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Interpretation Bias in Social Anxiety as Detected by Event-Related Brain Potentials

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Little is known about psychophysiological correlates of interpretation bias in social anxiety. To address this issue, the authors measured event-related brain potentials (ERPs) in high and low socially anxious individuals during a task wherein ambiguous scenarios were resolved with either a positive or negative ending. Specifically, the authors examined modulations of the P600, an ERP that peaks approximately 600 ms following stimulus onset and indexes violations of expectancy. Low-anxious individuals were characterized by an increased P600 to negative in comparison with positive sentence endings, suggesting a positive interpretation bias. In contrast, the high-anxious group evidenced equivalent P600 magnitude for negative and positive sentence endings, suggesting a lack of positive interpretation bias. Similar, but less reliable results emerged in earlier time windows, that is, 200–500 ms poststimulus. Reaction time, occurring around 900 ms poststimulus, failed to show a reliable interpretation bias. Results suggest that ERPs can detect interpretation biases in social anxiety before the emission of behavioral responses.

Keywords: social anxiety, social phobia, interpretation bias, event-related potentials, P600

Interpersonal interactions and communications contain considerable ambiguity. From the moment an individual begins to speak to the point just before the last word of a sentence is uttered, multiple outcomes are possible. Even complete sentences can have multiple meanings (e.g., "That tie you are wearing is. . .interesting"). Given the level of uncertainty built into verbal communication, it should come as no surprise that individual differences exist with respect to expectations for, and interpretations of, interpersonal interaction. In particular, individuals with high levels of social anxiety and patients diagnosed with social phobia demonstrate abnormalities in their expectations for, and interpretations of, ambiguous social information. In fact, these *interpretation biases* (i.e., tendencies) are posited to play a central role in the genesis and maintenance of anxious psychopathology (cf. Hirsch & Clark, 2004).

Interpretation bias in social anxiety has been studied mostly through the use of self-report measures, many of which reveal that socially anxious individuals display a tendency to interpret ambiguous social information as negative. For example, in comparison with low anxious individuals and individuals with other anxiety disorders, socially anxious individuals tend to rank negative interpretations of social situations as more likely to come to mind than positive and neutral interpretations (Amir, Foa, & Coles, 1998; Franklin, Huppert, Langner, Leiberg, & Foa, 2005; Stopa & Clark, 2000). Also consistent with a negative interpretation bias in social anxiety, studies have shown that socially anxious participants spontaneously generate more negative endings to ambiguous situations (Franklin et al., 2005; Huppert, Pasupuleti, Foa, & Mathews, 2007; Stopa & Clark, 2000), rate negative sentences as more similar to previously presented ambiguous scenarios (Huppert, Foa, Furr, Filip, & Mathews, 2003; Murphy, Hirsch, Mathews, Smith, & Clark, 2007), and rate negative scenarios as more likely to be self-descriptive (Huppert et al., 2007).

To this point, the studies reviewed on interpretation bias in social anxiety have utilized self-report measures, often referred to as *off-line* measures, because they reveal more about reflective processes engaged when substantial time is allotted to contemplate responses. Other studies on interpretation bias, however, utilize reaction time (RT) as a measure of stimulus processing. Insofar as these studies require quick and accurate decisions, RT is thought to reflect an *online* measure of information processing. Studies of interpretation bias using these so called online measures have shown that socially anxious individuals lack a positive bias—the

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tendency to expect positive outcomes or interpret ambiguous information as positive—that characterizes low anxious individuals (Hirsch & Mathews, 2000; Hirsch, Mathews, Clark, Williams, & Morrison, 2003). For instance, Hirsch and Mathews (1997, 2000) utilized a lexical-decision task and found that nonanxious control subjects showed faster RTs to words that completed an ambiguous passage in a positive manner, whereas interview anxious and socially phobic patients failed to show this positive bias in RT. Hirsch et al. (2003) later replicated the positive bias found in nonanxious individuals in a separate sample of low interview anxious subjects.

Although both online and off-line methodologies help elucidate the nature of interpretation biases in social anxiety, online measures provide a unique opportunity to examine how individuals with social anxiety initially process incoming information, which is of central importance to information processes theories (Clark & Wells, 1995; Huppert & Foa, 2004; Mathews & Mackintosh, 1998). While RT measures do, indeed, offer insights into online interpretation biases, it is difficult to determine the exact nature and time-course of these biases because RT reflects the end point—the behavioral response—that follows from a number of different cognitive processes. Event-related brain potentials (ERPs), on the other hand, are characterized by excellent temporal resolution and can provide a direct measure of neural activity that occurs well before the behavioral response is emitted. Specifically, ERP waveforms allow for the examination of the sequence of constituent operations involved in processing incoming information on the order of milliseconds. Therefore, ERPs provide more specific information about the mechanisms underlying information processing biases. While several psychophysiological studies of emotion face processing biases in social anxiety already exist (Moser, Huppert, Duval, & Simons, 2008; Phan, Fitzgerald, Nathan, & Tancer, 2006; Stein, Goldin, Sareen, Zorilla, & Brown, 2002; Straube, Mentzel, & Miltner, 2005), we are not aware of studies that have examined psychophysiological correlates of interpretation biases in social anxiety, and thus, we aim to examine this in the current study.

One ERP component that seems to be a good candidate for studying interpretation biases in social anxiety is the P600, a broad positive deflection that reaches its maximum amplitude at centroparietal recording sites approximately 600 ms after stimulus onset in sentence processing tasks (Friederici, Hahne, & Mecklinger, 1996; Hagoort, Brown, & van Groothusen, 1993; van Herten, Kolk, & Chwilla, 2005). Although a number of early studies suggested that the P600 reflects syntactic violations (e.g., Friederici et al., 1996), recent data suggest that it also reflects semantic and thematic violations (Kolk, Chwilla, van Herten, & Oor, 2003; Kuperberg, Sitnikova, Caplan, & Holcomb, 2003; van Herten et al., 2005). In addition to establishing that the P600 is sensitive to semantic expectancy, other researchers have argued that the P600 might reflect violations of expectancy more generally (Coulson, King, & Kutas, 1998a, 1998b; Gunter, Stowe, & Mulder, 1997). Coulson and colleagues (1998b), for instance, have shown that, as with the classic P300 component, the P600 is larger for improbable stimuli and more salient events (Donchin, 1981; Donchin & Coles, 1988). Consistent with theories of the P300 (Donchin, 1981; Donchin & Coles, 1988), Coulson et al. (1998a) further suggested that the enhanced P600 to expectancy violations reflects the engagement of attention and memory updating processes involved in the evaluation and reinterpretation of an unexpected event. In the current study, we measured the P600 time-locked to the presentation of a sentence terminating word that resolved the ambiguity of a preceding sentence stem in either a positive or negative manner in high and low socially anxious individuals.

It should be noted that the classic N400 component—a centrally maximal stimulus-locked ERP observed as a negative deflection occurring approximately 400 ms after stimulus onset (Kutas & Hillyard, 1980, 1984)–is typically measured in studies investigating violations of expectancy in sentence processing tasks along with the P600. However, it has been shown that the N400 is most related to the cloze probability of sentence endings. Specifically, the N400 is most sensitive to particularly strong semantic violations. For example, enhanced N400 is elicited by endings of sentences such as "I like my coffee with cream and. . .*socks*" – in which the subjective predictability (cloze probability) of *socks* is close to zero given the sentence context. In the current study, we examine sentence endings that are both semantically correct and potentially relevant, making the N400 less likely to inform the bias under investigation in the current study. Because the primary aim of the current study was to examine biases in interpretation of ambiguous scenarios in which the cloze probability of the sentence endings would be more variable, we focused on modulations of the P600, which has been shown to be sensitive to a wider range of expectancy violations.

On the basis of previous studies that found a lack of online positive interpretation bias in socially anxious individuals as measured by RT, we hypothesized that the P600 would similarly reflect a lack of positive bias in high socially anxious subjects. Specifically, we predicted that low anxious subjects would show larger P600s to negative sentence endings than to positive sentence endings, suggesting that positive endings to ambiguous scenarios were more expected than were negative ones. However, we predicted that high socially anxious subjects would lack this positive bias and would therefore fail to show any P600 difference between positive and negative sentence endings.

Method

Participants

Participants were recruited from the University of Pennsylvania and surrounding communities via email and advertisements to participate in several experiments of thoughts and emotions, one of which was the ERP procedure described in the current paper. Participants were initially screened via phone by a trained research assistant using the Social Phobia Inventory (SPIN; Connor et al., 2000) and a brief interview. Individuals scoring greater than or equal to a 30 on the SPIN were recruited for the high socially anxious group, and individuals scoring less than or equal to a 10 on the SPIN were recruited for the low socially anxious group. Individuals reporting any of the following complicating factors on the brief interview were excluded: active substance abuse, active bipolar disorder, active psychosis, active suicidality, difficulties using computers, and learning disabilities and language barriers that would limit subjects' abilities to complete the computerized tasks. The SPIN cutscores were based on receiver operating characteristic (ROC) analyses reported in Connor et al. (2000) and previous experience with use of this instrument in studies of social anxiety.

Of 267 individuals initially screened, 40 met criteria and were selected to participate in the study. Thirty-four subjects who agreed to have their electroencephalogram(EEG) recorded during performance of the task had usable data (16 high socially anxious and 18 low socially anxious) and are reported in the present study. Demographic and self-report data for the two groups reported can be found in Table 1. The two groups did not differ with regard to age or gender distribution; however, the high socially anxious group, as expected, scored significantly higher on several measures of socially relevant anxiety, distress, and depression. Written informed consent was obtained from all participants, and the experiment was approved by the research ethics committee of the University of Pennsylvania. All participants were paid $20.00 per hour for their participation.

Stimuli and Measures

Grammar decision task and stimuli. One hundred twenty-five sentence stems and accompanying sentence-terminal words were created by the Center for the Treatment and Study of Anxiety (CTSA) research team. The sentences were circulated to experts in social anxiety who provided feedback, and then revised according to the experts' comments. All sentence stems were ambiguous until the final word and therefore the cloze probability of the final word was relatively low and more variable. Of the 125 sentences, 80 described experiences within social situations (e.g., "As you give a speech, you see a person in the crowd smiling, which means that your speech is. . .") and were resolved by either a negative (e.g., "stupid") or a positive (e.g., "funny") terminal word; 20 sentences described experiences within nonsocial contexts (e.g., "You've just started reading a new book that you bought and you find it to be. . .") and were also resolved by either a negative (e.g., "boring") or positive (e.g., "interesting") terminal word; and 20 sentences were social in nature but emphasized neutral aspects of social situations (e.g., "While walking with a friend through the park, you decide to stop and rest on a. . .") and were always terminated with a neutral word (e.g., "bench"). The 80 sentences were piloted and administered to a separate group prior to this experiment, and endings were selected on the basis of those that differentiated high and low socially anxious individuals in a previous sample (Huppert et al., 2007). Nonsocial sentences were included as fillers, and neutral sentences were included to establish a baseline of responding to the sentence stimuli. Finally, 5 additional sentences were generated for use as practice trials. The sentence stems were recorded into .wav files by Jonathan D. Huppert. The terminal words were visual text displays. Half of the sentences of each type were completed with a grammatical terminal word, while the other half were completed with a nongrammatical terminal word.

Table 1
Mean Demographic and Self-Report Data for High and Low Socially Anxious Subjects

Variable	High socially anxious (n = 16)	Low socially anxious (n = 18)
Demographics		
Age (years)	26.6 (7.2)	25.7 (7.2)
Female (%)	68.6	66.7
Self-report		
SPIN[a]	38.1 (7.3)	5.2 (3.1)
LSAS[a]	79.3 (13.6)	20.7 (11.1)
SIAS[a]	53.7 (11.3)	13.0 (9.4)
BFNE[a]	53.3 (5.1)	34.9 (10.1)
DASS-D[a]	10.2 (5.2)	2.2 (2.4)
DASS-A[a]	8.9 (4.2)	.9 (1.4)
DASS-S[a]	13.1 (4.7)	3.3 (3.3)

Note. Standard deviations are given in parentheses. SPIN=Social Phobia Inventory; LSAS=Liebowitz Social Anxiety Scale; SIAS=Social Interaction Anxiety Scale; BFNE=Brief Fear of Negative Evaluation; DASS=Depression-Anxiety-Stress Scales (D=Depression, A=Anxiety, S=Stress Reactivity subscales).
[a] Between-groups difference is $p < .001$.

The task was administered on a Pentium II class computer, using Presentation software (Neurobehavioral Systems, Inc.) to control the presentation and timing of all stimuli. All sentence stems were presented at a constant volume to all subjects. The sentence-terminal word was displayed in white against a black background and occupied approximately 5 degrees of visual angle on an 18-inch monitor.

Brief Fear of Negative Evaluation Scale (BFNE; Leary, 1983). The BFNE is a 12-item measure of anxiety regarding perceived negative evaluation in social situations. The BFNE is widely used and demonstrates good psychometric properties in both clinical (Weeks et al., 2005) and nonclinical samples (Leary, 1983).

Liebowitz Social Anxiety Scale—-self-report (LSAS; Liebowitz, 1987). The LSAS is a 24-item measure of social anxiety, which asks individuals to rate both fear and anxiety on a 0–4 (*none* to *extreme*) scale. It is commonly used in treatment outcome research for social anxiety and has been shown to have good psychometric properties (Baker, Heinrichs, Kim, & Hofmann, 2002; Fresco et al., 2001). ROC analyses of the LSAS suggest cutscores of >30 for social anxiety disorder, and >60 for generalized social anxiety disorder (Mennin et al., 2002).

Social Interaction Anxiety Scale (SIAS; Mattick & Clarke, 1998). The SIAS is a commonly used measure of social anxiety, which evaluates the severity of social anxiety in interpersonal situations. It has 16 items, and is scored on a 0 to 4 scale. It has been shown to have good psychometric properties in multiple samples (Mattick & Clarke, 1998; Ries et al., 1998; Safren, Turk, & Heimberg, 1998).

Social Phobia Inventory (SPIN; Connor et al., 2000). This is a 17-item measure of social anxiety that asks about a range of social interactions, fears of embarrassment, and discomfort with physical symptoms of social anxiety. The SPIN has been used in clinical and nonclinical samples, and its psychometrics have been found to be sound (Connor et al., 2000).

Depression, Anxiety, and Stress Scales—21- item version (DASS; Lovibond & Lovibond, 1995). The DASS comprises three subscales developed to evaluate anxiety, depression, and stress, as described by the tripartite model of affect (Watson et al., 1995). Its psychometric properties have been shown to be good in clinical (Antony Bieling, Cox, Enns, & Swinson, 1998; Brown, Chorpita, Korotitsch, & Barlow, 1997) and nonclinical (Crawford & Henry, 2003; Lovibond & Lovibond, 1995) populations.

Procedure

The current article describes an ERP study that was one of several experiments aimed at investigating cognitive biases in social anxiety. The ERP interpretation paradigm described here was the first of the procedures administered during a longer testing session. Upon arrival at the CTSA all participants read and signed consent to participate in the study. The experiment began with five practice trials. Participants were instructed to listen to the beginning of a sentence, and to watch for the sentence-terminal word on the computer screen. Participants were then instructed to determine whether the sentence-terminal word was grammatical or nongrammatical by pressing the left or right mouse button. This task ensured that Participants had to pay close attention to the context of the sentences to appropriately categorize the endings. The actual experiment consisted of the 120 sentences described above. A white fixation cross was always present at the center of the computer screen to help participants keep their focus. Each trial began with the sentence stem played over the speakers. Five hundred milliseconds after the offset of the sentence stem the sentence-terminal word was presented until the participant responded. The following trial began at a random interval between 500 and 1250 ms after the participant's response. Participants were instructed to respond as quickly and as accurately as possible. Following the grammar decision task, Participants completed the LSAS, SIAS, BFNE, and DASS-21.

Psychophysiological Recording, Data Reduction, and Analysis

The EEG was recorded using a Neurosoft Quik-Cap. Recordings were taken from three locations along the midline: frontal (Fz), central (Cz), and parietal (Pz). In addition, Med-Associates miniature Ag-AgCl 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 participant's right eye. The right earlobe served as a ground site. All electrode impedances were below 10KΩ.

Fz, Pz, M1, M2, and EOG were recorded by a Grass Model 8–10 D polygraph with Grass Model 8A5 preamplifiers (bandpass = 1–35 Hz). The EEG was digitized on a laboratory microcomputer at 200 samples per second, using VPM software (Cook, 1999). Data collection began 500 ms prior to visual stimulus presentation and continued for 1500 ms.

Off-line, the EEG for each trial was corrected for vertical EOG and artifacts using the method developed by Gratton, Coles, and Donchin (1983; Miller, Gratton, & Yee, 1988) and then rereferenced to the average activity of the mastoid electrodes. Trials were rejected and not counted in subsequent analysis if the data fell out of A/D conversion range, or if there was a "flat" analog signal exceeding 25 ms in duration; in addition, trials were rejected if the reaction time fell outside of a 200–2000-ms window. 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 the onset of the sentence-terminal word and averaged across trial types for each electrode site. To quantify the stimulus-locked ERP, a baseline equal to the average activity in a 100-ms window prior to stimulus onset was used. The P600 was scored at Cz, where it was maximal, as the average activity in the window from 500 to 700 ms poststimulus onset.

As stated previously, nonsocial sentences were used primarily as fillers; thus they were not subjected to statistical analyses. Social and neutral social sentences that were completed with grammatical endings were the focus of analyses. Thus, a maximum of 20 social sentences completed with a negative ending, 20 social sentences completed with a positive ending,[1] and 10 neutral sentences completed with a neutral ending were available for statistical tests. Of these, only correct trials were analyzed for ERP and behavioral measures. Because individual subject RT distributions were not normal, median RTs were used instead of mean RTs for each subject (see Ratcliff, 1993) and then averaged together to create mean RT for negative, positive, and neutral endings for each group. Behavioral and ERP measures were statistically evaluated using SPSS General Linear Model software (Version 14.0). Partial eta squared (η_p^2) and Cohen's *d* values are reported as estimates of effect size. Analysis of behavioral and ERP measures proceeded as follows: (a) independent-samples *t* tests were conducted on behavioral and ERP responses to neutral sentences to ensure that high and low socially anxious individuals did not differ with regard to their baseline responses; (b) 2 (Group; high vs. low socially anxious) × 2 (Sentence Ending; negative vs. positive) analyses of variance (ANOVAs) were conducted on behavioral and ERP responses to examine the primary hypotheses of interest concerning interpretation bias; and (c) if the critical Group × Sentence Ending interaction was significant, we followed up the ANOVA with paired-samples *t* tests in each group. Neutral sentences were treated separately, and not included in ANOVAs, because they were constructed separately from the social sentences and therefore did not share their properties—that is, neutral sentences emphasized the neutral aspects of scenarios whereas social sentences emphasized social aspects of scenarios (see above examples)–and were fewer in number (10 vs. 20).

Results

Behavioral Data

Table 2 contains the RT data for the high and low socially anxious participants for positive, negative, and neutral sentence endings. Independent-samples *t* test conducted on RT to neutral sentences indicated that the two groups did not differ, $t(32) < 1$. Results of the ANOVA conducted on RT indicated no effect of Sentence Ending, $F(1, 32) < 1$, or Group, $F(1, 32) < 1$. The Group × Sentence Ending interaction approached significance,

[1] Given that the primary measure of interpretation bias in the current study was the difference in responses between positive and negative terminating words, we ensured that the terminating words did not differ in other important ways such as in length and their parts of speech. Analysis of the length of negative and positive terminal words revealed that they were not different (*M* letters per word negative = 7.05; *M* letters per word positive = 6.90; $p > .83$). Additionally, 16 of 20 (80%) of the negative terminal words and 14 of 20 (70%) of the positive words were adjectives, indicating that the two terminal word categories were similar in grammatical composition.

Table 2
Median Reaction Time (RT) and Mean ERP Data for High and Low Socially Anxious Subjects

Variable	High socially anxious	Low socially anxious
	RT (ms)	
Social		
Positive	973 (352)	919 (263)
Negative	902 (262)	984 (432)
Neutral	785 (221)	759 (214)
	P600 (μV)	
Social		
Positive	3.9 (3.5)	2.1 (5.6)
Negative	3.2 (4.0)	5.8 (3.4)
Neutral	4.1 (3.9)	3.6 (6.9)
	N400 (μV)	
Positive	4.02 (4.33)	1.48 (5.32)
Negative	2.49 (4.52)	4.60 (4.47)
	P300(μV)	
Positive	6.42 (3.00)	3.33 (4.86)
Negative	5.66 (3.18)	5.44 (2.40)

Note. Standard deviations are in parentheses.

$F(1, 32) = 3.74$, $p = .06$, $\eta_p^2 = .11$. Although follow-up tests within each group failed to yield significant effects of Sentence Ending (ps $> .17$), the RT data suggest some evidence for a negative interpretation bias in the high anxious participants, as evidenced by faster RTs to negative endings than to positive endings, and a positive bias in the low anxious participants, as evidenced by faster RTs to positive endings than to negative endings (see Table 2).

P600 Data

Table 2 contains the P600 data for the high and low socially anxious participants for positive, negative, and neutral sentence endings. Figure 1 presents ERP data from Cz, time-locked to the onset of the sentence-terminal word, for high socially anxious (top) and low socially anxious (bottom) participants. Independent-samples t test conducted on P600 magnitude on neutral sentences indicated that the two groups did not differ, $t(32) < 1$ (see Table 2). Results of the ANOVA showed that the main effect of Sentence Ending failed to reach significance, $F(1, 32) = 3.02$, $p = .09$, $\eta_p^2 = .086$; additionally, high and low socially anxious participants did not differ overall with respect to the magnitude of their P600s, $F(1, 32) < 1$. Importantly, however, the Group × Sentence Ending interaction was significant, $F(1, 32) = 5.13$, $p = .03$, $\eta_p^2 = .138$. Consistent with our hypothesis and confirming impressions given by Figure 1, post hoc paired-samples t tests within each group revealed that the P600 was larger to negative than to positive sentence endings in the low anxious group, $t(17) = 2.76$, $p = .013$, $d = .65$, but no difference between sentence endings was observed in the high anxious group, $t(15) < 1$.

While the P600 was our primary measure of interpretation bias in the current study, Figure 1 reveals that modulation of the ERP waveform by sentence ending seems to emerge earlier. Therefore, we investigated our primary hypothesis in two successive time windows preceding the P600 that captured the N400 (400–500 ms) and P300 (200–400 ms). Analysis of activity in the N400 time window showed no main effect of Sentence Ending, $F(1, 32) < 1$; additionally, high and low socially anxious participants did not differ overall with respect to the magnitude of their P600s, $F(1, 32) < 1$. As with the P600, the Group × Sentence Ending interaction was significant, $F(1, 32) = 5.07$, $p = .031$, $\eta_p^2 = .137$. Post hoc paired-samples t tests within each group revealed that activity in the N400 time window was only marginally larger to negative than to positive sentence endings in the low anxious group, $t(17) = 1.86$, $p = .081$, $d = .44$, and again showed no difference between sentence endings in the high anxious group, $t(15) = 1.39$, $p = .185$, $d = .35$. Analysis of the P300 time window revealed similarly less robust findings compared to the P600. No main effect of Sentence Ending emerged, $F(1, 32) < 1$. The main effect of Group only approached significance, $F(1, 32) = 3.54$, $p = .069$, $\eta_p^2 = .100$, suggesting somewhat larger P300s in the high anxious group. Likewise, the Group × Sentence Ending interaction only ap-

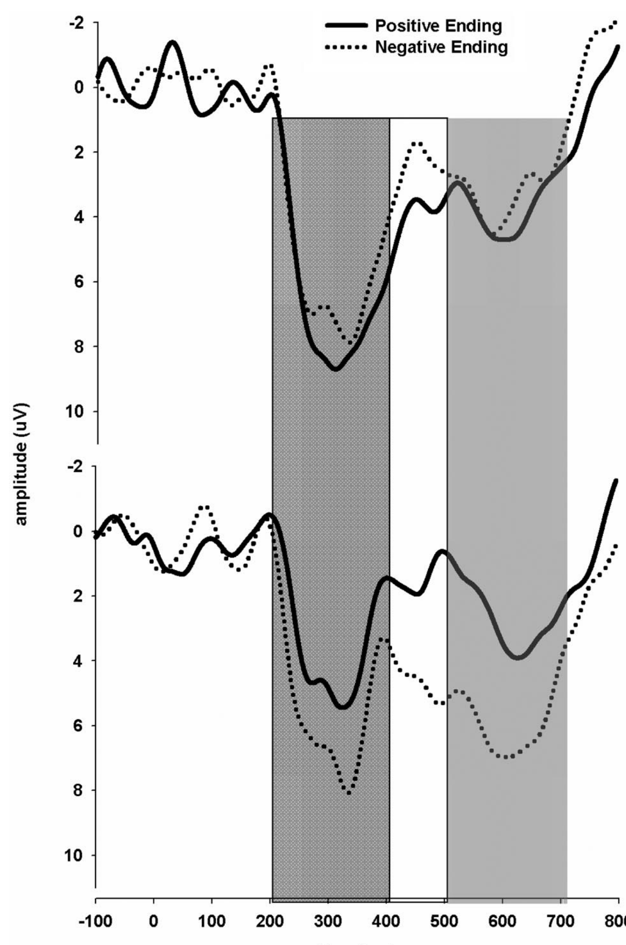

Figure 1. Event-related brain potentials (ERPs) at Cz time-locked to the onset of the sentence-terminal word in the high socially anxious group (top) and the low socially anxious group (bottom). The shaded areas represent the time windows submitted to statistical analysis: P300, N400, and P600, respectively.

proached significance in this time window, $F(1, 32) = 3.06$, $p = .09$, $\eta_p^2 = .087$. Post hoc *t* tests within each group revealed that activity in the P300 time window was only marginally larger to negative than to positive sentence endings in the low anxious group, $t(17) = 1.76$, $p = .096$, $d = .42$, and again showed no difference between sentence endings in the high anxious group, $t(15) < 1$.

Discussion

Findings from the current study are consistent with previous results suggesting a lack of "online" positive interpretation bias in social anxiety (e.g., Hirsch & Mathews, 2000). Specifically, we found that low anxious individuals were characterized by larger P600s to negative than to positive endings of ambiguous sentence stems, suggesting that negative endings were relatively unexpected; in other words, the ERP data from low anxious individuals suggest the presence of a positive interpretation bias. On the other hand, high socially anxious individuals failed to show any difference in P600 magnitude between negative and positive endings, suggesting a lack of positive bias. Similar results for both groups seemed to emerge prior to the P600, between 200 and 500 ms poststimulus; however, these findings were less robust. The current findings demonstrate the sensitivity of ERPs to interpretation biases in anxiety. While the P600 showed clear differences between high and low socially anxious groups in the current study, RT effects were more ambiguous—a point to which we will return below.

In the context of previous P600 findings and conceptualizations (Coulson et al., 1998a, 1998b), the current results suggest that low anxious participants treated negative endings to ambiguous scenarios as unexpected and inconsistent with their positive/benign interpretations of the preceding sentence stems, eliciting the engagement of attention and memory processes in reanalysis of the sentences' meanings. This positivity bias demonstrated in the present low anxious sample is consistent with the notion that mental health is maintained by positive views of self, world, and future (cf. Taylor & Brown, 1988). On the other hand, socially anxious individuals found negative and positive endings to ambiguous scenarios to be equally probable as indexed by the P600, supporting the notion that socially anxious individuals lack this online positive bias (Hirsch & Mathews, 2000). Recently, Moser et al. (2008) found convergent evidence for a lack of positive bias in social anxiety in a facial discrimination task using another ERP component occurring at a similar latency as the P600 and indexing action-monitoring processes. We are currently evaluating the relation between these two ERP modulations in ongoing experiments.

While modulations of the P600 seemed to clearly show a lack of online positive bias in the high anxious participants, modulations of earlier activity in the time windows of the P300 and N400 were less robust, although both components followed the predicted direction of effects for the P600 in both groups. At no point, however, did the high -anxious participants show any sign of a bias toward positive or negative endings of the ambiguous sentence stems. Rather, it was the low anxious participants who seemed to show signs of a positive bias in earlier ERP time windows, but only reliably so in the time window of the P600. These results suggest that the normal positive bias in interpretation of ambiguous scenarios emerges most strongly during attention and memory-processing stages dedicated to the analysis of sentence meaning and the monitoring of correct sentence perception (cf. van Herten et al., 2005)—at the very point at which the classic P600 effect emerges to syntactic and semantic anomalies (cf. Coulson et al., 1998a, 1998b). Earlier attention-related processes, then, do not seem to underlie the normal positive interpretation bias. And socially anxious individuals seem to lack any preferential processing of sentences during all stages of online processing.

It is also interesting to note that high and low socially anxious participants did not differ in overall resource allocation to task relevant stimuli as indexed by the absolute magnitude of the P600–-as well as during other time windows—across all trials. Under the current experimental conditions, then, these data suggest that socially anxious individuals had sufficient resources to allocate to the task in general. Thus, it does not appear that a general reduction in resource allocation to external stimuli (cf. Clark & Wells, 1995) is responsible for our lack of positive bias finding. It is possible, however, that given a more difficult task such a reduction in resource allocation might emerge, as task difficulty seems to be a critical factor in revealing overall differences in resource allocation between anxious and nonanxious individuals (cf. Eysenck, Derakshan, Santos, & Calvo, 2007). Rather, our findings suggest that other mechanisms are at play when socially anxious individuals encounter ambiguous social information such as enhanced competition between negative and positive meanings of ambiguous information (Mathews & Mackintosh, 1998) or the interpretation of all stimuli—whether generally rated as negative or positive—as negative (Alden, Taylor, Mellings, & Laposa, in press). For example, socially anxious participants might interpret the word *funny* at the end of the sentence "As you give a speech, you see a person in the crowd smiling, which means that your speech is. . ." to mean something more negative such as "silly" or "nonsensical" or even "stupid." Related to the notion of increased competition between activations of negative and positive meanings, recent studies suggest that negative self-imagery blocks or interferes with positive interpretations of ambiguous information in social anxiety and that induction of a negative interpretation bias leads to more negative self-imagery (for a review, see Hirsch, Clark, & Mathews, 2006). Future ERP studies can begin to tease apart these issues by priming or "training" certain interpretations of ambiguous stimuli (Grey & Mathews, 2000; Mathews & Mackintosh, 2000; Murphy et al., 2007), using imagery manipulations (e.g., Hirsch et al., 2003), and asking participants to rate the valence (and arousal) of the sentences and sentence endings.

Together, our results suggest that ERPs can be used to examine interpretation biases in anxious and nonanxious individuals. Furthermore, our P600 findings indicate that such biases can be revealed as early as 500 ms into stimulus processing—and perhaps somewhat earlier—well before the overt behavioral response is made. Given that we found a clear lack of positive bias in the P600 and a more mixed, less robust pattern in RT is consistent with the notion that the two measures are likely reflective of (or influenced by) somewhat different processes that unfold over time. In comparison to the clear lack of positive bias reflected in the P600, RT seemed to reflect somewhat of a negative *and* lack of positive bias in the socially anxious group. Future studies combining ERP and behavioral measures are necessary to further illuminate their relationship. Last, our current findings of significant ERP effects in the face of less reliable RT effects are also consistent with studies of other negative affective groups (Fallgatter et al., 2004; Hajcak, McDonald, & Simons, 2003, 2004; Hajcak & Simons, 2002; Holmes & Pizzagalli, 2008; Moser, Hajcak, & Simons, 2005; Moser et al., 2008; Shestyuk, Deldin, Brand, & Deveney, 2005).

That a lack of positive interpretation bias characterizes social anxiety suggests that treatment strategies aimed at helping socially anxious patients generate more positive interpretations/expectations are warranted (and more positive experiences overall; cf. Kashdan, 2007). Most current treatments for social anxiety focus on disconfirming negative interpretations/expectations (e.g., Clark & Wells, 1995). A recent study by Murphy et al. (2007), however, showed that priming or "training" a positive interpretation bias through repeated exposure to positively resolved ambiguous scenarios resulted in a positive interpretation bias on a subsequent task and lower predicted anxiety ratings for a future social interaction in high socially anxious participants, consistent with the notion that inducing a positive interpretation bias may be important in treatment of social anxiety. Additional research is needed in this area to further specify the effectiveness of inducing a positive bias in altering interpretations in and reducing symptoms of social anxiety, and ERPs may provide useful measures for testing its effects.

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 participants 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. Future research will also be needed to determine the specificity of these interpretation biases by examining ERPs in other anxious and depressed groups, as the socially anxious participants in the current study also demonstrated significant depression and general distress symptoms.

In summary, the current findings demonstrate the utility of ERPs in revealing information-processing biases in social anxiety. The continued evaluation of ERPs as temporally sensitive neural markers of information-processing biases could prove useful in furthering models of and treatments for social anxiety.

References

Alden, L. E., Taylor, C. T., Mellings, T. M. J. B., & Laposa, J. M. (in press). Social anxiety and the interpretation of positive social events. *Journal of Anxiety Disorders.*

Amir, N., Foa, E. B., & Coles, M. E. (1998). Negative interpretation bias in social phobia. *Behaviour Research and Therapy, 36,* 945–957.

Antony, M. M., Bieling, P. J., Cox, B. J., Enns, M. W., Swinson, R. P. (1998). Psychometric properties of the 42-item and 21-item versions of the Depression Anxiety Stress Scales in clinical groups and a community sample. *Psychological Assessment, 10,* 176–181.

Baker, S. L., Heinrichs, N., Kim, H., & Hofmann, S. G. (2002). The Liebowitz social anxiety scale as a self-report instrument: A preliminary psychometric analysis. *Behaviour Research and Therapy, 40,* 701–715.

Brown, T. A., Chorpita, B. F., Korotitsch, W., & Barlow, D. H. (1997). Psychometric properties of the Depression Anxiety Stress Scales (DASS) in clinical samples. *Behaviour Research and Therapy, 35,* 79–89.

Clark, D. M., & Wells, A. (1995). A cognitive model of social phobia. In R. G. Heimberg, M. Liebowitz, D. Hope, & F. Schneier (Eds.), *Social phobia: Diagnosis, assessment, and treatment* (pp. 69–93). New York: Guilford Press.

Connor, K. M., Davidson, J. R. T., Churchill, L. E., Sherwood, A., Foa, E., & Weisler, R. H. (2000). Psychometric properties of the Social Phobia Inventory (SPIN): New self-rating scale. *British Journal of Psychiatry, 176,* 379–386.

Cook, E. W. III (1999). *VPM reference manual.* Birmingham, AL: Author.

Cook, E. W. III, & Miller, G. A. (1992). Digital filtering–Background and tutorial for psychophysiologists. *Psychophsyiology, 29,* 350–367.

Coulson, S., King, J. W., & Kutas, M. (1998a). ERPs and domain specificity: Beating a straw horse. *Language and cognitive processes, 13,* 653–672.

Coulson, S., King, J. W., & Kutas, M. (1998b). Expect the unexpected: Event-related brain response to morphosyntactic violations. *Language and cognitive processes, 13,* 21–58.

Crawford, J. R., & Henry, J. D. (2003). The Depression Anxiety Stress Scales (DASS): Normative data and latent structure in a large nonclinical sample. *British Journal of Clnical Psychology, 42,* 111–131.

Donchin, E. (1981). Surprise! . . . Surprise? *Psychophysiology, 18,* 493–513.

Donchin, E., & Coles, M. G. H. (1988). Is the P300 component a manifestation of contextual updating? *Behavioral and Brain Sciences, 11,* 357–427.

Eysenck, M. W., Derakshan, N., Santos, R., & Calvo, M. G. (2007). Anxiety and cognitive performance: Attentional control theory. *Emotion, 7,* 336–353.

Fallgatter, A. J., Herrmann, M. J., Roemmeler, J., Ehlis, A.-C., Wagener, A., Heidrich, A., et al. (2004). Allelic variations of serotonin transporter function modulates the brain electrical response for error processing. *Neuropsychopharmacology, 29,* 1506–1511.

Franklin, M. E., Huppert, J. D., Langner, R., Leiberg, S., & Foa, E. B. (2005). Interpretation bias: A comparison of treated social phobics, untreated social phobics, and controls. *Cognitive Therapy and Research, 29,* 289–300.

Fresco, D. M., Coles, M. E., Heimberg, R. G., Leibowitz, M. R., Hami, S., Stein, M. B., et al. (2001). The Liebowitz social anxiety scale: A comparison of the psychometric properties of self-report and clinician-administered formats. *Psychological Medicine, 31,* 1025–1035.

Friederici, A. D., Hahne, A., & Mecklinger, A. (1996). The temporal structure of syntactic parsing: Early and late event-related brain potential effects. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 22,* 1219–1248.

Gratton, G., Coles, M. G. H., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology, 55,* 468–484.

Grey, S., & Mathews, A. (2000). Effects of training on interpretation of emotional ambiguity. *Quarterly Journal of Experimental Psychology: Human Experimental Psychology, 53,* 1143–1162.

Gunter, T. C., Stowe, L. A., Mulder, G. (1997). When syntax meets semantics. *Psychophysiology, 34,* 660–676.

Hagoort, P., Brown, C., & van Groothusen, J. (1993). The syntactic positive shift (SPS) as an ERP measure of syntactic processing. *Language and Cognitive Processes, 8,* 439–483.

Hajcak, G., McDonald, N., & Simons, R. F. (2003). Anxiety and error-related brain activity. *Biological Psychology, 64,* 77–90.

Hajcak, G., McDonald, N., & Simons, R. F. (2004). Error-related psychophysiology and negative affect. *Brain and Cognition, 56,* 189–197.

Hajcak, G., & Simons, R. F. (2002). Error-related brain activity in obsessive–compulsive undergraduates. *Psychiatry Research, 110,* 63–72.

Hirsch, C. R., & Clark, D. M. (2004). Information-processing bias in social phobia. *Clinical Psychology Review, 24,* 799–825.

Hirsch, C. R., Clark, D. M., & Mathews, A. (2006). Imagery and interpretations in social phobia: Support for the combined cognitive biases hypothesis. *Behavior Therapy, 37,* 223–236.

Hirsch, C. R., & Mathews, A. (1997). Interpretative inferences when reading about emotional events. *Behaviour Research and Therapy, 35,* 1123–1132.

Hirsch, C. R., & Mathews, A. (2000). Impaired positive inferential bias in social phobia. *Journal of Abnormal Psychology, 109,* 705–712.

Hirsch, C. R., Mathews, A., Clark, D. M., Williams, R., & Morrison, J. (2003). Negative self-imagery blocks inferences. *Behaviour Research and Therapy, 41,* 1383–1396.

Holmes, A. J., & Pizzagalli, D. A. (2008). Spatiotemporal dynamics of error processing dysfunctions in major depressive disorder. *Archives of General Psychiatry, 65,* 179–188.

Huppert, J. D., & Foa, E. B. (2004). Maintenance mechanisms in social anxiety: An integration of cognitive biases and emotional processing theory. In J. Yiend (Ed.), *Cognition, emotion and psychopathology: Theoretical, empirical and clinical directions* (pp. 213–231). New York: Cambridge University Press.

Huppert, J. D., Foa, E. B., Furr, J. M., Filip, J. C., &Mathews, A. (2003). Interpretation bias in social anxiety: A dimensional perspective. *Cognitive Therapy and Research, 27,* 569–577.

Huppert, J. D., Pasupuleti, R. V., Foa, E. B., & Mathews, A. (2007). Interpretation bias in social anxiety: Response generation, response selection, and self-appraisals. *Behaviour Research and Therapy, 45,* 1505–1515.

Kashdan, T. B. (2007). Social anxiety spectrum and diminished positive experiences: Theoretical synthesis and meta-analysis. *Clinical Psychology Review, 27,* 348–365.

Kolk, H. H. J., Chwilla, D. J., van Herten, M., & Oor, P. J. W. (2003). Structure and limited capacity in verbal working memory: A study with event-related potentials. *Brain & Language, 85,* 1–36.

Kuperberg, G. R., Sitnikova, T., Caplan, D., & Holcomb, P. J. (2003). Electrophysiological distinctions in processing conceptual relationships within simple sentences, *Cognitive Brain Research, 17,* 117–129.

Kutas, M., & Hillyard, S. A. (1980). Reading senseless sentences: Brain potentials reflect semantic incongruity. *Science, 207,* 203–205.

Kutas, M., & Hillyard, S. A. (1984). Brain potentials during reading reflect word expectancy and semantic association. *Nature, 307,* 161–163.

Leary, M. R. (1983). A brief version of the Fear of Negative Evaluation Scale. *Personality and Social Psychology Bulletin, 9,* 371–375.

Liebowitz, M. R. (1987). Social phobia. *Modern Problems in Pharmacopsychiatry, 22,* 141–173.

Lovibond, P. F., & Lovibond, S. H. (1995). The structure of negative emotional states—Comparison of the depression anxiety stress scales (DASS) with the Beck Depression and Anxiety Inventories. *Behavior Research and Therapy, 33,* 335–343.

Mathews, A., & Mackintosh, B. (1998). A cognitive model of selective processing in anxiety. *Cognitive Therapy and Research, 22,* 539–560.

Mathews, A., & Mackintosh, B. (2000). Induced emotional interpretation bias and anxiety. *Journal of Abnormal Psychology, 109,* 602–615.

Mattick, R. P., & Clarke, C. J. (1998). Development and validation of measures of social phobia scrutiny fear and social interaction anxiety. *Behaviour Research and Therapy, 36,* 455–470.

Mennin, D. S., Fresco, D. M., Heimberg, R. G., Schneier, F. R., Davies, S. O., & Liebowitz, M. R. (2002). Screening for social anxiety disorder in the clinical setting: Using the Liebowitz social anxiety scale. *Journal of Anxiety Disorders, 16,* 661–673.

Miller, G. A., Gratton, G., & Yee, C. M. (1988). Generalized implementation of an eye movement correction procedure. *Psychophysiology, 25,* 241–243.

Moser, J. S., Hajcak, G., & Simons, R. F. (2005). The effects of fear on performance monitoring and attentional allocation. *Psychophysiology, 42,* 261–268.

Moser, J. S., Huppert, J. D., Duval, E., & Simons, R. F. (2008). Face processing biases in social anxiety: An electrophysiological study. *Biological Psychology, 78,* 93–103.

Murphy, R., Hirsch, C. R., Mathews, A., Smith, K., & Clark, D. M. (2007). Facilitating a benign interpretation bias in a high socially anxious population. *Behaviour Research and Therapy, 45,* 1517–1529.

Phan, K. L., Fitzgerald, D. A., Nathan, P. J., & Tancer, M. E. (2006). Association between amygdala hyperactivity to harsh faces and severity of social anxiety in generalized social phobia. *Biological Psychiatry, 59,* 424–429.

Ratcliff, R. (1993). Methods for dealing with reaction time outliers. *Psychological Bulletin, 114,* 510–532.

Ries, B. J., McNeil, D. W., Boone, M. L., Turk, C. L., Carter, L. E., & Heimberg, R. G. (1998). Assessment of contemporary social phobia verbal report instruments. *Behaviour Research and Therapy, 36,* 983–994.

Safren, S. A., Turk, C. L., & Heimberg, R. G. (1998). Factor structure of the social interaction anxiety scale and the social phobia scale. *Behaviour Research and Therapy, 36,* 443–453.

Shestyuk, A. Y., Deldin, P. J., Brand, J. E., Deveney, C. M. (2005). Reduced sustained brain activity during processing of positive emotional stimuli in major depression. *Biological Psychiatry, 5,* 1089–1096.

Stein, M. B., Goldin, P. R., Sareen, J., Zorrilla, L. T. E., & Brown, G. G. (2002). Increased amygdala activation to angry and contemptuous faces in generalized social phobia. *Archives of General Psychiatry, 59,* 1027–1034.

Stopa, L., & Clark, D. M. (2000). Social phobia and interpretation of social events. *Behaviour Research and Therapy, 38,* 273–283.

Straube, T., Mentzel, H.-J., & Miltner, W. H. R. (2005). Common and distinct brain activation to threat and safety signals in social phobia. *Neuropsychobiology, 52,* 163–168.

Taylor, S. E., & Brown, J. D. (1988). Illusion and well-being: A social psychological perspective on mental health. *Psychological Bulletin, 103,* 193–210.

van Herten, M., Kolk, H. H. J., & Chwilla, D. J. (2005). An ERP study of P600 effects elicited by semantic anomalies. *Cognitive Brain Research, 22,* 241–255.

Watson, D., Clark, L. E., Weber, K., Assenheimer, J. S., Strauss, M. E., McCormick, R. A. (1995). Testing a tripartite model: II. Exploring the symptom structure of anxiety and depression in student, adult, and patient samples. *Journal of Abnormal Psychology, 104,* 15–25.

Weeks, J. W., Heimberg, R. G., Fresco, D. M., Hart, T. A., Turk, C. L., Schneier, F. R., et al. (2005). Empirical validation and psychometric evaluation of the brief fear of negative evaluation scale in patients with social anxiety disorder. *Psychological Assessment, 17,* 179–190.

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