Context and Domain Matter: The Error-Related Negativity in Peer Presence Predicts Fear of Negative Evaluation, not Global Social Anxiety, in Adolescents

Yanbin Niu[1], Zixuan Li[1], Jeremy W. Pettit[2], George A. Buzzell[2*], and Jingjing Zhao[1*]

**These authors contributed equally to this manuscript (co-corresponding/senior authors)*

[1]School of Psychology, Shaanxi Normal University, and Shaanxi Provincial Key Research Center of Child Mental and Behavioral Health, Xi'an, Shaanxi, China

[2]Florida International University and the Center for Children and Families, Miami, FL, USA

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Abstract

Background: Social anxiety symptoms are most likely to emerge during adolescence, a developmental window marked by heightened concern over peer evaluation. However, the neurocognitive mechanism(s) underlying adolescent social anxiety remain unclear. Emerging work points to the error-related negativity (ERN/ΔERN) as a potential neural marker of exaggerated self/error-monitoring in social anxiety, particularly for errors committed in front of peers. However, social anxiety symptoms are marked by heterogeneity and it remains unclear exactly what domain(s) of social anxiety symptoms are associated with ERN/ΔERN variation in peer presence, particularly within the adolescent period. **Methods:** To advance and deepen the mechanistic understanding of the ERN/ΔERN's putative role as a neural marker for social anxiety in adolescence, we leveraged a social manipulation procedure and assessed a developmentally-salient domain of social anxiety during adolescence—Fear of Negative Evaluation (FNE). Adolescents residing in Hanzhong, a small city in the southwestern region of mainland China, had EEG recorded while performing a flanker task, twice (peer presence/absence); FNE, as well as global social anxiety symptoms were assessed. **Results:** Overall ERN increases in peer presence. FNE specifically, but not global levels of social anxiety symptoms, predicted ΔERN in peer presence. **Conclusions:** These data are the first demonstration that the ΔERN relates to a specific domain of social anxiety in adolescents, as well as the first evidence of such relations within a non-WEIRD (Western, Educated, Industrialized, Rich and Democratic) sample. Results have important implications for theory and research into adolescent social anxiety.

Keywords: error-related negativity, ERN, social observation, fear of negative evaluation, FNE, adolescence

Social anxiety refers to an intense fear of social situations or social scrutiny (Morrison & Heimberg, 2013; Rapee & Heimberg, 1997), with symptoms most likely to emerge during adolescence (Kessler et al., 2005), a developmental window marked by increased social motivation and heightened concern over peer evaluation (Crone & Dahl, 2012; Dahl, 2004; Parker, Rubin, Erath, Wojslawowicz, & Buskirk, 2006; Steinberg & Morris, 2001). Cognitive models suggest that social anxiety involves negative biases in cognitive processing and greater self-monitoring within social settings, among other cognitive processes (Clark & Wells, 1995; Rapee & Heimberg, 1997). To extend cognitive models and advance a mechanistic understanding of social anxiety, it is important to identify neurocognitive processes linked to social anxiety symptoms in adolescence. In the current study, we focus on the error-related negativity (ERN/ΔERN) as a theoretically-relevant neurocognitive process.

Prior work demonstrates that the ERN/ΔERN, an event-related potential (ERP) elicited by errors of commission (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Goss, Coles, Meyer, & Donchin, 1993), can serve as a neural marker of exaggerated error monitoring (self-monitoring) in individuals with general anxiety (Hajcak, Klawohn, & Meyer, 2019; Meyer, 2022; Moser, Moran, Schroder, Donnellan, & Yeung, 2013; Olvet & Hajcak, 2008) and social anxiety (Endrass, Riesel, Kathmann, & Buhlmann, 2014; Kujawa et al., 2016; Meyer, Carlton, Crisler, & Kallen, 2018). Emerging work investigates associations between social anxiety and ERN/ΔERN specifically when errors are committed in social (vs. nonsocial) settings (Barker, Troller-Renfree, Pine, & Fox, 2015, 2015; Buzzell et al., 2017b; Voegler et al., 2018). However, only one study has investigated these relations during adolescence (Buzzell, Troller-Renfree, et al., 2017), and none within a non-WEIRD (Western, Educated, Industrialized, Rich and Democratic) (Henrich, Heine, & Norenzayan, 2010) population. Moreover, prior work has been

limited to global measures of social anxiety symptoms, and yet, social anxiety symptomology is marked by considerable heterogeneity and includes subdomains of fear of negative evaluation, social inhibition/avoidance, feelings of distress within social situations, and less confidence regarding social relationships (Hofmann, Heinrichs, & Moscovitch, 2004; Spokas & Cardaciotto, 2014; Yu, Zhou, Wang, & Tang, 2020). Work is needed to understand whether/how error monitoring (ERN/ΔERN) in social settings relates to subdomains of social anxiety symptoms, particularly within diverse, adolescent samples.

While considering the heterogeneity of social anxiety symptoms, it is noteworthy that adolescence is marked by increased social motivation, increased salience of peer relations (Brown & Larson, 2009), and heightened concern over peer evaluation (Parker et al., 2006; Steinberg & Morris, 2001). Thus, we focus here on a theoretically-relevant and developmentally-salient domain of social anxiety in adolescents, Fear of Negative Evaluation (FNE)—which refers to apprehension and distress arising from concerns about being judged negatively by others. FNE not only exhibits a normative peak during adolescence, but this construct is also proposed to reflect a hallmark symptom of social anxiety in cognitive models (Brown & Larson, 2009; Crone & Dahl, 2012; Dahl, 2004; Gerada, 2020; Nelemans et al., 2019; Parker et al., 2006; Steinberg & Morris, 2001; Westenberg et al., 2007). Cognitive models propose a "vicious cycle" in which negatively-biased cognitive processing—such as FNE—leads to greater self-focus and self-monitoring within social settings, further exacerbating FNE (Clark & Wells, 1995; Rapee & Heimberg, 1997). As such, FNE may be a theoretically-relevant and developmentally-salient domain of social anxiety in adolescents that can be leveraged to delineate the precise link between the ERN/ΔERN—elicited within social settings—and social anxiety. Indeed, neural responses associated with anticipated social feedback are correlated with FNE (Topel et al.,

2021; Van der Molen et al., 2014), although prior work has not directly assessed the link between FNE and the ERN/ΔERN in social settings.

The primary goal of the current study was to extend neurocognitive understandings of social anxiety in adolescence, as the first study to examine relations among the FNE subdomain of social anxiety symptoms and the ERN/ΔERN in peer presence. A secondary goal was to respond to calls for the psychological and neural sciences to expand inquiry beyond exclusively WEIRD samples (Henrich et al., 2010), as this is also the first study to examine such relations within a non-WEIRD sample. Factors related to social anxiety may vary by culture and exhibit differences in prevalence and/or expression (Hofmann, Asnaani, & Hinton, 2010), in line with a lower reported prevalence rate of SAD among East Asian (e.g., Japanese, Korean, and Chinese) compared with US (Cho et al., 2007; Kawakami et al., 2005; Kessler et al., 1994; Shen et al., 2006) samples. In the current study, a sample of adolescents (ages 15.68 – 17.91 yrs.) residing in mainland China were assessed for social anxiety symptoms. EEG was recorded while performing a modified flanker task, twice, once while observed by a peer, and once while alone. Our hypotheses were twofold: 1) Given normative increases in peer importance during adolescence, participants would exhibit an overall increase in ERN/ΔERN magnitude in peer presence; 2) Higher FNE, but not global levels of social anxiety symptoms, would predict ERN/ΔERN magnitudes in peer presence.

Method

2.1. Participants and procedure

All participants in this study were recruited from grade 10 at Nanzheng High School, Hanzhong, mainland China. Exclusion criteria were 1) uncorrected visual impairments, 2) a history of head injury with loss of consciousness, and 3) neurological and developmental

disorders. All parents and children provided written informed consent/assent, and the research procedures were approved by the Shaanxi Normal University Human Research Ethics Board.

The current sample consisted of 30 adolescents (14 male, 16 female; mean age = 16.98 years, SD = 0.45, range: 15.68 – 17.91). One participant was excluded as the result of feeling unwell on the day of the assessment; two participants due to technical errors in data collection. In line with prior work (Pontifex et al., 2010; Steele et al., 2016), participants with less than 6 error trials were removed from further analysis (two participants from the social condition and one from the nonsocial condition). The final sample consisted of 27 participants (13 male, 14 female) included in behavioral analyses, 25 (11 male, 14 female) in EEG analyses of the nonsocial condition, and 24 (11 male, 13 female) in EEG analyses of the social condition.

Families that agreed to participate were invited to the lab. Upon arrival at the lab site, parents and children were provided parental consent and child assent. Then parents were brought to another room to complete a demographic survey and children were asked to complete a modified flanker task (Eriksen & Eriksen, 1974) twice, once while they were being observed by a gender-matched peer who was actually the confederate (the social condition), and once while not being observed (the nonsocial condition). The order of the social and nonsocial conditions was counterbalanced across participants.

In the social condition, the child was informed that there was another participant who would conduct the experiment next to them and wanted to observe their performance to learn more about the task. The ages of the female and male confederates were 16.7 and 18.3 years old, respectively. During the social condition, the confederate was brought to the experiment room and introduced to the participant. To increase the ecological validity of the manipulation of social context and create a typical anxiety-provoking social situation, both confederates were

trained to greet participants and make eye contact, but not to initiate any further oral communications, and only provide the simplest answers (i.e., yes, no, etc.) while being asked questions by participants. At the end of each block, the confederate read aloud the text feedback presented on the screen without any further comment.

In both conditions, steps were taken to minimize possible social observation effects of the experimenter being in the room while participants completed the flanker task, consistent with prior work (Barker et al., 2015; Voegler et al., 2018). The experimenter informed the participant that they would not observe their performance and was only there in case of unexpected technical problems. The experimenter then sat four meters away from the participant and pretended to read a book while the participant completed the flanker task.

2.2. Task, EEG Acquisition, and Preprocessing

Flanker Task—A modified version of the flanker task (Eriksen & Eriksen, 1974) was administered using e-prime software (Psychology Software Tools, Inc., Sharpsburg, PA). There were 8 blocks of 40 trials with a total of 320 trials. The target stimulus was a central arrowhead that pointed to the left or right and was flanked by four additional arrowheads (two on either side of the central arrowhead). Within each block, 50% of trials (20) consisted of target/flanker arrowheads pointing in the same direction (congruent) and 50% trials (20) consisted of arrowheads pointing in the opposite direction (incongruent); congruent and incongruent trials were presented in random order within each block. Arrowheads were presented in Lucida Console, size 240 font. All stimuli were presented for 200 ms followed by a 500 ms response window which ended upon the response. The response–stimulus interval jittered between 1000 to 1300 ms following the response or after 700 ms from stimulus onset. Figure 1 shows examples of stimulus sequences.

Insert Figure 1 Here.

To ensure an adequate number of error trials for response-locked EEG analyses, block-level text-based feedback was provided at the end of each trial block contingent on the participant's accuracy performance (Gehring, Liu, Orr, & Carp, 2012). If the accuracy for that block was below 75%, a message of "Please improve your accuracy!" was presented; If the accuracy was above 90%, a message of "Please respond a bit faster" was presented; if the accuracy was in-between 75% and 90%, a message of "Good job!" was presented. Block-level feedback was presented onscreen the same way within both the nonsocial and social conditions, however, the feedback text was additionally read aloud by the confederate in the social condition.

EEG Acquisition—EEG data sampled at 500 Hz were acquired using a BrainVision 64 Channel ActiCHamp EEG system and recorded in a 64-channel workspace of the BrainVision Recorder software. Before data collection, impedances were reduced to below 30 kΩ; data were online-referenced to the Cz electrode.

EEG Preprocessing—EEG data were preprocessed in MATLAB (Mathworks, Natick, MA) using the Maryland Analysis of Developmental EEG (MADE) Pipeline (Debnath et al., 2020). A detailed description of the preprocessing steps employed can be found in the original MADE publication (Debnath et al., 2020). Briefly, MADE consists of a set of MATLAB scripts and EEGLAB (Delorme & Makeig, 2004) functions/plugins, including FASTER (Nolan, Whelan, & Reilly, 2010) and Adjusted-ADJUST (Leach et al., 2020); MADE performs standard EEG preprocessing steps, including artifact removal via Independent component analysis (ICA) for artifact removal (Winkler, Debener, Müller, & Tangermann, 2015).

Following preprocessing via MADE, EEG data were epoched into 3000 ms segments starting 1000 ms before the response and baseline-corrected to the -400 to -200 ms window. Epochs that exceeded voltages ±100 μV, if the epochs were recorded from ocular channels (Fp1, Fp2, AF7, and AF8), they were further removed, and if the epochs were recorded from non-ocular channels, they were interpolated at the epoch level. All removed channels were interpolated using the spherical spline interpolation and then the data were referenced to the average of all electrodes. Epochs associated with anticipatory responses (RTs < 200 ms) were removed. The mean numbers of clean incongruent trial epochs were: 107 nonsocial-correct, 28 nonsocial-error, 109 social-correct, and 30 social-error, respectively.

2.3. Measures

Global Social Anxiety Symptom Severity—Self-reports of global social anxiety symptoms were assessed via the Social Phobia subscale of a Chinese translation of Screen for Child Anxiety Related Emotional Disorders (SCARED) (Birmaher et al., 1999; Su, Wang, Fan, Su, & Gao, 2008). The Social Phobia subscale consists of seven items (e.g., “It is hard for me to talk with people I don’t know well”) assessing global social anxiety symptom severity. Higher scores indicate higher levels of social anxiety symptom severity. Prior work on the SCARED Social Phobia subscale demonstrates moderate to high internal consistency and test-retest reliability, and good discriminant validity within a Chinese population (Su et al., 2008). The internal consistency of the Social Phobia subscale in the current sample was $\alpha = 0.85$.

Fear of Negative Evaluation by Peers—Self-reports of Fear of Negative Evaluation (FNE) were assessed via the FNE subscale of a Chinese translation of the Social Anxiety Scale for Adolescents (SAS–A) (A. La Greca, 1998). The FNE subscale consists of eight items (e.g., "I worry about what other kids think of me") assessing adolescents’ subjective experiences of fears,

concerns, or worries regarding peers' negative evaluations. Higher scores indicate higher levels of FNE. The Chinese version of the SAS has demonstrated appropriate internal consistency, test-retest reliability, and construct validity (Zhou, Xu, Inglés, Hidalgo, & La Greca, 2008). The internal consistency of the SAS–FNE subscale in the current sample was $\alpha = 0.94$.

ERPs—Only incongruent trials were included and analyzed (incongruent error trials for ERN, and incongruent correct trials for CRN) in order to isolate error-related effects and avoid stimulus-related confounds (errors are more common on incongruent trials in the flanker task). First, to obtain the CRN and ERN, the mean amplitudes from 0 to 100 ms following correct and incorrect responses were computed respectively at the frontocentral electrode (FCz), where error-related brain activity was maximally negative (Meyer, Mehra, & Hajcak, 2021). To isolate error-specific effects, ΔERN was computed by subtracting the CRN from the ERN.

Flanker Task Behavior—Mean accuracy (ACC) and response time (RT) in each condition (nonsocial and social conditions) were calculated. Participants were required to have greater than 70% accuracy to be included in further behavioral and EEG analyses (all participants met this criterion, mean ACC = 87.23% for the nonsocial condition, and mean ACC = 87.04% for the social condition).

2.4. Analytic Plan

To examine differences in behavioral performance (accuracy and reaction time) between conditions, a two-way repeated measures analysis of variance (ANOVA) model was tested for accuracy with condition (nonsocial, social) and congruency (congruent, incongruent) as within-subjects factors, and a three-way repeated measures ANOVA model was tested for reaction time (RT) with condition (nonsocial, social), response (correct, error) and congruency (congruent, incongruent) as within-subjects factors. Similarly, separate 2 (condition) x 2 (response) repeated

measures ANOVAs were conducted for the ERN/CRN. Having found that there existed a response-by-condition interaction for the ERN, we then explored the associations between ΔERN and self-report questionnaires (global social anxiety and FNE) for the nonsocial and social conditions, respectively.

Results

3.1. Self-report Questionnaires

The mean SCARED social anxiety score was 7.52 (SD = 3.50), and the mean FNE score was 21.11 (SD = 8.74). FNE was significantly correlated with SCARED social anxiety ($r = .592$, $p < .001$).

3.2. Behavioral Results

The mean (± standard deviation [SD]) accuracies in the nonsocial and social conditions were 87.23 ± 4.34% and 87.04 ± 4.61%, respectively (see Table 1). Analysis of accuracy revealed a main effect of congruency, with participants responding less accurately in incongruent trials (F [1, 26] = 127.78, $p < .001$, partial $\eta^2 = .831$). The main effect of social condition (F [1, 26] = 0.07, $p = .80$, partial $\eta^2 = .003$) and interaction effect between the congruency and the social condition (F [1, 26] = 1.76, $p = .20$, partial $\eta^2 = .063$) were not significant.

The mean RTs of the nonsocial and social conditions were 343.15 ± 36.36 ms and 343.02 ± 34.49 ms, respectively. In the following statistical analyses, all RT was log-transformed to address positive skew (Luce, 1986). Analysis of RT showed a main effect of response, with participants responding faster in error trials (F [1, 25] = 467.92, $p < .001$, partial $\eta^2 = .949$), and a main effect of congruency, with participants responding faster in congruent trials (F [1, 25] = 149.47, $p < .001$, partial $\eta^2 = .867$). Moreover, there was a response-by-congruency interaction effect (F [1, 25] = 11.92, $p = .002$, partial $\eta^2 = .323$). Follow up analyses exploring the nature of

this interaction showed that: within congruent trials, participants responded slower in correct responses (t(25) = -13.12, $p < .001$, Cohen's d = 2.57); within incongruent trials, participants responded slower in correct responses (t(26) = -26.884, $p < .001$, Cohen's d = 5.17). No significant main effect of social condition or other interaction effects were identified (all *p*s > .58). No correlations between behavioral data (accuracy and RT) and self-report questionnaires were statistically significant (all *p*s > .26).

Insert Table 1 Here.

3.3. ERP Results

The descriptive statistics for CRN, ERN, and ΔERN in nonsocial and social conditions respectively are shown in Table 1. Figure 2 displays the ERP waveforms and scalp topography for the nonsocial and social conditions across the participants at the FCz electrode (where the ERN was maximal).

Insert Figure 2 Here.

ERN/CRN—The ANOVA investigating ERN/CRN revealed a main effect of response (F [1, 22] = 54.48, $p < .001$, partial $\eta^2 = .712$), with the ERN being more negative than the CRN. There was no significant main effect of social condition (F [1, 22] = 1.06, $p = .32$, partial $\eta^2 = .046$). However, there was a significant response-by-condition interaction (F [1, 22] = 6.77, $p = .016$, partial $\eta^2 = .235$). Follow-up analysis for the interaction effect revealed that the ERN showed a trend of larger (more negative) amplitude under the social condition (M = -5.45, SD = 3.38) compared to the nonsocial condition (M = -4.19, SD = 3.18), t(22) = 1.83, $p = .08$,

Cohens'd = .381, whereas the CRN did not differ between the nonsocial and social conditions (t(22) = - 0.20, *p* = .85, Cohens'd = .041).

To further explore this response-by-condition interaction, two separate Pearson correlations between ΔERN and self-report questionnaires were conducted for the social and nonsocial conditions, respectively. In the social condition, FNE was significantly correlated with ΔERN (*r* = -.452, *p* = .027, See Figure 3A) whereas global social anxiety was not (*r* = -.164, *p* = .444). In the nonsocial condition, neither FNE (*r* = -.222, *p* = .287) nor global social anxiety (*r* = .007, *p* = .975) were correlated with ΔERN. While all statistical analyses were performed using continuous measures, for plotting purposes only, participants were grouped into high and low FNE groups based on the median value (FNE median score = 20). Figure 3B depicts averaged ERPs for incongruent-error trials and incongruent-correct trials within the social condition for the low and high FNE groups, respectively. As shown in Figure 3B, ΔERN (incongruent-error trials vs. incongruent-correct trials) was larger for the high FNE group compared to the low FNE group.

Insert Figure 3 Here.

To determine whether FNE predicted unique variance in ΔERN in the social condition, above and beyond global social anxiety symptoms, a hierarchical regression analysis was conducted in which global social anxiety was entered in the first step, and FNE in the second step. As depicted in Table 2, the addition of FNE within the regression model yielded a significant change in R^2 (F [1, 21] = 5.22, p = .033), demonstrating that FNE predicted unique variance in ΔERN, above and beyond global social anxiety symptoms.

Insert Table 2 Here.

Discussion

Consistent with our hypotheses, we observed an overall increase in ERN/ΔERN magnitude in peer presence. Moreover, higher levels of FNE were predictive of increased ΔERN in the peer setting—above and beyond global social anxiety symptoms. Results of the current study are consistent with cognitive models of social anxiety (Clark & Wells, 1995; Rapee & Heimberg, 1997), which propose a close link between FNE and self-monitoring in social settings, providing a crucial neurocognitive extension of prior work. Moreover, these findings are consistent with the developmental theory that describes an increase in the importance of peers and normatively high levels of FNE during adolescence (Brown & Larson, 2009; Crone & Dahl, 2012; Dahl, 2004; Gerada, 2020; Nelemans et al., 2019; Parker et al., 2006; Steinberg & Morris, 2001; Westenberg et al., 2007).-These findings have implications for theory and measurement of adolescent social anxiety, and suggest promising new directions for research efforts.

Given that social anxiety is characterized by a heterogeneous set of symptoms (Inderbitzen-Nolan & Walters, 2000; A. M. La Greca & Lopez, 1998; Watson & Friend, 1969), it is reasonable to assume that no single neurocognitive marker/mechanism would capture social anxiety symptomology broadly (or at least not reliably across study samples); results of the current study are in line with this notion. Moreover, our data suggest that successful mapping of symptom domains onto neurocognitive constructs requires precision at the level of symptom assessment as well as taking into account the situational context of neural assessment and the broader developmental context. Toward these ends, the current study focused on relations

between a developmentally-salient symptom domain of social anxiety—FNE (e.g., A. M. La Greca & Lopez, 1998; Watson & Friend, 1969) and neural activity associated with error-monitoring (self-monitoring) under peer observation (e.g., Hajcak et al., 2005; Kim et al., 2005), within the context of adolescence—when FNE and the importance of peers reach peak levels (Brown & Larson, 2009; Crone & Dahl, 2012; Dahl, 2004; Gerada, 2020; Nelemans et al., 2019; Parker et al., 2006; Steinberg & Morris, 2001; Westenberg et al., 2007).

Importantly, the current study demonstrates that an increased ERN/ΔERN in social settings is specifically linked to the FNE symptom domain in adolescents. Yet, we do not suggest that the ERN/ΔERN reflects the neurocognitive basis of FNE per se. Prior work demonstrates that the ERN/ΔERN indexes a neurocognitive process underlying error-monitoring (self-monitoring) (Agam et al., 2011; Buzzell et al., 2017a; Dehaene et al., 1994; Falkenstein et al., 1991; Gehring et al., 1993; Miltner et al., 1997; Ullsperger, Fischer, Nigbur, & Endrass, 2014). Similarly, we suggest that an increased ERN/ΔERN in social settings indexes increased self-monitoring. As noted, cognitive models propose a vicious cycle whereby greater FNE leads to greater self-monitoring within social settings, which in turn further strengthens/worsens FNE (Clark & Wells, 1995; Rapee & Heimberg, 1997). Thus, we argue that the link between FNE and the ERN/ΔERN in peer presence reflects a neurocognitive extension of cognitive models of social anxiety. These models further state that social anxiety is specifically associated with increased self-monitoring for negative aspects of one's behavior (e.g., errors) as opposed to a general increase in self-monitoring (Clark & Wells, 1995; Rapee & Heimberg, 1997). Our data provide converging neural evidence to support this supposition, as peer presence and FNE predicted larger increases in the ERN (self-monitoring on error trials) relative to the CRN (self-monitoring on correct trials). As noted by cognitive models (Clark & Wells, 1995; Rapee &

Heimberg, 1997), increased self-monitoring of negative aspects of one's behavior could explain why social anxiety is maintained/worsened across repeated social encounters in daily life: social encounters are experienced through the lens of one's (neuro-) cognitive biases. A bias towards greater self-monitoring for errors in social settings may serve to confirm one's initial fears of negative evaluation, strengthening/worsening FNE.

It is worth noting that this is the first study to directly investigate relations between FNE and the ERN/ΔERN in peer presence among adolescents. Given our cross-sectional study design, it remains unknown whether the association between FNE and ERN/ΔERN remains stable across development. Emerging developmental theory on the nature of anxiety-ERN relations argues that whereas the ERN-anxiety link in childhood is primarily driven by external threats/fears, ERN-anxiety relations fundamentally change with the transition to adolescence—to self-conscious shyness and worry about behavioral competence and social evaluation (Meyer, 2017, 2022). Meyer et al. have shown that adolescent ERN-anxiety relations are primarily driven by social anxiety symptoms, as opposed to symptoms of other anxiety disorders (Meyer et al., 2018). Moreover, normative ERN increases during the transition to adolescence are mediated by (normative) increases in subclinical social anxiety symptoms (Meyer et al., 2018). Based on the results of the current study, taken together with the normative increase in FNE during the transition to adolescence (Gerada, 2020; Nelemans et al., 2019; Westenberg et al., 2007), we propose that ERN/ΔERN variation becomes more closely coupled with individual differences in FNE across adolescence. Longitudinal studies that measure ERN/ΔERN and FNE across the peri-adolescent window are needed to evaluate this proposal.

Last but not least, the current study has several implications for clinical neuroscience research and efforts to develop novel assessment approaches. Broadly, the current findings

provide additional emphasis on the importance of understanding error sensitivity (Chong & Meyer, 2019) and specifically targeting error-related processing (Meyer et al., 2020) in pediatric anxiety, particularly during adolescence. Moreover, assessment of the ERN/ΔERN in peer presence may reflect a promising neural marker, indicating the degree to which an individual exhibits greater self-monitoring in social settings. While we argue that the ERN/ΔERN underlies self-monitoring, as opposed to a direct index of FNE, cognitive models of social anxiety (Clark & Wells, 1995; Rapee & Heimberg, 1997) and converging neurocognitive evidence from the current study, establish a close association between self-monitoring in peer presence and FNE. Thus, the ERN/ΔERN could also be employed as an (indirect) neural marker of FNE levels. Going one step further, an intriguing possibility is that repeated assessments of FNE and ERN/ΔERN, at the intraindividual level, could provide the means to directly capture the "vicious cycle" proposed by cognitive models of social anxiety (Clark & Wells, 1995; Rapee & Heimberg, 1997). However, further work examining intraindividual relations among FNE and ERN/ΔERN are needed, to include dissociating trait- vs. state-based associations in these constructs. There is also a need for additional work studying these constructs via methods capable of identifying causal pathways (e.g., longitudinal designs or causal manipulation studies). Such work would provide strong evidence for whether/how FNE and the ERN/ΔERN causally influence one another, and a critical test of whether these constructs are implicated in a "vicious cycle" in which they mutually strengthen/worsen one another.

Strengths, Limitations and Future Directions

Strengths of the current study include the targeted assessment of a theoretically relevant and developmentally-salient symptom domain of social anxiety—FNE, inclusion of a non-WEIRD sample of adolescents, and at the theoretical level, providing a neurocognitive extension

of cognitive models of social anxiety. A limitation is that our sample size was relatively small, resulting in low statistical power to detect small effects. The fact that hypothesized effects were statistically significant in spite of lower statistical power provides compelling support for our theoretical model. Nonetheless, results of the current report should be interpreted in light of the small sample size, and future work is needed to replicate our findings within a larger sample. While a strength of the current study is the inclusion of a non-WEIRD sample, it remains unknown whether associations between social anxiety symptomology and the ERN/ΔERN in peer presence are stable across cultures; cross-cultural studies are needed. Lastly, when interpreting the findings, the cross-sectional design of the current study should be taken into account, since it does not allow us to draw conclusions on the causal direction of associations between FNE and ERN/ΔERN. Regardless, the current study has important implications for clinical theory and social anxiety research; it demonstrates the utility of mapping neurocognitive construct(s) onto specific symptom domain(s) of social anxiety, and highlights the importance of carefully considering precision in symptom assessment, the situational context of neural measurement, and the developmental backdrop in which such work is conducted.

Key points

- Greater self/error-monitoring within social settings, as indexed by ERN/ΔERN, has been linked to social anxiety. However it remains unclear what social anxiety symptom domain is most closely associated with ERN/ΔERN variation.
- FNE is a theoretically-relevant and developmentally-salient domain of social anxiety in adolescents; FNE exhibits a normative peak during the adolescent window.
- Results from the current study included an overall increase in ERN/ΔERN magnitude in peer presence.
- Higher FNE predicted increased ΔERN magnitudes in the peer setting—above and beyond global social anxiety symptoms.
- This Study demonstrates the utility of mapping neurocognitive construct(s) onto specific symptom domain(s) of social anxiety, and the importance of carefully considering precision in symptom assessment, the situational context of neural measurement, and the developmental backdrop in which such work is conducted.

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Correspondence

Co-corresponding/Senior Authors:

Jingjing Zhao, Ph.D.
School of Psychology, Shaanxi Normal University, 199 South Chang'an Road, Xian, Shaanxi, China 710062
Phone: +86 (029) 85303395
Email: jingjing.zhao@snnu.edu.cn

George A. Buzzell, Ph.D.
Florida International University and the Center for Children and Families, 11200 SW 8th Street, DM 256, Miami, FL, USA 33199
Phone: +1 (305) 348-2880
Email: gbuzzell@fiu.edu

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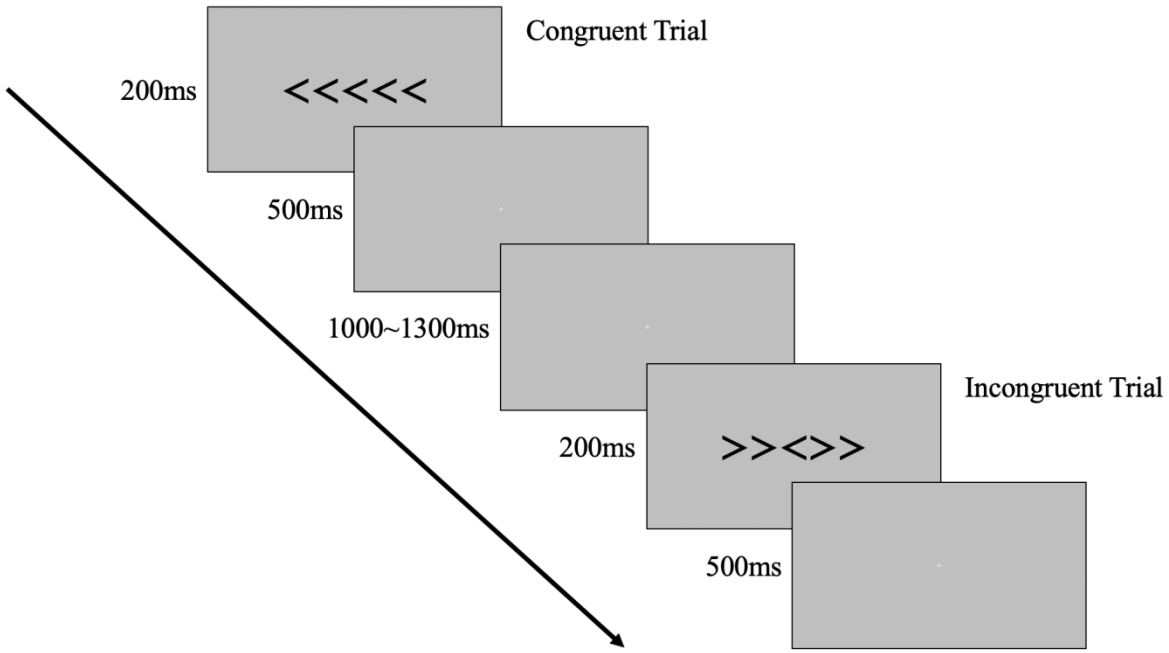
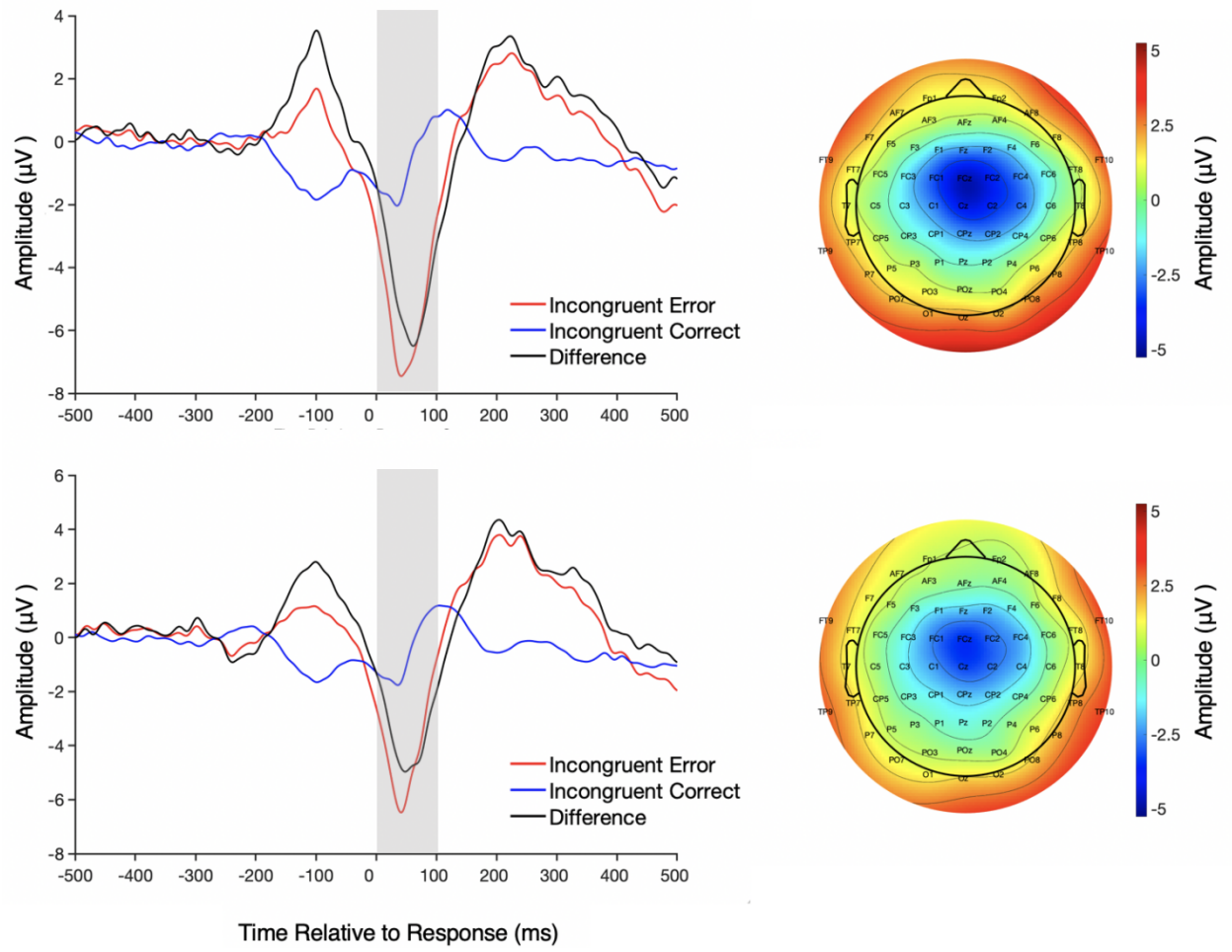
Figure 1



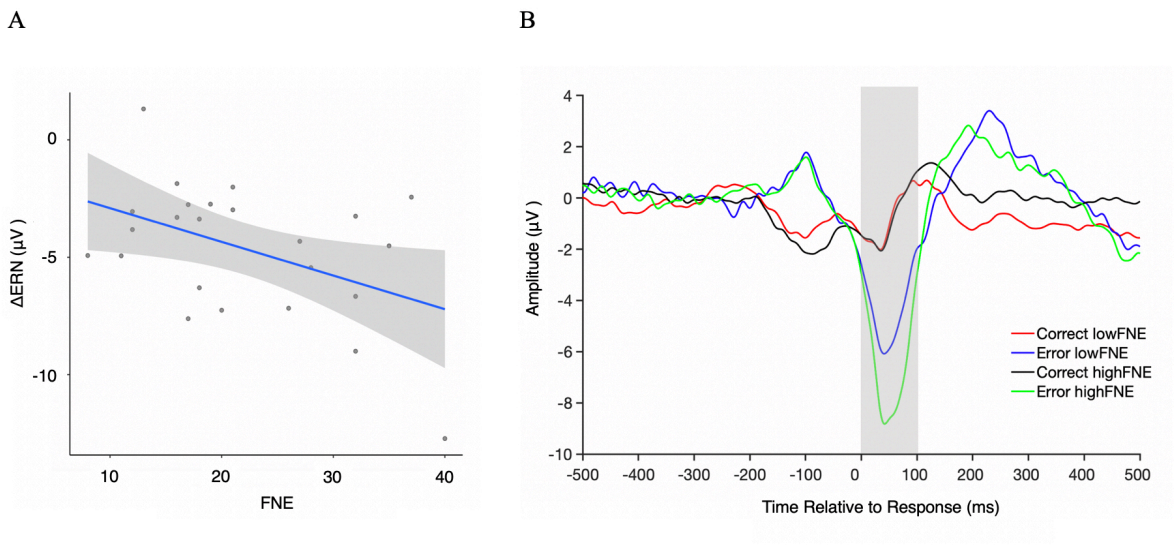
Schematic outline of Flanker task paradigm.

Figure 2



Averaged ERP and topographic plots for the social and nonsocial conditions. ERP plots depict averaged ERPs for incongruent-error trials (ERN: red), incongruent-correct trials (CRN: blue), and their difference (ΔERN: black), as a function of condition (top: social; bottom: nonsocial). Topographic plots corresponding to the shaded region within each ERP plot (0 – 100 ms) depict mean amplitude differences between incongruent-error and incongruent-correct trials (ΔERN), separately for each condition (top: social; bottom: nonsocial).

Figure 3



Association between FNE and ΔERN within the social condition. A) Scatterplot depicting the significant correlation between FNE and ΔERN within the social condition (r = -.452, p = .027). B) Averaged ERP plots as a function of trial accuracy and FNE group within the social condition. For plotting purposes only, participants were grouped into high and low FNE groups based on the median value of FNE scores; all statistical analyses treated FNE as a continuous variable. ERP plots depict averaged ERPs for: incongruent-error trials for the low FNE group (ERN: blue), incongruent-error trials for the high FNE group (ERN: green), incongruent-correct trials for the low FNE group (CRN: red), incongruent-correct trials for the high FNE group (CRN: black). The shaded region reflects the 0 – 100 ms time window.

Table 1

Descriptive statistics characterizing behavior and ERPs as a function of condition

	Non-social condition	Social condition
Behavior Measures	(N=27)	(N=27)
Accuracy (%)	87.23 (4.34)	87.04 (4.61)
Correct Reaction Time (ms)	350.02 (35.78)	350.20 (34.08)
Error Reaction time (ms)	295.71 (30.50)	294.31 (27.98)
ERPs (μV)	(N=25)	(N=24)
CRN	-0.57 (2.70)	-0.82 (2.43)
ERN	-4.19 (3.18)	-5.45 (3.38)
ΔERN	-3.62 (2.66)	-4.63 (2.86)

Note. Values reflect mean scores (standard deviation in parentheses).

Table 2

Hierarchical linear regression with SCARED Social Phobia Scale and SAS-A FNE Scale

Predictors	Step 1		Step2	
	Standardized beta	*p*	Standardized beta	*p*
SCARED Social Phobia Scale	- .16	.44	- .16	.51
SAS–A FNE Scale			-.55	.03*
	R^2=.027		ΔR^2=.19*	

Note: * $p < .05$.