

SOCIAL ANXIETY IS ASSOCIATED WITH A LACK OF EXPECTED DECREASE IN
NEURAL ACTIVITY WHILE ANALYZING EMOTIONAL MEMORIES

By

Chelsea Kneip

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ABSTRACT

SOCIAL ANXIETY IS ASSOCIATED WITH A LACK OF EXPECTED DECREASE IN NEURAL ACTIVITY WHILE ANALYZING EMOTIONAL MEMORIES

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Extant literature suggests that individuals with social anxiety experience hyper-reactivity to and trouble reappraising negative autobiographical memories, but the functional, neural mechanisms involved are unclear. Further, existing studies have been limited by the ecological validity of both the emotional stimuli used to measure emotion processing as well as the memory retrieval process. To address these gaps, I investigated the relationship between social anxiety symptoms and a neurophysiological marker of emotion-related memory processes, the Late Positive Potential (i.e., LPP), in an autobiographical memory paradigm that taps two phases of memory processing -- the initial recall of the event and the later analysis of meaning and emotions elicited by the event. Findings first showed that the LPP was reduced during the analysis compared to the recall phase, suggesting a decrease in emotional memory activity when evaluating meaning and emotions elicited by a personal experience. Most important to the primary aim of the study, higher levels of social anxiety were not associated with this expected decrease in LPP during the analysis phase, suggesting that social anxiety acts in opposition to the down-regulating effects of deeply analyzing one's emotions and thoughts surrounding a negative memory. These findings offer the first neurophysiological evidence that socially anxious individuals do not benefit from analyzing their negative autobiographical memories, consistent with existing evidence of hyper-reactivity to negative memories in social anxiety. Future research should take into consideration the importance of isolating phases of memory processing, as they may differentiate individual differences in emotional health.

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Introduction

Social anxiety disorder (i.e., SAD) is the most common subtype of the anxiety disorders, with a 7% to 13.3% lifetime prevalence (Kessler et al., 1994). Characterized by marked anxiety in and avoidance of social settings, social anxiety disorder is associated with significant distress and functional impairment in work and social domains (American Psychiatric Association, 2013; Schneier et al., 1994). A core feature of social anxiety is a negative bias in autobiographical memory processes. The extant literature on this topic has been limited, however, by the use of behavioral and self-report measures alone; thus, the field is lacking evidence from online measures that socially anxious individuals experience meaningful differences in their reactivity to troubling memories. Further, existing studies have been limited by the ecological validity of both the stimuli used to elicit emotional memories as well as the simulation of the memory retrieval process. In this study, I aimed to address these gaps by investigating associations between symptoms of social anxiety and differences in the Late Positive Potential (i.e., LPP), an Event-Related Potential (i.e., ERP) index of the temporal dynamics of emotion processing across phases of autobiographical memory processing. That is, from the initial recall of the memory cue through later stages when emotions and meaning surrounding the memory are being processed.

Social Anxiety and Emotional Reactivity to Autobiographical Memories

Emerging evidence suggests that socially anxious individuals exhibit biases in their autobiographical memories (Krans et al., 2013; reviewed in Morgan, 2010). Erwin, Heimberg, Marx, and Franklin (2006) found that individuals with SAD reacted to their memories of stressful social events with hyper-arousal and avoidance, unlike non-anxious controls. Evidence further suggests that individual differences in social anxiety relate to a tendency to experience memories of anxiety-producing social situations from an observer perspective, which may reflect

an attempt to avoid activating emotions surrounding these memories (Coles, Turk, Heimberg, & Fresco, 2001; Wells, Clark, & Ahmad, 1998). In addition to recalling their interactions from an observer's perspective, there is evidence that individuals with social anxiety tend to distort these images of themselves to see their fears visualized (Coles, Turk & Heimberg, 2002; Clark & Wells, 1995; Rapee & Heimberg, 1997). For example, an individual with social anxiety may feel her hands shaking during an interaction, and in recalling the interaction, she may see herself looking extremely jittery and overtly anxious when in reality her anxiety was not necessarily obvious to the observer. Therefore, in analyzing their past experiences, individuals with social anxiety struggle to separate themselves from their own affect and biases enough to adopt a new perspective and resolve their emotions. In this regard, autobiographical memories are susceptible to cognitive biases which may maintain social anxiety symptoms.

Current cognitive models of SAD propose that negative beliefs and misrepresentations of internal and external stimuli are central to the maintenance of the disorder (Heimberg, Brozovich, & Rapee, 2010). That is, individuals with social anxiety are more likely to make biased interpretations of ambiguous stimuli as dangerous, such as their own interoceptive physical sensations and mental events –including memories – or the behaviors of other individuals (Bounton et al., 2001, Mathews and MacLeod, 2005). Further, avoidance of social situations is commonplace in individuals with SAD, and many researchers such as Clark (1999) and Heimberg (2010) have outlined that this may involve retrieval of personally relevant information (i.e., memories) from the past that confirm preconceived biases about themselves and others. Other findings suggest that socially anxious individuals' autobiographical memories of social events are biased by the interpretations they make (Hertel, Brozovich, Joormann, & Gotlib, 2008). Further, current theories of autobiographical memory suggest that both the

encoding and retrieval of autobiographical memories are influenced by both bottom-up and top-down processes, wherein ambiguous sensory information is received, then information already stored as prior knowledge influences the interpretation of that sensory input (Anderson & Conway, 1993; Conway, 1996; Conway & Pleydell-Pearce, 2000). In this regard, the details of autobiographical memories depend on the person's conceptualizations of themselves and the world. Thus, biased interpretations of social events among socially anxious individuals are susceptible to becoming part of memories themselves. As a result, negatively biased memories of social situations are more threatening than was actually the case, and in turn, this contributes to greater anticipatory anxiety for future social situations, which is likely to maintain avoidance behaviors in individuals with social anxiety (Heimberg et al, 2010). As is the case with any fear-based disorder, avoidance does not allow opportunities to adopt new, less threatening conceptualizations of feared situations, and this contributes to the maintenance of fear and anxiety.

Beyond cognitive biases alone, there is evidence that individuals with social anxiety are more emotionally reactive to stressful social events. Goldin et al. (2009) found that when faced with social threat, individuals with social anxiety demonstrate exaggerated negative emotional reactivity and reduced cognitive regulation-related neural activation compared to non-anxious controls. The role of hyper-reactivity has been outlined in models of SAD as arising from distorted appraisals of social situations which in turn lead to negatively biased interpretations of social cues (Clark & Wells, 1995; Clark & McManus, 2002; Rapee & Heimberg, 1997). Indeed, it has been well-established that individuals with social anxiety are biased to attend to threatening social information (Musa, Lépine, Clark, Mansell & Ehlers, 2003). With this biased perspective, it follows that socially anxious individuals would exhibit more emotional reactions

to stressful social stimuli.

Goldin et al. (2009) also found that individuals with social anxiety have a difficult time obtaining a positive benefit from reappraising. This process is hypothesized to maintain social anxiety, as no resolution is reached when thinking back on past negative memories. Thus, it has been established that individuals with social anxiety 1) experience cognitive biases in their memories of past experiences, including imagining themselves looking overtly anxious, 2) tend to misinterpret social cues, and these misinterpretations can alter memories themselves, 3) tend to rely on these negatively biased memories to predict future social interactions which leads to avoidance, 4) tend to experience increased emotional reactivity when thinking back on stressful social encounters, and 5) have a hard time reappraising their negatively biased interpretations. However, our understanding of memory processing in socially anxious individuals has been limited to findings from self-report and behavioral studies. No study to date has used neurophysiological measures to map emotional reactivity during the processing of autobiographical memories across dimensions of social anxiety.

Neurophysiological Marker of Emotional Reactivity

Whereas measures of self-reported affect rely on post-hoc subjective experiences, ERPs provide markers of on-line processes with millisecond precision, which allows a more in-depth analysis of the nature of emotion processing. Thus, ERPs have the potential to provide a real-time metric of differences in autobiographical memory processing across the spectrum of social anxiety. Specifically, the late positive potential (LPP), a positive deflection in the ERP waveform that reaches maximum amplitude 400-700 milliseconds after the onset of emotional stimuli, indexes sustained attention to emotional stimuli related to their motivational salience (Proudfit et al., 2014). Positivity in this time window has also been shown to index conscious recollection of

episodic memories (Paller, Kutas, & McIsaac, 1995; Rugg & Curran, 2007; Vilberg, Moosavi, & Rugg, 2006). Thus, the LPP is the ideal ERP marker for recollection of emotional memories. As opposed to referring to the value-laden definition of “positivity”, take note that the positivity in this waveform refers only to the voltage of the ERP; further, the LPP occurs in response to both positively and negatively valenced emotional stimuli. The LPP further reflects emotion regulation processes as it is modulated by instructions to decrease and increase emotional intensity while viewing emotionally arousing stimuli (Hajcak & Nienhuis, 2006; Krompinger et al., 2008; Moser et al., 2006, 2009, 2014; Thiruchselvam et al., 2011). In particular, the LPP is modulated by cognitive reappraisal, which involves reinterpreting the meaning of emotional content. When participants are asked to decrease negative emotions to negative arousing stimuli, the LPP is reduced or less positive (Moser et al., 2009). Thus, it follows that the LPP can be used as a robust measure of emotional reactivity, in that a larger LPP would index increased emotionality.

How would one expect this marker of emotional reactivity to behave across phases of memory processing in socially anxious individuals? Kross and Ayduk (2008) have proposed that analysis of one’s negative emotions should be associated with a natural decrease in negative affect, as this process should allow for reappraisal and thus a new understanding of one’s emotions. Indeed, self-reported trait-level positive reappraisal has been linked to positive psychological health outcomes (Penley, Tomaka, & Wiebe, 2002; Gross & John, 2003). However, Kross & Ayduk (2008) further propose that this is dependent on the perspective one takes during analysis of emotions, i.e., one should be self-distanced from versus self-immersed in their emotions in order to achieve positive reappraisal and meaning-making. Indeed, they found that self-distancing while analyzing one’s emotions is associated with greater well-being (2011).

However, it has already been outlined here that socially anxious individuals do not seem to benefit from self-distancing, as their tendency to reflect on past social situations from an observer's perspective is associated with an image of themselves looking overtly anxious. This image in turn is associated with increased reactivity, an inability to reappraise, and the memory itself becoming negatively biased, which influences avoidance behavior and symptom maintenance. Therefore, while this tendency to self-distance may be an effort to emotionally down-regulate, it may be the case that instead, it backfires, not allowing the expected reduction in emotionality to take place during analysis of the memory. Whereas down-regulating while analyzing negative autobiographical memories might allow individuals to reappraise their emotions surrounding the memory, a maintenance of increased emotional reactivity might not allow for reappraisal and instead only lead to recounting the negative affect associated with the memory (Ayduk & Kross, 2010). Moser et al. (2014) found that a more positive LPP during reappraisal is linked with worse emotional health outcomes such as higher worry symptoms; thus, a lack of decreased positivity in the LPP during analysis of emotional memories, where reappraisal would be expected to take place, may also be associated with worse outcomes. Note that while self-reported trait reappraisal is associated with better outcomes, the LPP literature shows that a lack of reduced neural activity during reappraisal is associated with worse outcomes. In the current study, I therefore predicted that socially anxious individuals would exhibit a lack of reduced neural activity during the analysis phase of memory processing, when reappraisal would be expected to take place.

Although one might expect socially anxious individuals to exhibit this increased LPP during analysis of emotional memories, is it also reasonable to expect a similar trend during recall of these memories? Cognitive neuroscience research indicates that both shared and distinct

sets of neural activity underlie these different phases of memory processing, lending evidence that memory retrieval and post-retrieval processing are related but separate processes (e.g., Cabeza, Dolcos, Graham, & Nyberg, 2002; Israel, Seibert, Black, & Brewer, 2009). Whereas deeply analyzing a memory involves elaborating on what has already been retrieved, and taking into account past, present, and future experiences to understand one's feelings, motivations, and thoughts, recalling a memory involves simply retrieving it from long-term memory in order to bring it into consciousness (Ayduk & Kross, 2010). Further, evidence suggests that anxious individuals bring anxious memories to mind more often than non-anxious controls (Burke & Mathews, 1992; Rubin, Boals & Berntsen, 2008), but they avoid elaborating on these memories once they have been brought to mind, theoretically as an avoidance strategy (Clark & Wells, 1995; Rapee & Heimberg, 1997). These findings suggest that individuals low and high in social anxiety might differentiate during later stages of memory processing, when the emotions and thoughts surrounding these memories are being analyzed, given evidence that socially anxious individuals do not typically allow themselves to “get to” this phase of memory processing. Thus, whereas individuals lower in social anxiety may be able to effectively process their emotions during this phase and thus experience reduced emotionality, socially anxious individuals may not experience the same “cooling down” effect. Therefore, it was predicted that the LPP would only be associated with individual differences in social anxiety during the analyze phase of memory processing.

Ecologically Valid Behavioral Paradigm

Thus, separate predictions have been made for the recall and the analyze phases of memory processing for social anxiety. In order to isolate these phases of memory processing, it was necessary to use a behavioral paradigm that allowed for parsing brain activity during the

recall phase from that during the analyze phase of memory processing. As mentioned, extant literature on autobiographical memory biases in social anxiety has been limited by investigating only a snapshot of memory processing as opposed to differentiating between the phases. I am arguing that there may be meaningful differences across these phases of the memory retrieval process.

To date, no study has examined both “recall” and “analyze” instructions and thus it has not been possible to investigate individual differences in emotion processing across recall and analyze phases of negative autobiographical memory processing. Further, past research on the LPP across dimensions of social anxiety has been mostly limited by the use of standardized emotional stimuli, and faces in particular (e.g., Moser, Huppert, Duval & Simons, 2008; Kolassa, Kolassa, Musial & Miltner, 2007; Schmitz, Scheel, Rigon, Gross, & Blechert, 2012), which 1) limits this area of research to understanding biases in the processing of faces alone and 2) does not take into account the idiosyncrasies of each participant. Participants in the current study recalled and then analyzed their own negative autobiographical memories, which assured emotional saliency across participants as well as mimicked spontaneous memory recall and processing in daily life.

Present Study: Aims & Hypotheses

In sum, evidence exists that socially anxious individuals exhibit cognitive biases in their autobiographical memories. Further, there is evidence that socially anxious individuals have a tendency to reflect on their memories of social situations from an observer’s perspective, but instead of this self-distanced perspective providing a down-regulating effect as it may be intended to, these individuals tend to see themselves looking overtly anxious. Further, misinterpretations like these have been shown to alter the content of memories themselves. This

may introduce a feedback loop wherein memories that are already biased become perceived as true memories as they are further reflected on. As it has been outlined, these memories of social situations going poorly likely influences decisions to avoid future social situations for fear that they will again go poorly, and avoidance behaviors have been linked with symptom maintenance. Relatedly, socially anxious individuals are hyper-reactive to social stimuli, and they have difficulty cognitively reappraising their biased interpretations. Thus, they may experience difficulty reappraising their emotional reactions to negative memories. However, no study to date has combined these literatures to investigate whether individuals higher in symptoms of social anxiety indeed exhibit sustained neural activity during the analysis of negative autobiographical memories, when a decrease in neural activity would be expected to take place.

The current study involved examining associations between symptoms of social anxiety and neurophysiological indices of emotional reactivity during recall and analyze phases of negative memory recollection. I predicted that the LPP would be overall less positive during the analyze compared to the recall phase of memory processing, as this is when participants would be interpreting the emotions surrounding their memories, presumably resulting in a less intense emotional experience (Ayduk & Kross, 2010; Moser et al., 2009). Next, I predicted that higher scores on self-reported measures of social anxiety would not be associated with this smaller (i.e., less positive) LPP in the analyze phase of memory processing, given evidence that socially anxious individuals experience increased emotional reactivity to negative memories and difficulty reappraising their reactions.

Method

Participants

Twenty-six young adults (14 female, mean age = 21.08 years, $SD = 2.23$) from the East Lansing / Michigan State University community participated in the study for course credit or \$10 per hour. Participants were recruited through advertisements posted on the Lansing www.craigslist.com as well as flyers placed around the campus and surrounding community. The racial composition of the sample was 74% White, 14.8% Black, 3.7% Asian or Asian American, 3.7% Hawaiian, and 3.7% other ethnicities. Written informed consent was obtained from all participants prior to their participation and the Michigan State University Institutional Review Board approved all procedures. All participants reported no history of epilepsy, never having been unconscious from a head injury for more than five minutes, and did not have any hearing, visual or other cognitive deficits that would have impaired their ability to perform simple computer tasks.

Procedures and Materials

The study consisted of a single experimental session that lasted between 2.5 and 3 hours. Participants first completed a questionnaire that prompted them to generate five upsetting autobiographical memories using procedures adapted from Kross et al. (2009). Specific memory prompts included 1) a time when you were treated unfairly by someone; 2) a time when you felt rejected by someone who meant a lot to you; 3) a time when you experienced conflict with someone; 4) a time when you felt extremely frustrated by someone; and 5) a time when you felt sad or depressed because you failed to live up to your ideals. While this last prompt may seem more specific to depressed mood instead of social anxiety, there is a great deal of evidence to suggest that social anxiety and depression have a high rate of comorbidity (Kessler, Stang,

Wittchen, Stein & Walters, 1999; Ohayon & Schatzberg, 2010). The social exclusion theory of anxiety proposes that social anxiety and depression share the latent trait of low self-esteem and thus sensitivity for rejection, failure, and loss (Leary, 1990). Further, Watson and Clark (1988) found that whereas anxiety and depressive disorders alike are associated with negative emotionality (i.e., fear, anxiety, hostility, scorn, and disgust), social anxiety is the only anxiety disorder that commonly shares low positive emotionality (i.e., lethargy and fatigue) with depressive disorders. In summary, there appear to be latent traits that are shared between social anxiety and depression. Thus, memories of feeling down because of a failure to live up to ideals might likely tap this latent trait in socially anxious individuals.

After identifying a memory for each of these prompts, participants were then asked to describe each memory in detail (what happened, where it took place, when it occurred, who else was present, etc.) using the computer keyboard. Finally, they constructed a “memory cue”, which consisted of one or two words. This cue was used in the experimental session to help them recall the memory. After completing the online survey, participants sat quietly outside the experiment room while the experimenters prepared the next part of the experiment. EEG set-up then took place for the second part of the experiment.

Following EEG set-up (see below for details), participants practiced recalling their memories to ensure they would be able to bring the memory to mind within the allotted time during the actual task. This training session and the actual experiment were presented on the computer using E-Prime 2.0 software (Psychology Software Tools, Pittsburgh, PA, USA). First, participants completed a hypothetical memory trial with the experimenter. After this practice, the experimenter left the room and participants were then presented with the description of each of their own memories along with the cue to recall it. They were given as much time as they needed

to pair the cue with the memory so that they would be able to quickly recall the memory when they saw the corresponding cue during the experiment. Participants obtained three practice trials for all five memories. Next, only the memory cues were randomly presented on the computer screen without the description of the memory, and participants were asked to press the space bar as soon as they were able to recall the specific memory to which the cue referred.

Experimental Task

After completing the training session, participants were given instructions for the experimental phase. Following a fixation cross (“+”) presented for 5000ms, the first part of each trial--the “Recall” phase--consisted of a memory cue created by the participant which was presented on the screen until the participant pressed the space bar, indicating that they had recalled the memory. Following a fixation cross (5000ms) the second part of the trial--the “Analyze” phase--began, in which the word “Analyze” was presented on the screen for 15 seconds, during which participants were instructed to reflect over their deepest thoughts and feelings regarding that experience. After the 15 seconds (and a 5000ms fixation cross), the trial ended with a short “filler task” designed to clear participants’ minds of the previous memory they had just recalled. This filler task consisted of 15 seconds of five horizontally oriented “flanker” arrows (all arrows pointed in the same direction) to which the participants pressed a keyboard button if they were pointing left (“<<<<<”) and another button if they were pointing right (“>>>>>”). The entire experiment consisted of 20 trials, with each memory being recalled and analyzed four times.

Post-Experiment Questionnaires

Following removal of electrodes and cap, participants were asked to complete a battery of questionnaires using the computer, including the Social Phobia Inventory (SPIN). The SPIN 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); the SPIN in the current sample had high internal consistency ($\alpha = .93$).

EEG Data Collection

Continuous EEG activity was recorded using the ActiveTwo BioSemi system (BioSemi, Amsterdam, The Netherlands). Recordings were taken from 64 Ag-AgCl electrodes placed in accordance with the 10/20 system. In addition, two electrodes were placed on the left and right mastoids. Electro-oculogram (EOG) activity generated by eye movements and blinks was recorded at FP1 and three additional electrodes placed inferior to the left pupil and on the left and right outer canthi (all approximately 1 cm from the pupil). During data acquisition, the Common Mode Sense active electrode and Driven Right Leg passive electrode formed the ground, as per BioSemi's design specifications. All signals were digitized at 512 Hz using ActiView software (BioSemi). Offline analyses were performed using BrainVision Analyzer 2 (BrainProducts, Gilching, Germany). Scalp electrode recordings were re-referenced to the numeric mean of the mastoids and band-pass filtered with cutoffs of 0.01 and 20 Hz (12 dB/oct rolloff). Ocular artifacts were corrected using the method developed by Gratton, Coles and Donchin (1983). EEG data were segmented into Recall or Analyze trials beginning 500ms before the stimulus (the memory cue for Recall trials or the word "Analyze" for Analyze trials) and continuing for 15s following the stimulus. Only the first five seconds were subsequently entered into data analysis, given ambiguity about the meaning of modulations of the LPP after 5 seconds (Hajcak, Dunning & Foti, 2009). To maximize the number of trials included for ERP analysis, data were averaged across all five memory types. Physiologic artifacts were detected using a

computer-based algorithm such that trials in which the following criteria were met were rejected: a voltage step exceeding 50 μV between contiguous sampling points, a voltage difference of more than 300 μV within a trial or a maximum voltage difference less than 0.5 μV within a trial. ERPs were time-locked to the memory cue or the word “Analyze”.

Data Analysis

For all analyses, ERPs were referenced to a -500ms to 0ms baseline correction time window. Additionally, all ERP analyses included fronto-central and parietal electrode locations given involvement of cognitive control regions and emotion perception regions, respectively, in reflecting on emotional experiences (Hajcak, Weinberg, MacNamara, & Foti, 2012). The fronto-central locations included were FCz, FC1, and FC2, whereas the parietal locations were Pz, P1, and P2. Averaged activity across the 3 sites for each scalp location – fronto-central vs. parietal – were used in subsequent analyses. ERPs were time-locked to (1) the presentation of the memory cue, heretofore referred to as the “Recall” phase, (2), the button-press indicating the memory had been brought to mind, i.e., the “Response”, and (3) presentation of the word “Analyze”, i.e., the “Analyze” phase.

The LPP is a broad and sustained waveform; thus, ERPs were calculated in several different time windows to characterize the time course of effects, as per convention (Cuthbert et al., 2000; Moser et al., 2009). First, maximal LPP activity was identified as occurring between 400 and 700 as well as 700 to 1000s ms. Activity in these time windows was separately submitted to a 2 (Site: FCz pool vs. Pz pool) X 2 (Instruction: “Recall” vs. “Analyze”) repeated measures analysis of covariance (rANCOVA) with social anxiety symptoms entered as a covariate. Next, activity in the 1 – 5 s time window was analyzed in 1-s bins to index sustained LPP processes using a 4 (Time: 1-2 vs. 2-3 vs. 3-4 vs. 4-5) X 2 (Site: FCz pool vs. Pz pool) X 2

(Instruction: “Recall” vs. “Analyze”) rANCOVA with social anxiety symptoms entered as a covariate.

To test the primary hypotheses, individual differences correlational analyses were conducted to follow-up interactions from the ANCOVA analyses, in order to investigate the associations between the SPIN and ERP correlates of recall, response, and analyze processes. ERPs from the recall and analyze phases, as well as a difference score created by subtracting the recall from the analyze phase, were submitted to bivariate correlation analyses with social anxiety measures. It is helpful to first illustrate the concept of difference waves and difference scores before interpreting main and interaction effects. If ERPs time-locked to the “recall” and “analyze” instructions were considered in isolation, each wave would include processing specific to recalling and analyzing memories, respectively, in addition to all the nonspecific activity that is present during these conditions. By subtracting the recall condition from the analyze condition, the underlying source waveforms that are identical in the two conditions are eliminated, making it possible to isolate the components that differ, leaving only the topography of analyze-specific brain activity (Luck, 2014). In other words, the analyze minus recall difference wave is uncontaminated by the nonspecific activity that the two conditions share. Note that it is also possible to test for the effects of the “analyze” instruction by statistically controlling for the effects of the recall condition; however, the use of a difference score is a conceptually more accurate approach given neural activity can be measured directly. That is, controlling for variables is more appropriate when constructs are being measured indirectly. In contrast, neural activity can be considered more of a “true score”, and subtracting one observed true score from another is not susceptible to error.

Results

400-1000ms time window

During the 400-700ms time window, results revealed main effects of both site, $F(1,24) = 14.03, p = .001, \eta_p^2 = .37$, and instruction, $F(1,24) = 15.76, p = .001, \eta_p^2 = .40$, indicating greater positivity at (1) parietal sites ($M = 1.72, SE = .83$) compared to fronto-central sites ($M = -1.66, SE = .80$) and (2) during the recall instruction ($M = 3.27, SE = .77$) compared to the analyze instruction ($M = -3.21, SE = 1.15$), respectively. This was expected, given 1) earlier time windows of the LPP are associated with bottom-up emotional experiences and thus involvement of parietal brain regions, and 2) emotionality should “cool down” during the analysis of emotions surrounding a memory compared to the initial recall of an emotional memory. Results also indicated a significant two-way interaction between site and instruction, $F(1,24) = 5.03, p = .03, \eta_p^2 = .17$. Follow-up analysis indicated a larger LPP amplitude at parietal compared to fronto-central locations for both recall ($t(25) = -5.49, p < .001$) and analyze ($t(25) = -2.14, p = .04$) instructions; however, this parietal distribution was more pronounced for recall compared to analyze instructions ($t(25) = -2.29, p = .03$), indicating that while recalling and analyzing emotional memories are both emotional experiences involving emotional regions of the brain, there was a “cooling” effect in parietal brain regions during the analyze compared to the recall instruction.

Important to the primary aims of the study, results indicated a two-way interaction between instruction and social anxiety symptoms, $F(1,24) = 4.66, p = .04, \eta_p^2 = .16$. Correlational analyses indicated that increased LPP amplitude averaged across fronto-central and parietal sites in the 400-700 ms time window was associated with higher symptoms of social anxiety during the analyze phase ($r = .47, p = .02$), but not the recall phase ($r = .10, p = .63$) of

memory processing. Further, higher social anxiety symptoms were associated with a smaller analyze minus recall LPP difference wave ($r = .40, p = .04$). Thus, social anxiety symptoms were associated with a reduced difference between LPP activity on recall compared to analyze phases, indicating a lack of the expected “cooling down” effect from the recall to analyze phase in these individuals.

During the 700-1000ms time window, results again indicated a main effect of instruction, $F(1,24) = 7.94, p = .01, \eta_p^2 = .25$, indicating greater positivity during the recall instruction ($M = 2.95, SE = 1.23$) compared to the analyze instruction ($M = -4.75, SE = 1.17$). However, no other main or interaction effects emerged during this time window ($F_s < 2.33, p_s > .14$).

1-5s time window

Results in this time window revealed a main effect of instruction, $F(1,24) = 6.95, p = .01, \eta_p^2 = .23$, indicating greater positivity during the recall instruction ($M = .70, SE = 1.31$) compared to the analyze instruction ($M = -4.80, SE = 1.49$) across the full time window, as was the case during the 400-1000ms time window. No other main or interaction effects emerged ($F_s < 2.69, p_s > .39$). However, visual inspection of the waveforms highlights key differences, albeit not statistically significant differences, in the time course of effects across site. At the FCz pool (Figure 1), the waveform after the “analyze” instruction indicates sustained relative negativity compared to the “recall” instruction. Such sustained activity is indicative of a sustained underlying mental process (Luck, 2014). At the Pz pool (Figure 2), the waveform for the “analyze” instruction appears to trail toward baseline across time, indicating no sustained underlying mental process. In combination, this is further evidence that the “analyze” instruction appears to be a top-down, fronto-centrally distributed process as opposed to a bottom-up, parietally distributed process, as predicted. However, there was no statistically significant main

effect of site during this time window.

Consistent with the analyses of the LPP in the 400-700 ms time window, results suggested a two-way interaction between instruction and social anxiety symptoms; however, it failed to reach conventional levels of significance, $F(1,24) = 2.69, p = .11, \eta_p^2 = .10$. Because this was the primary aim of the study and the effect size was in the moderate range, I further investigated my hypothesis. Correlational analyses indicated that ERP amplitude averaged across fronto-central and parietal sites in the 1-5s time window was not significantly associated with symptoms of social anxiety during the analyze phase ($r = .29, p = .15$) nor the recall phase ($r = -.12, p = .57$) of memory processing. However, consistent with the 400-700ms time window, social anxiety symptoms were moderately, though not statistically significantly, related to a smaller analyze minus recall difference wave ($r = .32, p = .11$). No other main or interaction effects emerged ($F_s < 2.69, p_s > .39$).

Response-locked ERPs

rANCOVAs in the 400-700ms, 700-1000, and 1-5s time windows were mimicked to test whether effects were different when comparing analyze to the LPP locked to the button press, indicating memory retrieval, as opposed to the presentation of the memory cue. Aside from main effects of instruction during the 400-700ms [$F(1,24) = 7.31, p = .01, \eta_p^2 = .23$] and 700-1000ms [$F(1,24) = 8.96, p = .006, \eta_p^2 = .27$] time windows, indicating greater positivity after the button press compared the analyze instruction, no other main or interaction effects emerged ($F_s < 2.61, p_s > .12$).

Discussion

These findings offer the first neurological evidence that individuals with increased symptoms of social anxiety experience sustained emotional brain activity from recall to analysis of their feelings and thoughts surrounding negative autobiographical memories. This finding was specific to earlier time windows (i.e., 400-700ms), but the data suggested a similar trend in later time windows as well (i.e., 1-5s).

The primary aim of this study was to use the LPP to understand memory processing across dimensions of social anxiety. First, it was important to understand the modulation of the LPP across phases of memory processing before uncovering individual differences as predicted by social anxiety symptoms. Results showed that during early time windows (i.e., 400-700 ms), there was increased positivity at parietal compared to fronto-central sites, indicating greater recruitment of the emotion processing compared to executive functioning areas of the brain (Hajcak et al., 2012). However, visual inspection of the waveform suggests that the “analyze” condition was associated with a sustained relative negativity in fronto-central regions of the brain, indicating a top-down process during this phase. Further, results showed greater positivity at both parietal and fronto-central sites in the recall condition compared to the analyze condition during both the 400-700ms and 700-1000ms time windows, suggesting increased emotional reactivity during early stages of the recall phase versus early stages of the analyze phase overall. Finally, a site by instruction interaction during the 400-700ms time window indicates that greater LPP amplitude at parietal sites is more pronounced after recall versus analyze instructions. However, individuals with increased symptoms of social anxiety did not experience a decreased LPP amplitude during the analyze instruction. Further, social anxiety was associated with a smaller difference between LPP amplitude from the recall to the analyze instructions, and this

difference appears to be driven by a lack of decreased amplitude during analysis of emotional memories. Results suggested similar effects during the 1-5s time window. It remained that there was greater positivity overall during the recall compared to the analyze phase of memory processing during this time window, and the data showed a trend for increased LPP amplitude during the analyze instruction in more socially anxious individuals. Although this trend was not statistically significant, moderate effect sizes suggest an increased sample size may have resulted in significant findings. These findings offer insight into the temporal dynamics of memory processing, such that recalling emotional memories is associated with early increased emotional reactivity, whereas analyzing one's feelings and thoughts surrounding such memories is associated with a less emotional experience in the early time window. Further, individuals with increased symptoms of social anxiety did not exhibit this decreased LPP amplitude during the analyze instruction when emotional reactivity is expected to decrease.

Overall, these findings offer the first neurophysiological evidence that individuals with social anxiety do not experience a decrease in LPP amplitude during early analysis of emotional memories -- when emotionality is expected to decrease -- and a similar trend emerged during later time windows. This finding may help bridge current models of social anxiety. That is, extant research suggests that individuals with social anxiety experience negative cognitive biases in their autobiographical memories, as well as hyper-reactivity to and trouble reappraising reactions to social stimuli (Krans et al., 2013; Morgan, 2010; Erwin et al, 2006; Goldin et al., 2009). It has been further outlined here that socially anxious individuals' attempts to down-regulate during analysis of emotional memories via self-distancing techniques may contribute to an increase in emotional reactivity. That is, socially anxious individuals' tendency to view social memories from an observer's perspective has been linked to biased images of the self looking

objectively anxious (Coles, Turk & Heimberg, 2002; Clark & Wells, 1995; Rapee & Heimberg, 1997). Current cognitive models of social anxiety posit that these correlates of social anxiety likely contribute to the maintenance of avoidance behaviors and thus the maintenance of the disorder (Clark, 1999; Heimberg, 2010). However, these literatures have not been combined to test whether individuals with symptoms of social anxiety indeed do not experience decreased reactivity during analysis of negative autobiographical memories. Further, current models of social anxiety have relied on behavioral and self-report indices; thus, there has been no real-time biological evidence of sustained reactivity to emotional memories in individuals with social anxiety symptoms across phases of memory processing. The findings of the current study therefore address this gap in our current understanding of memory processing across dimensions of social anxiety.

Clinical Implications

Current findings suggest individual differences in autobiographical memory processing across the spectrum of social anxiety, such that socially anxious individuals experience a paradoxically more emotional analysis of feelings and thoughts surrounding past negative memories. It has also been outlined throughout that socially anxious individuals tend to avoid confronting their own negative affect as well as experience hyper-reactivity when asked to do so (Clark, 1999; Heimberg, 2010; Erwin et al., 2006), and findings from the current study offer further evidence to the latter. Cognitive therapies for social anxiety require patients confront their past negative experiences in order to reconstruct initial interpretations (Heimberg, 2002; Wells, 2004). Theoretically, restructuring biased cognitions surrounding social experiences allows socially anxious individuals to accept a new, less biased meaning of the event, which should in turn decrease anticipatory anxiety before future social events and decrease avoidance behaviors.

Research on the differential effectiveness of the active components (i.e., cognitive restructuring and exposure exercises) of cognitive-behavioral therapies for social anxiety is limited, but existing evidence suggests that cognitive restructuring alone generally results in more modest effect sizes compared to exposure alone or exposure combined with cognitive restructuring techniques (Federoff & Taylor, 2001; Feske & Chambless, 1995; Gould, Buckminster, Pollack, Otto, & Yap, 1997; Taylor, 1996). Thus, it remains unclear just how effective cognitive restructuring in and of itself is for reducing symptoms of social anxiety. Findings from the current study, within the context of broader models of social anxiety, suggest a need to better understand socially anxious individuals' ability to reflect on past negative experiences in a way that will allow for the active mechanisms of cognitive restructuring to unfold. This area of research in particular would benefit from future studies that investigate socially anxious individuals' reactivity to past negative experiences over time, in order to better understand whether the ability to down-regulate during analysis of these memories can improve. It is concurrently important to understand whether cognitive restructuring in and of itself is an active mechanism of change within the broader structure of cognitive-behavioral therapies for social anxiety. Otherwise, it will remain unclear whether cognitive restructuring techniques are conducive to symptom reduction in this population.

Basic Science Implications

The current study was the first to index memory processing using personally-relevant stimuli across recall and analyze instructions using the LPP. First, emergence of reliable positivity in expected time windows suggests that attention to affective internal stimuli elicits an LPP. Next, modulation of the waveform from recall to analyze instructions suggests the LPP is capable of mapping changes in emotional reactivity across these phases of memory processing.

Thus, future studies could adopt the behavioral paradigm used in the current study to 1) capture LPP activity elicited by personally relevant, internal stimuli and/or 2) map differences in LPP activity across phases of emotional memory processing.

Limitations and Future Directions

First, it is important to note that we did not assess diagnostic criteria in this study, and thus, findings should not be linked with a diagnosis of social anxiety disorder per se. Further research on the neural underpinnings of emotional memory processing in individuals diagnosed with social anxiety disorder or other related anxiety disorders will thus be necessary to corroborate these findings.

Second, as outlined by Luck (2014), interpretations of the functional significance of ERPs should be made with caution. In particular, broad and long-lasting ERPs like the LPP likely arise from several underlying neural signals and thus a number of psychological processes. In turn, it cannot be assumed there is a 1-to-1 correspondence of modulations in ERP signatures and their proposed underlying processes. However, a great deal of evidence has been outlined here for sound interpretation of modulations in the LPP, and thus, I believe the conclusions made here are justified. Nonetheless, future research should continue to investigate alternative explanations for modulations in the LPP across phases of emotional memory processing among individuals with and without social anxiety and other related disorders.

Third, the current study did not incorporate a control memory condition into its design. Thus, it was not possible to compare negative memories to positive or non-emotional memories. In turn, it remains unclear whether individuals across dimensions of social anxiety can be differentiated by neural markers of emotional reactivity while recalling and analyzing positive or neutral memories. Therefore, future studies adopting this behavioral paradigm should build on

these findings to incorporate control conditions into their design.

Next, while many of the memory prompts used in this study involved social interactions that would likely be anxiety-inducing for socially anxious individuals, future studies could continue to investigate prompts even more specific to social anxiety. For example, prompts could elicit memories of feeling anxious while speaking in front of others to assess whether memories more specific to the symptoms of social anxiety would modulate the effects.

Also, the current study used neurophysiological measures as evidence for emotional reactivity. Future studies could incorporate multi-modal analysis of emotional experiences, such as “feeling dials” - where participants track the valence and arousal of their emotions over time - or electromyographic (EMG) indices of emotional valence, to better understand emotionality over time across the spectrum of social anxiety during these phases of memory processing.

Finally, in order to maintain fidelity to the ecological nature of the memory retrieval process, the “analyze” phase was always preceded by the “recall” phase in the current study’s design. Thus, it was not possible to test for order effects on the modulation of the ERPs from the recall to the analyze phase of memory processing.

Conclusion

The current findings provide novel insights into the nuances of the neural underpinnings of autobiographical memory processing across dimensions of social anxiety. They also highlight how reactivity to emotional memories evolves over time and suggest that a lack of the expected decrease in the LPP during analysis of emotional memories may be linked to increased social anxiety. That is, individuals with social anxiety seem to have difficulty down-regulating their emotions during analysis of emotional memories, which may contribute to the maintenance of their anxiety.

APPENDIX

Table 1. Means and Standard Deviations of ERP amplitudes (μV).

	<u>Recall</u>		<u>Analyze</u>	
	<u>FCz Pool</u>	<u>Pz Pool</u>	<u>FCz Pool</u>	<u>Pz Pool</u>
400-700ms	.82(4.42)	5.72(4.54)	-4.13 (5.84)	-2.28(7.79)
700-1000ms	1.90(6.71)	4.00(6.71)	-4.88(6.27)	-4.61(7.34)
1-2s	.83(6.67)	1.58(5.78)	-5.91(7.45)	-5.84(9.07)
2-3s	.88(7.50)	.23(7.79)	-5.12(8.43)	-4.62(9.99)
3-4s	1.68(8.16)	-3.20(10.24)	-5.44(7.86)	.09(8.55)
4-5s	.98(7.71)	-.68(8.22)	-5.18(7.29)	-.68(8.22)

Note. FCz pool and Pz pool created by averaging FCz, FC1, FC2, and Pz, P1, P2, respectively.

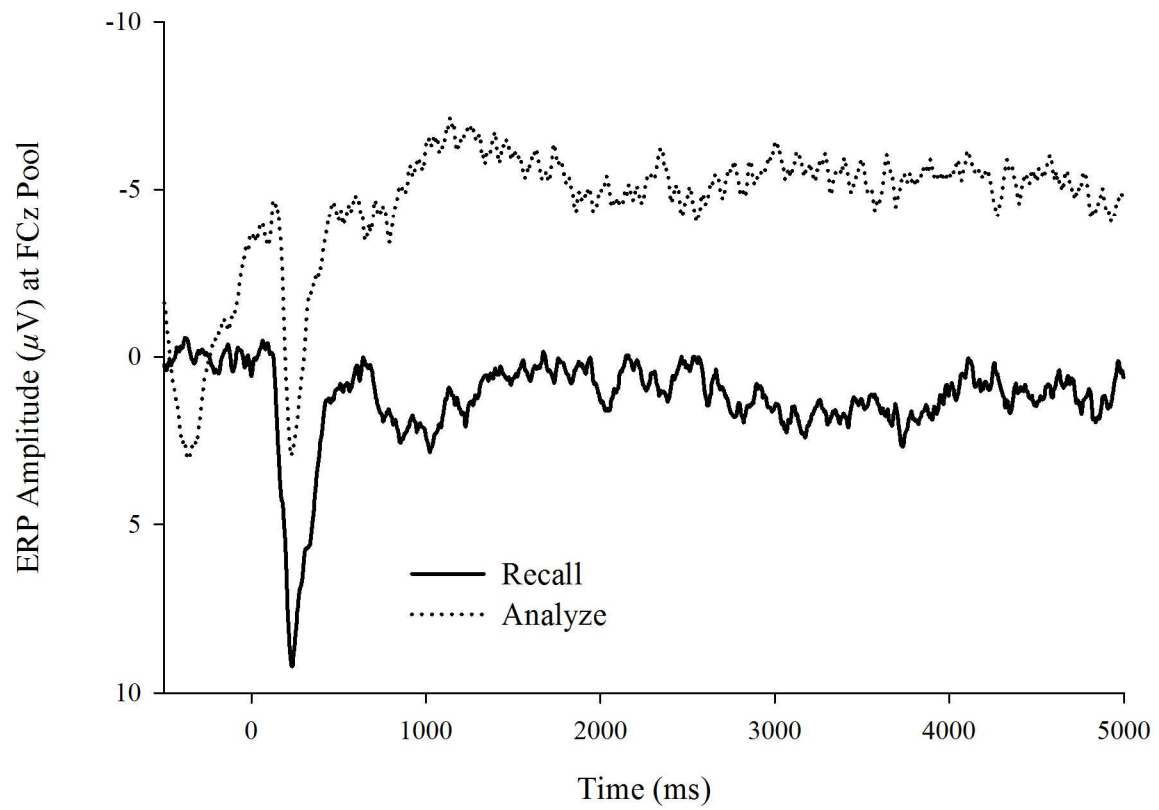


Figure 1. ERP waveforms time-locked to the “Recall” and “Analyze” instructions, averaged across sites FCz, FC1, and FC2.

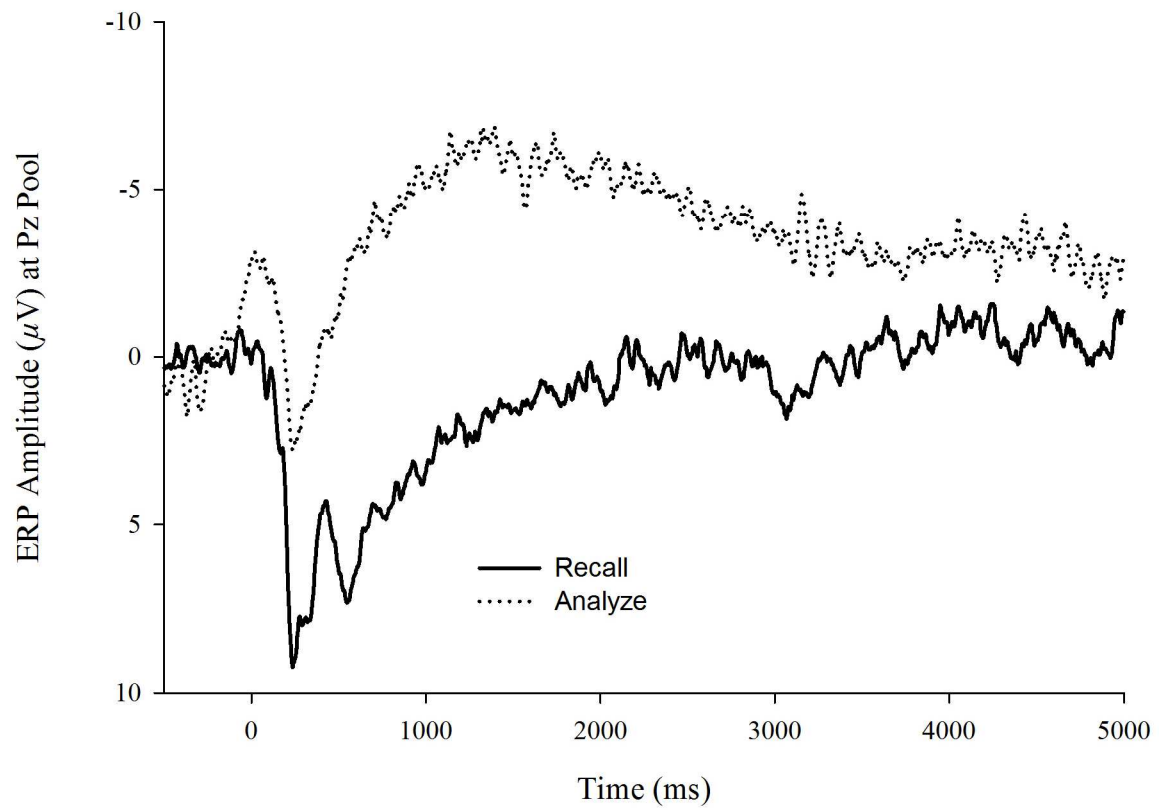


Figure 2. ERP waveforms time-locked to the “Recall” and “Analyze” instructions, averaged across sites Pz, P1, and P2.

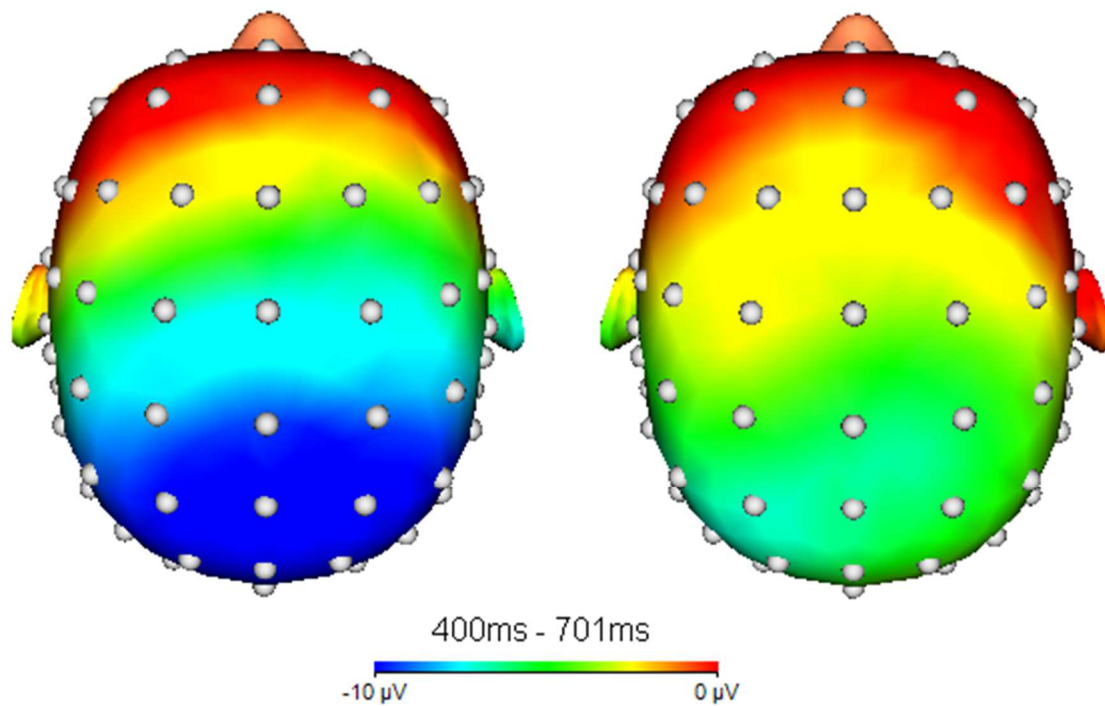


Figure 3. Topographical head maps illustrating Analyze minus Recall brain activity during the 400ms-700ms time window in low (left) and high (right) socially anxious participants. Whereas low socially anxious individuals exhibit decreased positivity in parietal regions during the “analyze” compared to the “recall” instruction, high socially anxious individuals do not, indicating a lack of the expected “cooling down” effect during this time window.

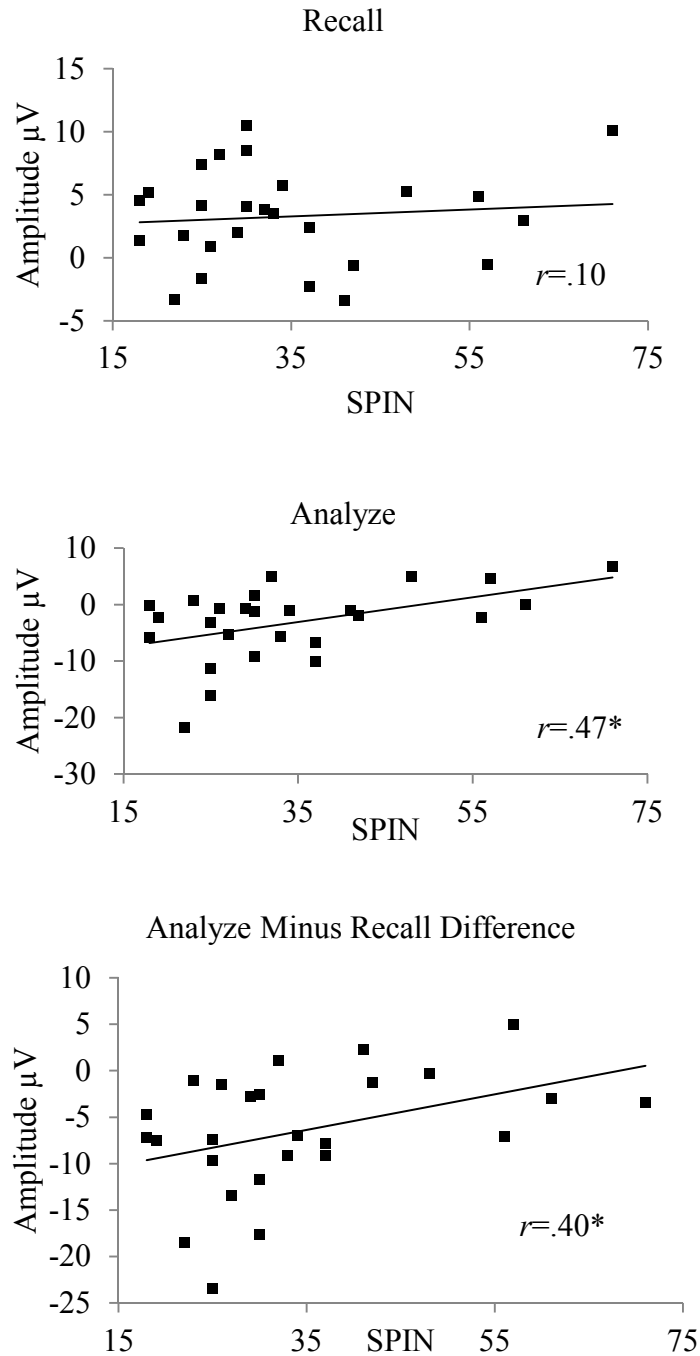


Figure 4. Scatter plots illustrating the relationship between social anxiety symptoms and ERP amplitude during the “recall” (top) and “analyze” (middle) instructions, as well as the difference between the two (bottom), during the 400-700ms time window. Higher social anxiety symptoms are associated with a smaller difference in amplitude across instructions, and this is driven by a lack of decreased positivity during “analyze”. (* = Significant at the .05 level.)

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