anxious subjects,

Table 2
Means (standard deviation) for stimulus-locked ERP measures in microvolts

Component	Target face	High-SA	Low-SA
P2 (Cz)	Threatening	12.42 (5.74)	11.11 (6.22)
	Reassuring	12.63 (5.70)	12.07 (6.53)
N2 (Fz)	Threatening	−3.30 (6.17)	−2.57 (5.04)
	Reassuring	−3.01 (5.48)	−1.82 (5.36)
P3/LPP (Pz)	Threatening	25.06 (7.21)	20.29 (5.94)
	Reassuring	22.67 (6.35)	19.79 (6.71)

during later, more elaborated resource allocation in the high-socially anxious individuals.

2.2.2. Response-locked results

If social anxiety is characterized by a lack of positive bias during response-related processes in an emotion classification task, then the CRN should reflect a lack of positive bias in the socially anxious subjects. Specifically, while the low-socially anxious individuals should show a positive bias as indexed by enhanced CRN flanker interference on threatening target trials because of the increased demands imposed by the distracting reassuring flanking faces, the high-socially anxious individuals should show no differences in CRN flanker interference between target faces.

Fig. 3 depicts the response-locked grand average ERP waveforms at FCz for threatening and reassuring congruent and incongruent face flanker trials in the high- and low-socially anxious groups. As illustrated in Fig. 3, the CRN is observed as a negative deflection peaking approximately 50 ms after response execution. Table 3 contains the peak-to-peak measurement of CRN magnitude for threatening and reassuring congruent and incongruent face flanker trials in the high- and low-socially anxious groups. Consistent with previous research, the 2 (Group) × 2 (Target Face Valence) × 2 (Congruence) ANOVA conducted on CRN amplitude yielded a significant main effect of Congruence ($F(1, 40) = 5.84$, $p = 0.02$, $\eta_p^2 = 0.13$) such that incongruent trials elicited larger (more negative) CRNs than congruent trials (i.e., the typical *flanker interference effect*). Neither the main effect of Group nor Target Face Valence was significant ($ps > 0.20$, $\eta_p^2 s < 0.04$). More importantly, the ANOVA also revealed a significant Group -

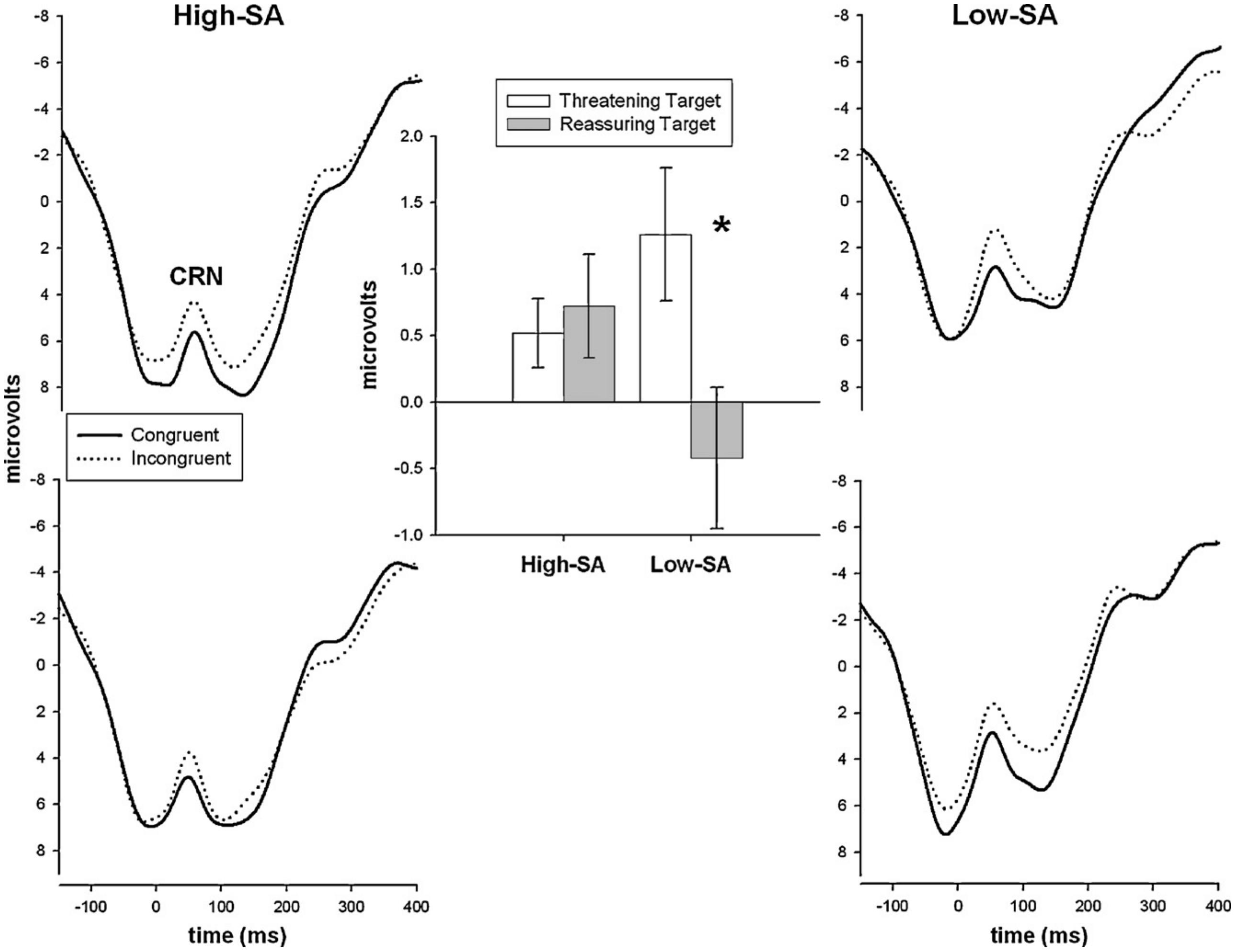

Fig. 3. Response-locked grand average ERP waveforms at FCz on threatening (top) and reassuring (bottom) target trials for congruent and incongruent flankers in the high- and low-socially anxious groups (High-SA and Low-SA, respectively). The CRN is labeled in the upper left panel of the figure. Bar graphs depict difference scores between CRN amplitude on congruent and incongruent flanker trials (i.e., CRN flanker interference effect) for threatening and reassuring target faces in the high- and low-socially anxious groups. Asterisk (*) indicates within-group difference $p < 0.05$.

Table 3
Means (standard deviation) for CRN at FCz in microvolts

Target face	Congruence	High-SA	Low-SA
Threatening	Congruent	−4.24 (3.99)	−5.66 (4.25)
	Incongruent	−4.77 (4.47)	−6.92 (4.26)
Reassuring	Congruent	−4.75 (4.38)	−6.75 (4.49)
	Incongruent	−5.47 (4.85)	−6.34 (4.42)

× Target Face Valence × Congruence interaction ($F(1, 40) = 4.69$, $p = 0.036$, $\eta_p^2 = 0.11$). To further examine this interaction, follow up tests were conducted within each group. In the high-socially anxious group, the 2 (Target Face Valence) × 2 (Congruence) ANOVA revealed only a significant main effect of Congruence ($F(1, 20) = 5.71$, $p = 0.027$, $\eta_p^2 = 0.22$), indicating larger CRNs on incongruent than on congruent trials (see left panel of Fig. 3, bar graph in Fig. 3 and Table 3; positive scores in the bar graph and following text indicate larger CRNs – more negativity – on incongruent trials). However, for the low-socially anxious group, there was a significant Target Face Valence × Congruence interaction ($F(1, 20) = 4.78$, $p = 0.041$, $\eta_p^2 = 0.19$). As indicated by the right panel of Fig. 3, the bar graph in Fig. 3, and Table 3, this interaction suggested that the CRN flanker interference effect was larger on trials in which reassuring faces flanked threatening target faces (M flanker interference effect = 1.26 μV) than on trials in which threatening faces flanked reassuring target faces (M flanker interference effect = −0.42 μV). Stated another way, the flanking threatening faces failed to elicit interference in the low-anxious group. The flanker interference effects in the high-anxious group, however, were very similar for threatening ($M = 0.53$ μV) and reassuring ($M = 0.72$ μV) target trials, suggesting a lack of preferential processing of affect during resource competition/response monitoring stages. Thus, the CRN results demonstrated a lack of positive bias in the socially anxious group such that the positive face advantage observed in the low-socially anxious group was absent in the high-socially anxious group.

3. Discussion

The results of the current study suggest that ERPs are sensitive to biases in anxious and non-anxious subjects at multiple stages of information processing. Specifically, the present study revealed that high-socially anxious subjects lacked the positive bias characterizing low-anxious subjects during early stages of stimulus processing, as indexed by the P2. Second, socially anxious subjects, but not low-anxious subjects, showed the presence of a negative bias during elaborative stimulus processing stages, as reflected in the P3/LPP. Last, socially anxious subjects lacked the positive bias characterizing the low-anxious subjects during processing stages involving resource competition and response monitoring, as indexed by the CRN.

Together, results revealed that low-socially anxious subjects showed a positive bias across multiple ERP measures as well as in RT. In particular, the low-anxious subjects' positive bias was evident in the fronto-central positive shift to reassuring faces during the time window of the P2 and the larger fronto-central flanker interference effect for distracting reassuring faces in the CRN. While some have suggested that the processing advantage for positive stimuli, including positive faces, might be attributable to their simpler perceptual characteristics (Bradley et al., 2007; Johnston et al., 2001; Russell and Bullock, 1986); studies by Leppanen and colleagues (Leppanen et al., 2003; Leppanen and Hietanen, 2003) show that emotional factors also play a role. In the context of these findings, the positive face advantage reported here for the low-anxious group is consistent with the notion that normal individuals are characterized by a general positive view of the self and world that promotes well-being (Diener and Diener, 1996; Moran et al., 2006; Taylor and Brown, 1988). In addition, the fact that the positive bias in the low-anxious subjects was evident in ERP components proposed to arise from medial frontal cortex, and more specifically the ACC (Bartholow et al., 2005; Eimer and Holmes, 2007) is consistent with a recent study by Moran and colleagues showing enhanced ACC activity to self-referential positive words in an unselected group of subjects. Thus, the sensitivity of the ACC to positive information may be important in the maintenance of a positive view of self and world (cf. Beer, 2007). However, it should be noted that the ACC itself is not the seat of such a *positive bias*, as previous ERP studies have shown enhanced processing of happy faces in occipito-temporal cortex (Williams et al., 2006) and greater activation in fusiform gyrus and occipito-temporal cortex for liked faces (Pizzagalli et al., 2002). It will therefore be important to consider the multiple sources involved in processing positively valenced facial stimuli in future studies. Consistent with previous research using arousal-matched positive and negative stimuli – like the faces used here – the non-anxious subjects in the current study did not show evidence of a negative bias in the P3/LPP (e.g., Schupp et al., 2000), or any measures for that matter. This *lack of negative bias* in the low-anxious group is also consistent with the notion that under mild threat conditions, non-anxious subjects fail to show a bias toward negative stimuli (cf. Bar-Haim et al., 2007).

In contrast to the low-anxious subjects, the high-anxious subjects showed a negative bias only, as evident in an enhanced P3/LPP to threatening target faces. The present finding of larger P3/LPPs to threatening target faces in socially anxious participants is consistent with contemporary information processing theories of social anxiety (cf. Heinrichs and Hofmann, 2001) as well as behavioral (Mogg and Bradley, 2002; Mogg et al., 2004; Eastwood et al., 2005) and neuroimaging studies (Straube et al., 2005; Stein et al., 2002) suggesting a threat bias in social anxiety and other anxiety disorders (e.g., Attias et al., 1996; Bar-Haim et al., 2007). A recent review of the literature suggests that the P3/LPP reflects phasic output of the locus coeruleus-norepinephrine (LC-NE) system to neocortex thus increasing attentional processing of motivationally relevant stimuli for the purposes of facilitating appropriate action (Nieuwenhuis et al., 2005). In the context of the LC-NE hypothesis of the P3/LPP (Nieuwenhuis et al., 2005) and recent neuroimaging data showing that the P3/LPP correlates with activation of the extrastriate visual cortex (Sabatinelli et al., 2007), the current data suggest that socially anxious subjects might be characterized by an enhanced LC-NE system output to visual cortex during later attentional/perceptual processing of threatening faces for the purposes of facilitating appropriate action to threatening faces (cf. Gilbert, 2001; Ohman et al., 2001).

At the same time, socially anxious subjects failed to show a positive bias in any ERP measure but, along with the low-anxious subjects, showed faster RTs to reassuring faces. However, the follow up tests reported for each group indicated that the low-socially anxious subjects showed a much larger effect size (2.5 times larger) for this RT valence effect than the high-socially anxious subjects – $\eta_\text{p}^2 = 0.48$ versus $\eta_\text{p}^2 = 0.19$, respectively – consistent with previous research showing a larger effect for the positive face advantage in low-anxious subjects (Silvia et al., 2006). The lack of positive bias in the current sample of socially anxious subjects is also consistent with behavioral studies demonstrating faster RTs to positive words in non-anxious subjects and no RT advantage in socially anxious subjects (Hirsch and Mathews, 2000; Silvia et al., 2006; Tanner et al., 2006). While the RT and P3/LPP results seem to be at odds in the high-anxious group, several lines of research show that the magnitude of the P3/LPP does not correlate well with RT (cf. Nieuwenhuis et al., 2005) and thus does not seem to reflect response-related processes, but rather reflects stimulus processing load. Therefore, although both groups show faster RTs to reassuring faces, the high-anxious group was characterized by greater processing load associated with threatening faces.

Seemingly inconsistent with views that social anxiety is characterized by an early attention bias to social threat (e.g., Mogg et al., 2004), the current findings regarding the P2 showed that the high-socially anxious group processed negative and positive facial affect in a like manner. Our findings also contrast with results from other ERP studies of social anxiety suggesting an early negative face bias (Kolassa and Miltner, 2006; Rossingol et al., 2007). There are, however, methodological differences between the previous studies and the current one that could account for the disparate findings. For instance, the presence of an early negative bias in socially anxious subjects reported by Kolassa and Miltner was found in a paradigm comparing negative, neutral and positive faces where the negative faces were rated as more arousing than the other two expressions. Therefore, the negative bias reported by Kolassa and Miltner might represent an arousal effect rather than a valence effect, per se. The stimuli used in the current study, however, were matched on arousal ratings and therefore suggest that earlier processes might be affected by the arousal levels of stimuli in terms of reflecting information processing biases in social anxiety. Consistent with our lack of bias found in the P2 time window for high-socially anxious subjects, on the other hand, Williams et al. (2007) recently found that subjects scoring high on the DASS anxiety scale showed a reduced P2 difference between fearful and neutral faces compared to subjects scoring low on the DASS anxiety scale suggesting that high-anxious individuals more generally might show reduced biases in processes reflected in the P2. Overall, findings of early modulations of brain activity as a function of emotion are mixed, with some only finding emotion effects after 300 ms (Bradley et al., 2007), whereas others report arousal effects (enhanced processing of positive and negative stimuli compared to neutral) starting around 150 ms (Eimer and Holmes, 2007; Schupp et al., 2003, 2004), while still others report biases toward negative stimuli around 100 ms (e.g., Pourtois et al., 2004). Future studies investigating the nuances of early processing biases in normal and anxious individuals using multiple measurement methods and experimental designs will be necessary.

Together, the present findings indicate that socially anxious subjects evidenced a negative bias and non-anxious subjects evidenced a positive bias. The fact that the lack of positive biases shown here seemed to arise mainly from fronto-centrally generated ERPs – the P2 and CRN – whereas the presence of a negative bias seemed to arise mainly from a posteriorly generated ERP – the P3/LPP – suggest that different neural sources or processes might be at play in different information processing biases in high- versus low-socially anxious subjects. It is possible that the fronto-central sources that were biased towards positive information in the low-anxious subjects were overpowered by the negatively biased occipito-temporal and parietal sources in the high-anxious subjects. Consistent with this notion, Eysenck et al. (2007) recently proposed an "Attentional Control Theory" of processing biases in anxiety suggesting that anterior attentional control systems are impaired by enhanced processing of the posterior 'stimulus-driven' system that is most responsive to threatening stimuli in anxious individuals. This idea is also in line with previous research indicating abnormal fronto-limbic interactions in anxiety (for a review see LeDoux, 1996; Shin et al., 2005; Stein et al., 2002; Straube et al., 2005). Future studies employing dense electrode montages and fMRI are needed to further elucidate the contributions of anterior and posterior sources in information processing biases in social anxiety. Thus, the socially anxious individual's bias toward threatening faces and lack of bias toward positive cues might contribute to his/her constant scanning for threat and dominance in social situations and inability to incorporate positive feedback (cf. Mathews and MacLeod, 2005).

Future investigations will need to be conducted in patients diagnosed with and seeking treatment for social anxiety to determine whether the findings reported here generalize to clinical populations. Given the fact that the students in the high-socially anxious group of the current study scored well above the clinical cut score on the SPIN and within the range reported for patients, it is likely that the present findings will generalize to clinically anxious individuals as well (see also Bar-Haim et al., 2007 who found no differences in biases in dot probe tasks between clinical and high-anxious subjects). In addition, the flanker task provides only one context in which limited social information competes for available resources and it will therefore be important to examine ERP measures in other cognitive-emotional paradigms. Specifically, an important next step will be to include neutral facial expressions in the flanker task to further specify how and when processing resources are sensitive to valence and arousal differences between stimuli in socially anxious and control subjects. Last, future research will be needed to determine the specificity of these information processing biases by examining ERPs in other anxious and depressed groups, as the socially anxious subjects in the current study also demonstrated significant depression and general distress symptoms.

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