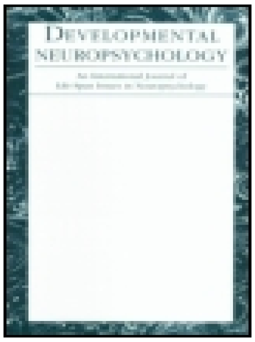

Developmental Neuropsychology

ISSN: 8756-5641 (Print) 1532-6942 (Online) Journal homepage: http://www.tandfonline.com/loi/hdvn20

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To cite this article: Lyndsey Juliane Chong & Alexandria Meyer (2018): Understanding the Link between Anxiety and a Neural Marker of Anxiety (The Error-Related Negativity) in 5 to 7 Year-Old Children, Developmental Neuropsychology, DOI: 10.1080/87565641.2018.1528264

To link to this article: https://doi.org/10.1080/87565641.2018.1528264

Published online: 08 Nov 2018.

DEVELOPMENTAL NEUROPSYCHOLOGY
https://doi.org/10.1080/87565641.2018.1528264

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Understanding the Link between Anxiety and a Neural Marker of Anxiety (The Error-Related Negativity) in 5 to 7 Year-Old Children

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ABSTRACT
Despite growing evidence that an elevated error-related negativity (ERN) is a risk marker for anxiety, it is unclear what psychological construct underlies this association. To address this gap, we devised a 9-item self-report scale for assessing error sensitivity (i.e. the fear of making mistakes) in children. The Child Error Sensitivity Index was administered to 97 children ages 5–7 years old and demonstrated good internal reliability and convergent validity. The Child Error Sensitivity Index related to the ERN, and the relationship between the ERN and child anxiety symptoms was mediated by scores on the Child Error Sensitivity Index.

ARTICLE HISTORY
Received 28 February 2018
Revised 13 September 2018
Accepted 15 September 2018

Introduction

Anxiety disorders most commonly begin in childhood and adolescence, and impairment frequently persists into adulthood (Beesdo, Knappe, & Pine, 2009; Beesdo, Pine, Lieb, & Wittchen, 2009; Kessler et al., 2005; Last, Perrin, Hersen, & Kazdin, 1996). Characterizing specific pathways that lead to the development of anxiety disorders may improve prevention and early intervention approaches.

One early pathway towards anxiety that has been identified is characterized by an increased neural response to making mistakes (Meyer, Glenn, Kujawa, Klein, & Hajcak, 2016b). The error-related negativity (ERN), is a negative deflection in the event-related potential (ERP) waveform, at frontocentral electrode sites, occurring approximately 50 ms after error commission and is thought to reflect activation of a generic error detection system across a variety of stimuli and response modalities (Falkenstein, Hohnsbein, Hoormann, & Blanke, 1991; Gehring, Goss, Coles, Meyer, & Donchin, 1993; Hajcak, Moser, Yeung, & Simons, 2005a). The ERN is postulated to have a principal source in the anterior cingulate cortex (ACC), an area of the brain responsible for integrating pain, threat, and punishment to change behavior (Shackman et al., 2011).

Researchers have found an increased ERN in anxious adults in over 50 studies to date (Cavanagh & Shackman, 2014; Meyer, 2017b; Weinberg, Riesel, & Hajcak, 2012b). Increased ERNs have also been observed in clinically anxious children (Carrasco et al., 2013; Hajcak, Franklin, Foa, & Simons, 2008; Hanna et al., 2012; Kujawa et al., 2016; Meyer, 2017a; Meyer et al., 2013a, 2016a, 2016b; Meyer, Riesel, & Proudfit, 2013b) both before and after treatment (Hajcak et al., 2008; Kujawa et al., 2016; Ladouceur et al., 2018). Furthermore, an elevated ERN in children at age 6 predicts the onset of anxiety disorders by age 9 (Meyer, Hajcak, Torpey-Newman, Kujawa, & Klein, 2015), even when controlling for baseline anxiety symptoms. We have interpreted these findings to suggest that an underlying increased response to making mistakes or sensitivity to one's own errors may be an important precursor to anxiety early in development.

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Despite the seeming importance of the ERN in predicting and indexing anxious trajectories, relatively little is known about the psychological construct(s) the ERN may reflect.

Several studies have suggested that the ERN is sensitive to stress and the motivational salience of errors (Amodio et al., 2004; Amodio, Devine, & Harmon-Jones, 2008; Amodio, Master, Yee, & Taylor, 2008; Compton et al., 2011, 2008). The magnitude of the ERN is larger when errors are more costly or significant (Chiu & Deldin, 2007; Endrass et al., 2010; Ganushchak & Schiller, 2008; Hajcak et al., 2005a), when accuracy is emphasized over speed (Falkenstein, Hoormann, Christ, & Hohnsbein, 2000; Gehring et al., 1993), and when performance is being evaluated (Hajcak, Nieuwenhuis, Ridderinkhof, & Simons, 2005b; Kim, Iwaki, Uno, & Fujita, 2005).

Previous work in adults has linked an increased ERN to trait perfectionism (Barke et al., 2017; Perrone-McGovern et al., 2017; Schrijvers, De Bruijn, Destoop, Hulstijn, & Sabbe, 2010; Stahl, Acharki, Kresimon, Völler, & Gibbons, 2015). Perfectionism is related to hypervigilance surrounding mistakes. Indeed, one recent study suggested that maladaptive perfectionism may be specifically related to the ERN (Perrone-McGovern et al., 2017), indicating that the ERN may be an index of the degree to which an individual is distressed by their performance or behavior not meeting their own standards. Another study found that "doubts about actions" or the tendency to not be satisfied with the quality of one's own performance related to the ERN (Stahl et al., 2015).

More generally, errors have been conceptualized as motivationally salient events that elicit the ERN (Weinberg et al., 2012b) – the commission of errors triggers a multitude of physiological responses similar to defensive responding, including skin conductance response, heart rate deceleration, potentiated defensive startle reflexes, and pupil dilation (Weinberg, Klein, & Hajcak, 2012a; Weinberg et al., 2012b). Therefore, we have conceptualized errors as a type of self-generated threat (Meyer, 2017b). In other words, the ERN may reflect an individual's perception of how aversive and salient an internally generated threat (i.e., error) is.

Despite the wealth of evidence suggesting that an increased ERN may be an important developmental risk marker and correlate for anxiety in children, no study has yet investigated what *psychological construct(s)* may underlie the association between the ERN and anxiety. In addition, although it has been hypothesized that an increased ERN in anxious children may reflect increased sensitivity to errors or perfectionism, no study has yet examined this directly. This is important for intervention and prevention efforts. For example, to develop a psychosocial intervention targeting this neural marker of risk (i.e., the ERN), we need to understand what psychological constructs to target.

In the current study, we aimed to develop and validate a self-report measure that indexes children's sensitivity to their own errors. In light of evidence suggesting that the ERN is an important risk marker for anxiety *early* in development, combined with evidence suggesting that early intervention may be more effective in reducing anxiety (Mancebo et al., 2014), we validated this measure in *young* children. While few self-report measures have been validated in children as young as 5 years old, there is some evidence that children this young can report on health-related information (Varni, Limbers, & Burwinkle, 2007). Additionally, given the fact that many *internalizing* symptoms (including error sensitivity) may not be observable to parents, children may be the optimal reporters of these experiences. To bridge this gap in the literature, we designed a self-report measure of error sensitivity in children between the ages of 5 to 7. The questions were tailored to be comprehensible and relevant to children, and a research assistant administered questionnaires in a board game format to encourage active participation.

To further validate the questionnaire as a measure of error sensitivity, electroencephalography (EEG) data were recorded while children completed an age-appropriate go/no-go task. We hypothesized that children who reported being more sensitive to making mistakes would also be characterized by an increased ERN. Additionally, we hypothesized that the relationship between the ERN and anxiety symptoms (as reported by both parents and children) would be mediated by children's error sensitivity.

Method

Participants

The study included 97 children between the ages of five and seven years old (M = 5.76, SD = .77) who were recruited from the Tallahassee community. A total of 48 females and 49 males participated in the study. Overall, 10% of the sample identified as Hispanic or Latino, 6% as Asian, 18% as Black, 65% as White, and 8% as Other. Regarding socioeconomic status, 3% of parents reported "some high school or a high school diploma," 29% reported "some college or a 2-year degree," 29% reported obtaining a college degree, and 37% reported obtaining a graduate degree. Additionally, for estimated annual family income, 3% reported making less than $10,000 per year, 7% reported making between $10,000–25,000 per year, 9% reported making between $25,000–40,000 per year, 37% reported making between $40,000–75,000 per year, and 43% reported making more than $75,000 per year.

Of these children, 79 had complete data for the go/no-go task in both the parent and experimenter conditions. Reasons for missing go/no-go data included: child refusal (N = 5), too much movement during EEG recording (N = 2), child did not make responses during the go/no-go task (N = 1), computer or experimenter error (N = 2), child quit during the task (N = 4), and unable to get good signal due to child's hair (N = 1). Additionally, children were only included in analyses if they made at least six errors per condition (Meyer, Bress, & Proudfit, 2014a; Olvet & Hajcak, 2009), leading to the exclusion of three children. A total of 36 female and 43 male children were included in the section of the current study that utilized EEG data (total N = 79). The average age of the children was 5.78 years old, SD = .77. Children excluded did not differ on any demographic or main study variables, all $ps > .10$.

Measures

Self-report

The Child Error Sensitivity Index measures children's sensitivity to making errors through a 9-item questionnaire. Items on the Child Error Sensitivity Index were developed based on previous literature suggesting that the ERN is related to performance concerns, checking, and perfectionism (Barke et al., 2017; Perrone-McGovern et al., 2017; Schrijvers et al., 2010). Further, items were loosely derived from the Error Orientation Questionnaire (EOQ; Rybowiak, Garst, Frese, & Batinic, 1999). Items include statements related to reactivity to making mistakes, e.g., "I feel upset when other people don't like something I have done," "If I make a mistake, I always want to fix it," and "When I make a mistake, I feel anxious." Scores range from 1 = not at all, 2 = somewhat, 3 = a lot, for each item, and the total error sensitivity score is computed by summing all the items. The children were kept engaged while completing the survey by a standardized board game with a research assistant. The board game consisted of a start and finish, with a number of "island" square spaces in between. Children had a game piece that they advanced after they answered a question. They were told they would be able to pick a prize when they completed the board game.

The Child Error Sensitivity Index was also administered to a subset of parents (N = 47; due to the fact that this measure was introduced mid-way through the study). The parent who accompanied the child into the lab completed the questionnaire (88% were mothers). In this questionnaire, the same items were presented as in the child version, but re-worded so that the parent would answer these items about their children. For example: "My child feels upset when other people don't like something she or he has done," "If my child makes a mistake, he/she always wants to fix it," and "When my child makes a mistake, she/he feels anxious." There were 9 items which were rated from 1 = not at all, 2 = somewhat, 3 = a lot, for each item, and the total error sensitivity score is computed by summing all the items. Parents completed these items independently. While the main focus of the current investigation was the child report of error sensitivity, we included the parent report for validation purposes.

Originally devised by Scherer and Nakamura (1968), the Fear Survey Schedule for Children–Revised (i.e., the FSSC-R; Ollendick, 1983) is a widely used 80-item self-report measure of children's fear. It obtains information on the number, severity, and types of fears that children experience. The scale is composed of five factors: 1) fear of failure and criticism, 2) fear of the unknown, 3) fear of minor injury and small animals, 4) fear of danger or death, and 5) medical or situational fears. Apart from having high internal consistency, test-retest reliability, and stability over time, the FSSC-R also has acceptable differentiation between normal and clinical samples, convergent and divergent validity, and a meaningful factor structure (Ollendick, 1983). A subsample of the children (N = 44) completed the FSSC-R in addition to the Child Error Sensitivity Index due to the fact that the measure was added mid-way through study completion. The items from the FSSC-R were also read out loud to the children.

To measure anxiety symptoms, we utilized the Screen for Child Anxiety-Related Emotional Disorders (SCARED; Birmaher et al., 1997). The SCARED was administered to the parent and child separately. Both versions broadly assess symptoms of anxiety as they manifest in children, including panic, general anxiety, separation anxiety, social phobia, and school phobia. Each version consists of a 38-item scale on which the participant answers 0 = not true or hardly ever true, 1 = sometimes true, or 2 = true or often true. Parents filled out the questionnaire independently and children completed the measure with a research assistant while playing a standardized board game.

Go/no-go task

As part of a larger study, children completed an age-appropriate go/no-go task under two conditions as EEG was being recorded. In one condition, they completed the go/no-go task while their parent sat next to them; in another condition, an experimenter sat next to them as they completed the task. The parent and experimenter conditions were counterbalanced across participants. The children were instructed to "shoot" aliens by clicking the mouse button as soon as the aliens appeared on the screen, and "save" astronauts by refraining from clicking the mouse button when the astronauts appeared on the screen. Stimuli included an image of an alien or astronaut that appeared on the screen for 500 ms, with an ITI of 1000–2000 ms. Children completed 400 trials in total, after receiving instructions and completing five practice trials.

Procedure

Upon the child's arrival in the laboratory with his or her parent, the experimenter oriented them to the study procedure and obtained informed consent from the parent. First, the children completed the go/no-go task as EEG data was recorded. Then, the children completed the self-report measures listed above. A research assistant read the items from all the questionnaires to the children to eliminate the issue of different reading abilities across this age range. The research assistant was instructed to reword, act out, give examples, or explain items to children when necessary. For the Child Error Sensitivity Index, the children were given a handout with their options for answers: 1 = not at all like me, 2 = somewhat like me, 3 = a lot like me, and were instructed to point to their answers. Each option was accompanied by an image depicting the concept of the answer, and the research assistant explained and demonstrated each answer before starting the assessment. The children were kept engaged by a standardized board game, where they were allowed to move their game piece for every question answered and would pick a prize when they completed the measure.

EEG data acquisition and processing

Continuous EEG data at 34 electrode sites and two electrodes on the left and right mastoids were recorded with an elastic cap and the BioSemi ActiveTwo system (BioSemi, Amsterdam, Netherlands). Electroculogram (EOG) data produced by eye movements and eye blinks were collected using four facial electrodes: two approximately 1 cm outside the outer edge of the right and left eyes (horizontal eye movements), and two approximately 1 cm above and below the right eye (vertical eye movements and blinks). The EEG signal was preamplified at the electrode to improve the signal-to-noise ratio, and amplified with a gain of one by a BioSemi ActiveTwo system. During data acquisition, all active electrodes were referenced to a common mode sense (CMS) active electrode producing a monopolar (non-differential) channel. EEG was recorded with a low-pass fifth order sinc filter with a half-power cutoff of 204.8 Hz and digitized at a 2-bit resolution with a sampling rate of 1024 Hz.

For offline analysis, EEG data were referenced to the mean of the left and right mastoids, and band-pass filtered between 0.1 and 30 Hz, and corrected for eye blinks and eye movements as per Gratton, Coles, and Donchin (1983). Through a semi-automatic procedure, specific intervals were eliminated from individual channels in each trial by detecting and rejecting artifacts using the following criteria: a voltage step of more than 50.0 μV between sample points, a voltage difference of 300.0 μV within a trial, and a maximum voltage difference of less than 0.50 μV within 100-ms intervals. Subsequently, visual inspection of the data was conducted to detect and reject any remaining artifacts. Approximately 2.36% additional trials were removed due to artifacts that were detected manually.

The EEG was segmented −500 to 1000 ms prior to and following response onset for each trial. Response-locked ERPs were averaged separately for correct and error trials, and baseline corrected using the interval from −500 to −300 ms. Next, a difference score (i.e., error minus correct) was computed for each individual at mid-line electrode FCz, where error-related brain activity was maximal. The ERN was defined as the average activity 50 ms around the most negative peak for each individual; peak detection was employed to identify the maximal negative peak of the *difference wave* from −50 to 100 ms around response onset.[1] This approach has been shown to be useful when examining ERPs in developmental populations (Bress, Meyer, & Hajcak, 2015; Lukie, Montazer-Hojat, & Holroyd, 2014). Latency in ERPs have more variance in young children (Lukie et al., 2014) and by using a peak detection approach and exporting the area around the peak, we are able to identify where *error-specific* activity is maximal for each child. We have also reported results for a standard area measure (0–100 ms) in a footnote. Behavioral data were measured by number of error and correct trials for each individual, as well as mean reaction times (RTs) in each condition.

For statistical analyses, we used SPSS (Version 17.0) General Linear Model software. Cronbach's alpha was calculated as a measure of internal consistency for the self-report measures. Convergent validity was examined through Pearson correlations with the FSSC-R factors and a stepwise regression analysis wherein all five factors of the FSSC-R were entered predicting the total score on the Child Error Sensitivity Index. A principal axis factor analysis was conducted with oblique rotation (direct oblimin) to identify factors in the Child Error Sensitivity Index. Next, we compared the five factors of the FSSC-R to the factors derived from the Child Error Sensitivity Index. Then, we utilized Pearson correlations to examine the relationship between the ERN and the total scores and subscale scores of the Child Error Sensitivity Index.

To examine a mediation model wherein the relationship between the ERN and child anxiety symptoms was mediated by child error sensitivity, we utilized a nonparametric bootstrapping approach (MacKinnon, Lockwood, & Williams, 2004). This approach has been shown to be more statistically powerful than other tests of mediation (MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002). We used an SPSS macro (Preacher & Hayes, 2004), which provides a bootstrap estimate of the indirect effect between the independent and dependent variable, an estimated standard error, and 95% confidence intervals for the population value of the indirect effect. When confidence intervals for the indirect effect do not include zero, this indicates a significant indirect effect at the $p < .05$ level. Direct and indirect effects were tested using 5,000 bootstrap samples.

Results

Child error sensitivity

Overall, the average total score on the Child Error Sensitivity Index was 17.53, *SD* = 4.58. Scores ranged between 9 and 27. The Cronbach's alpha for the 9 items included in the measure was .78, suggesting the measure obtained acceptable internal consistency. Total scores on the Child Error Sensitivity Index did not differ by gender, $F(1, 96) = .37$, $p = .54$, and did not relate to child age, $r(95) = -.02$, $p = .81$.

Convergent validity

To examine convergent validity, we compared the Child Error Sensitivity Index with the widely used FSSC-R. The FSSC-R contains five factors related to specific types of fears: 1) fear of failure and criticism, 2) fear of the unknown, 3) fear of minor injury and small animals, 4) fear of danger or death, and 5) medical or situational fears. For the purpose of the current study, we expected scores on the Child Error Sensitivity Index to be most closely aligned with the FSSC-R Factor 1: fear of failure and criticism. To examine convergent validity, we compared the Child Error Sensitivity Index to the five factors of the FSSC-R.

Overall, the FSSC-R obtained excellent internal reliability, Cronbach's alpha = .96. Additionally, Factor 1: fear of failure or criticism obtained a Cronbach's alpha of .91, Factor 2: fear of the unknown obtained a Cronbach's alpha of .85, Factor 3: fear of minor injury and small animals obtained a Cronbach's alpha of .85, Factor 4: fear of danger or death obtained a Cronbach's alpha of .89, and Factor 5: medical or situational fears obtained a Cronbach's alpha of .72. While only a subsample completed the FSSC–R ($N = 44$), the children did not differ on the Child Error Sensitivity Index or any other demographic variable from the overall sample, all *p*s > .70.

First, we conducted correlations between Child Error Sensitivity and the FSSC-R total score and factors (Table 1). Overall, Child Error Sensitivity was significantly correlated with the FSSC-R total score, $r(42) = .41$, $p < .01$, Factor 1: fear of failure or criticism, $r(42) = .47$, $p < .001$, Factor 2: fear of the unknown, $r(42) = .32$, $p < .05$, Factor 4: fear of danger or death, $r(42) = .37$, $p < .05$, and Factor 5: medical or situational fears, $r(42) = .35$, $p < .02$. However, Child Error Sensitivity was not significantly correlated to Factor 3: fear of minor injury and small animals, $r(42) = .17$, $p = .26$.

To examine specificity, we then conducted a stepwise regression wherein all five factors from the FSSC-R were entered predicting the total score for the Child Error Sensitivity Index. Results suggested that only Factor 1: fear of failure or criticism obtained significance, $F(1, 43) = 11.56$, $p < .001$, $\beta = .47$. All other factors were excluded from the model.

Factor analysis of the Child Error Sensitivity Index

A principal axis factor analysis was conducted on the nine items with oblique rotation (direct oblimin). The Kaiser-Meyer-Olkin measure verified the sampling adequacy for the analysis,

Table 1. Correlations between the Child Error Sensitivity Index and Fear Survey Schedule for Children–Revised.

	1	2	3	4	5	6	7	8	9	10
1. CESI Total	1									
2. CESI Social Concerns	.87**	1								
3. CESI Perfectionism	.61**	.41**	1							
4. CESI Physical Reactions	.85**	.63**	.29**	1						
5. FSSC-R Total	.41**	.49**	−.09	.48**	1					
6. FSSC-R Failure or Criticism	.47**	.53**	−.04	.51**	.93**	1				
7. FSSC-R Unknown	.32*	.43**	−.08	.33*	.85**	.74**	1			
8. FSSC-R Minor Injury and Small Animals	.17	.35*	−.24	.24	.73**	.56**	.65**	1		
9. FSSC-R Danger or Death	.37*	.38*	.01	.42**	.91**	.81**	.69**	.60**	1	
10. FSSC-R Medical or Situational	.35*	.42**	−.23	.45**	.89**	.79**	.74**	.64**	.76**	1

†$p < .10$, * $p < 0.05$, ** $p < 0.01$.

Table 2. Rotated factor loadings in the Child Error Sensitivity Index.

Item	Rotated Factor loadings		
	Factor 1 Social Concerns	Factor 2 Perfectionism	Factor 3 Physical Reactions
I feel upset when other people don't like something I have done.	**.78**	−.04	−.09
I am afraid of making mistakes in front of other people.	**.72**	.08	.08
When someone notices I did something wrong, I feel upset.	**.57**	.06	.24
If I make a mistake, I always want to fix it.	−.12	**.97**	−.07
I like to do things perfectly.	.11	**.44**	.04
When I make a mistake, I feel anxious.	.22	.08	**.62**
My stomach feels sick when I make a mistake.	−.12	−.02	**.58**
When I make a mistake, I start sweating or blushing.	.09	−.07	**.51**
When I notice a mistake I made, I feel upset.	.15	.21	**.40**
Eigenvalues	3.30	1.32	1.09
% of variance	36.99	14.67	12.11
α	.78	.61	.68

KMO = .76 (the minimum criteria is .50; Kaiser, 1974), and all KMO values for individual items were greater than .59. An initial analysis was run to obtain eigenvalues for each factor in the data. Three factors had eigenvalues over Kaiser's criterion of 1 and in combination explained 63.77% of the variance (the first four eigenvalues were 3.33, 1.32, 1.09, .86). The scree plot showed an inflexion that would justify retaining three factors, and thus we retained three factors. Table 2 shows the factor loadings after rotation. The first factor had high loadings (>.40) on items related to social evaluation of errors (Factor 1: Social Concerns). The second factor had high loadings on items related to perfectionism and wanting to fix mistakes (Factor 2: Perfectionism). The third factor had high loadings on items related to physical and emotional reactions to making mistakes (e.g., sweating or feeling upset; Factor 3: Physical Reactions).

Overall, Factor 2: Perfectionism and Factor 3: Physical Reactions did not differ by gender, all *ps* > .30. However, Factor 1: Social Concerns, was increased in girls compared to boys, at a trend level, $F(1, 96) = 3.29$, $p = .07$. Furthermore, child age did not relate to any of the three factors, all *ps* > .2.

To compare the factors of the Child Error Sensitivity Index to the FSSC-R, we conducted separate stepwise regressions wherein the five FSSC-R factors were entered predicting each of the three Child Error Sensitivity factors (Social Concerns, Perfectionism, and Physical Reactions). In the first model, predicting the Child Error Sensitivity Index Factor 1: Social Concerns, only FSSC-R Factor 1: fear of failure or criticism reached significance, $F(1, 43) = 16.29$, $p < .001$, $\beta = .52$. All other FSSC-R factors were excluded from the model. In the second model, predicting Child Error Sensitivity Index Factor 2: Perfectionism, no FSSC-R factors were entered into the equation. In the third model, predicting Child Error Sensitivity Index Factor 3: Physical Reactions, only FSSC-R Factor 1: fear of failure or criticism reached significance, $F(1, 43) = 14.74$, $p < .001$, $\beta = .51$. All other FSSC-R factors were excluded from the model.

A subset of parents completed the parent version of the Child Error Sensitivity Index regarding their child's error sensitivity ($N = 44$). Overall, this measure obtained good internal reliability, Cronbach's alpha = .83. However, the child and parent report were not significantly related, $r(45) = .10$, $p = .51$.

Error-related brain activity

We conducted a repeated-measures ANOVA with parent vs. experimenter condition and error vs. correct entered as within-subject variables. Results suggested that neural activity was significantly more negative during error trials compared to correct trials, $F(1, 79) = 187.30$, $p < .001$. However, the two-way interaction between response and condition did not reach significance, $F(1, 79) = .19$,

p = .66, suggesting that neural activity did not significantly differ between conditions. In the current study, we focus on the area around the peak of the difference wave (error minus correct) for each individual because this method has been shown to be advantageous in developmental samples (Bress et al., 2015; Lukie et al., 2014). We conducted a repeated-measures ANOVA with parent vs. experimenter condition difference scores (area around the peak) entered as the within-subject variable. Results suggested that the conditions did not differ either, $F(1, 79) = .02$, $p = .89$. Therefore, we z-scored and combined the ERN (area around the peak) measured during both conditions to create a measure of error-related brain activity for each individual to be used in subsequent analyses. Consistent with other studies in developmental samples (Meyer et al., 2014a), the split-half reliability of the ERN was moderate (0.55).

To examine the relationship between the ERN and Child Error Sensitivity, we conducted correlations between the ERN, the total score on the Child Error Sensitivity Index, and the subscales. Total scores on the Child Error Sensitivity Index were significantly correlated to the ERN, $r(74) = -.24$, $p < .05$, such that children who reported more sensitivity to errors were also characterized by an increased ERN. Regarding the subscales of the Child Error Sensitivity Index, Factor 1: Social Concerns related to the ERN, at a trend level, $r(74) = -.22$, $p = .06$. However, Factor 2: Perfectionism, $r(74) = -.18$, $p = .13$, and Factor 3: Physical Reactions, $r(74) = -.19$, $p = .10$ did not reach significance. Further, neither the total on the FSSC-R, nor any of the subscales, significantly related to the ERN in children, all ps > .10.

Figure 1 depicts error, correct, and difference (i.e., error minus correct) waveforms, as well as topographical headmaps (error minus correct) for children characterized by high and low error sensitivity using a median-split. As can be seen in Figure 1, children with high error sensitivity have a larger ERN compared to children who reported being low in error sensitivity.

Reaction time during the task did not relate to the total score on the Child Error Sensitivity Index or any of the subscales, all ps > .10. While accuracy did not relate to the total score on the Child Error Sensitivity Index, Factor 1: Social Concerns, or Factor 3: Physical Reactions, all ps > .10, children who reported increased Perfectionism (Factor 2) also performed more accurately on the task, $r(76) = .23$, $p < .05$.

To examine whether the relationship between the ERN and child-reported scores on the Child Error Sensitivity Index could be accounted for by performance during the task, we conducted a simultaneous regression wherein the Child Error Sensitivity Index, accuracy, and reaction times across the task were entered predicting the ERN. Results suggested that reaction time did not reach significance, $B = .14$, $t = 1.42$, $p = .16$, while both accuracy, $B = .45$, $t = 4.41$, $p < .001$, and the Child Error Sensitivity Index, $B = .33$, $t = 3.24$, $p < .01$, significantly predicted the ERN. Additionally, when we simultaneously entered child age into this equation, the relationship between the Child Error Sensitivity Index and the ERN remained significant, $B = .33$, $t = 3.23$, $p < .01$. These findings suggest that the relationship between the Child Error Sensitivity Index and the ERN is significant, even when taking into account the impact of performance and age.

We also wished to examine whether the parent-reported Child Error Sensitivity Index was related to the magnitude of the child's ERN. Total scores on the Child Error Sensitivity Index, as reported by the *parent*, were also significantly related to the ERN, $r(44) = -.34$, $p < .05$. The pattern was the same as the child report – parents who reported that their children were higher in error sensitivity also had children characterized by a larger ERN (i.e., more negative ERN). To examine whether the relationship between the child-report of error sensitivity and the parent-report of child error sensitivity was unique or overlapping regarding child ERN, we conducted a simultaneous multiple regression analysis wherein both the child and parent report on the Child Error Sensitivity Index were entered simultaneously predicting the ERN. Results suggested that both the child and parent report were unique predictors of child ERN: parent report, $B = -.30$, $t = -2.23$, $p < .05$, and child report, $B = -.28$, $t = -2.06$, $p < .05$; overall model, $F(2, 46) = 5.09$, $p < .01$. Moreover, results suggested that this effect was additive. By including *both* reports in the model, the amount of

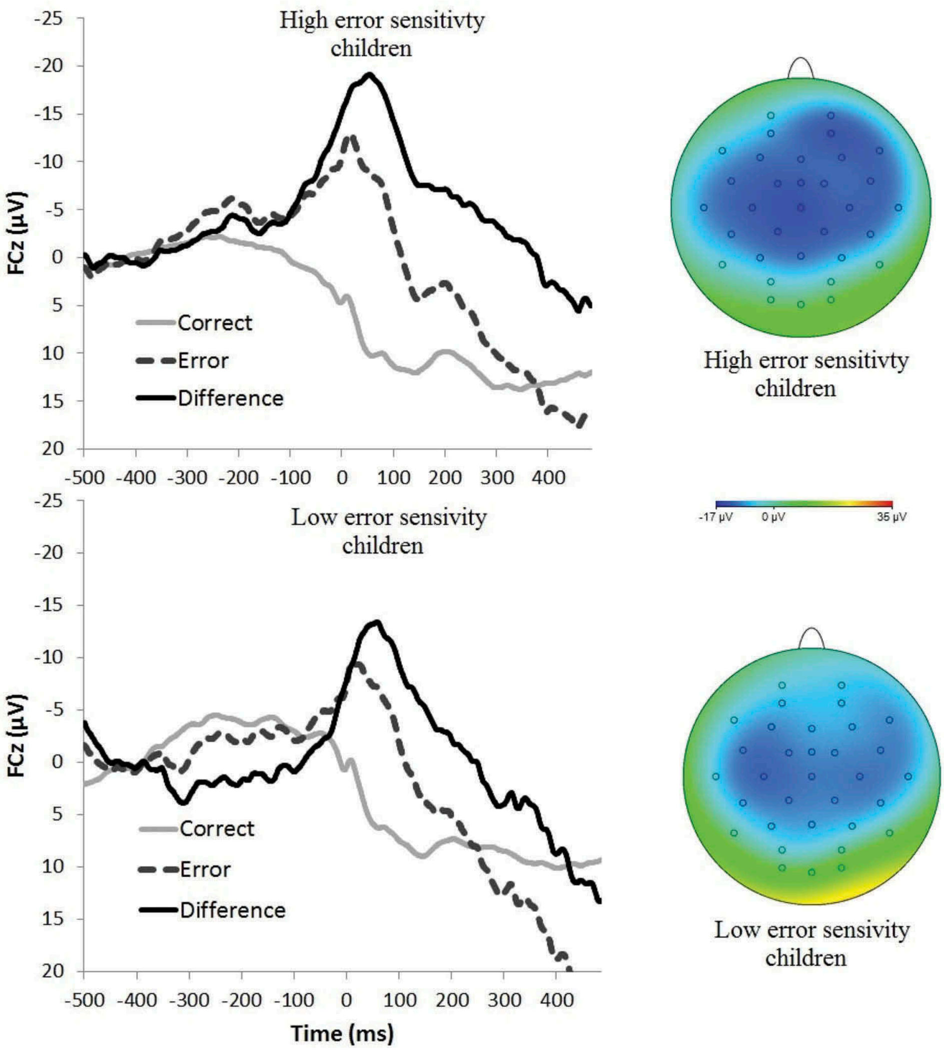

Figure 1. Error-related negativity waveforms (error, correct, and error minus correct) are depicted on the left. On the right, topographical headmaps are depicted for 0–100 ms after the response (error minus correct).

variance predicted in the ERN significantly increased, i.e., the r-squared increased from .11 to .19, $p < .05$.[2]

Error-related brain activity and anxiety symptoms

Both parent and child report on the SCARED were used to assess anxiety symptoms in the children. Overall, the parent report on the SCARED demonstrated adequate internal reliability, Cronbach's alpha for the total score = .89. The child report on the SCARED demonstrated adequate internal reliability as well, Cronbach's alpha for the total score = .94. The total scores on the parent and child SCARED were correlated at a trend level, $r(74) = .20$, $p = .07$.

To examine whether the Child Error Sensitivity Index would mediate the relationship between error-related brain activity and child anxiety symptoms, we conducted two separate mediation models (using the parent-report on the SCARED and then the child-report on the SCARED).

Table 3. Bivariate correlations between key study variables (i.e., ERN, SCARED, and Child Error Sensitivity Index).

	1	2	3	4
1. ERN	1			
2. Child Error Sensitivity Index Total	−.24*	1		
3. SCARED Total–Child	−.02	.20†	1	
4. SCARED Total–Parent	−.06	.69**	.20†	1

†$p < .10$, * $p < .05$, ** $p < .01$.

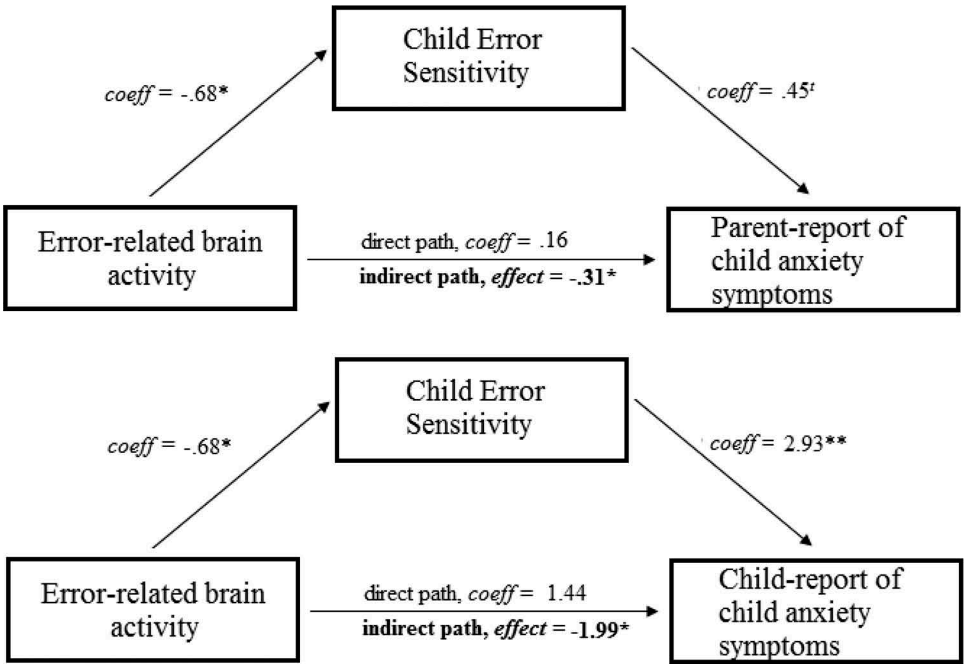

Figure 2. A graphical depiction of 2 mediation models examining the relationship between error-related brain activity (i.e., the ERN) and child anxiety symptoms (reported by parents on the SCARED, top; reported by children on the SCARED, bottom), mediated by child error sensitivity as measured by the Child Error Sensitivity Index.

Bivariate correlations between key study variables are included in Table 3. As can be seen in Figure 2, results from the first model suggested that the overall model was significant, $F(1, 74) = 4.62$, $p < .05$. The pathway from the ERN to the Child Error Sensitivity Index reached significance, *coeff* = −.67, $t = -2.15$, $p < .05$, 95% CI [−1.20, −.15]. Moreover, the pathway from the Child Error Sensitivity Index to the parent-report on the SCARED was significant at a trend level, *coeff* = .45, $t = 1.77$, $p = .08$, 95% CI [.02, .88]. The direct path from the ERN to parent-report on the SCARED did not reach significance, *coeff* = .16, $t = .21$, $p = .83$, 95% CI [−1.04, 1.35]. Results supported the mediation model – the indirect path from the ERN to child anxiety symptoms (parent-report on the SCARED) via the Child Error Sensitivity Index reached significance, *effect* = −.31, 95% CI [−.87, −.03]. Furthermore, we tested a reversed causal model (Preacher & Hayes, 2004) wherein the mediator and the outcome variables were switched (i.e., the Child Error Sensitivity Index and the parent-report on the SCARED were switched). Results from this model did not support the mediation model, *effect* = −.01, 95% CI [−.18, .14].

In the second model, we examined the relationship between error-related brain activity and child anxiety symptoms (reported by the child) mediated by the Child Error Sensitivity Index. As can be seen in Figure 2, results from the first model suggested that the overall model was significant, F(1,

74) = 4.62, $p < .05$. The pathway from the ERN to the Child Error Sensitivity Index reached significance, *coeff* = −.67, $t = -2.15$, $p < .05$, 95% CI [−1.20, −.15]. Moreover, the pathway from the Child Error Sensitivity Index to the child-report on the SCARED was significant, *coeff* = 2.93, $t = 8.17$, $p < .001$, 95% CI [2.33, 3.53]. The direct path from the ERN to parent-report on the SCARED did not reach significance, *coeff* = 1.44, $t = 1.43$, $p = .16$, 95% CI [−.24, 3.12]. Results supported the mediation model – the indirect path from the ERN to child anxiety symptoms (child-report on the SCARED) via the Child Error Sensitivity Index reached significance, *effect* = −1.99, 95% CI [−3.77, −.47]. We also tested a reversed causal model (Preacher & Hayes, 2004) wherein the mediator and the outcome variables were switched (i.e., the Child Error Sensitivity Index and the child-report on the SCARED were switched). Results from this model did not support the mediation model, *effect* = −.09, 95% CI [−.54, .41].

To examine specificity, we conducted the two mediation analyses above, replacing the Child Error Sensitivity Index with the FSSC-R Factor 1. To elaborate, we tested if the relationship between the ERN and SCARED scores, using the SCARED-parent and SCARED-child, would be mediated by FSSC-R Factor 1. Results from the first model suggested that the overall model was not significant, $F(1, 36) = .14$, $p = .71$. The pathway from the ERN to the FSSC-R Factor 1 was not significant, *coeff* = −.51, $t = -.38$, $p = .71$, 95% CI [−3.29, 2.26]. The pathway from the FSSC-R Factor 1 to the SCARED-parent was not significant, *coeff* = −.01, $t = -.05$, $p = .96$, 95% CI [−.29, .28]. The direct path from the ERN to the SCARED-parent was not significant, *coeff* = −.38, $t = -.33$, $p = .75$, 95% CI [−2.73, 1.98]. The indirect path from the ERN to the SCARED-parent was not mediated by the FSSC-R Factor 1, *effect* = .004, 95% CI [−.34, .29].

Next, results from the second model indicated that the overall model was not significant, $F(1, 36) = .14$, $p = .71$. The pathway from the ERN to the FSSC-R Factor 1 was not significant, *coeff* = −.51, $t = -.38$, $p = .71$, 95% CI [−3.29, 2.26]. However, the pathway from the FSSC-R Factor 1 to the SCARED-child was significant, *coeff* = 1.01, $t = 3.56$, $p < .01$, 95% CI [.43, 1.58]. The direct path from the ERN to the SCARED-child was not significant, *coeff* = .21, $t = .09$, $p = .93$, 95% CI [−4.51, 4.94]. The indirect path from the ERN to the SCARED-child was not mediated by the FSSC-R Factor 1, *effect* = −.52, 95% CI [−2.23, 1.95].

Discussion

To our knowledge, this is the first self-report measure created with the aim of measuring the psychological construct indexed by error-related neural activity. Overall, the Child Error Sensitivity Index obtained good internal reliability, and factor analyses suggested the measure consisted of three factors (Social Concerns, Perfectionism, and Physical Reactions). We demonstrated convergent validity by comparing the Child Error Sensitivity Index to Ollendick's (1983) FSSC-R subscale, wherein the Child Error Sensitivity Index displayed a robust and unique relationship to the fear of failure and criticism subscale. However, given that error sensitivity is a relatively novel and specific construct, there is no other comparable questionnaire measuring error sensitivity in the literature, and the FSSC-R Factor 1 subscale is the best approximation available. Moreover, children who reported being higher in error sensitivity were also characterized by increased error-related neural activity – suggesting that this self-report measure may, in part, reflect a psychological correlate of this neural risk marker. Parent-report of child error sensitivity also related to the magnitude of the child's ERN. Additionally, the relationship between the ERN and child anxiety symptoms was mediated by child error sensitivity, suggesting that this psychological construct may underlie the relationship between the ERN and anxiety observed in children.

Among the three subscales of the Child Error Sensitivity Index, only the Social Concerns factor had a trend level relationship with the ERN. This suggests that children who are more sensitive to making errors *in front of others* tend to have a bigger ERN. This is consistent with previous work linking the ERN to social anxiety (Barker, Troller-Renfree, Pine, & Fox, 2015; Buzzell et al., 2017; Endrass, Riesel, Kathmann, & Buhlmann, 2014; Kujawa et al., 2016). Future work is needed to determine whether this specific facet of error sensitivity (i.e., Social Concerns) is uniquely associated with the ERN at other stages of development.

While previous work has found associations between the ERN and perfectionism (Barke et al., 2017; Perrone-McGovern et al., 2017; Schrijvers et al., 2010; Stahl et al., 2015), in the current study, the Perfectionism subscale was not associated with the ERN. This may be a developmental phenomenon in which perfectionism does not begin to relate to the ERN until adolescence or adulthood. Future work is needed to clarify this issue. Additionally, the Physical Reactions subscale was not significantly correlated to the ERN. Notably, the total score on the Child Error Sensitivity Index related to the ERN, but the subscales did not (Social Concerns was a trend level relationship). It is possible that these three factors, *in combination*, best account for the magnitude of the ERN in children.

The Child Error Sensitivity Index demonstrated good psychometric properties, both as an overall measure and in terms of the three factors. Furthermore, a series of stepwise regressions suggested that the factor of the FSSC-R that was most related to the Child Error Sensitivity Index was fear of failure or criticism (Factor 1). This supports convergent validity insofar as we would expect the constructs of "error sensitivity" and fear of failure or criticism to be overlapping and thus, related. Furthermore, the results of the stepwise regression suggest that the other factors of the FSSC-R (i.e. 2) fear of the unknown, 3) fear of minor injury and small animals, 4) fear of danger or death, and 5) medical or situational fears) were not significantly related to the Child Error Sensitivity Index when the FSSC-R fear of failure or criticism factor (Factor 1) was entered into the equation. While we would expect these related constructs of fearfulness to relate to Child Error Sensitivity, we would expect fear of failure or criticism to display the most robust relationship, thus demonstrating divergent validity. Additionally, the ERN was significantly related to the Child Error Sensitivity Index, but not the FSSC-R fear of failure or criticism factor (Factor 1), which suggests that the Child Error Sensitivity Index is a superior measure of error sensitivity compared to the FSSC-R's Factor 1. This may indicate that the FSSC-R is a more general measure of anxiety rather than a specific measure of error sensitivity.

Although the parent and child report on the Child Error Sensitivity Index were not significantly related, both measures related to children's error-related neural activity. Moreover, the relationships between both the parent and child report and the ERN were unique and additive (using both measures, we were able to predict 20% of the variance in the ERN). This supports the value of both parent and child report on this construct, as it seems that both parent and child were able to report on meaningful and non-overlapping information on the construct of error sensitivity in children. Previous work suggests that parent and child report on internalizing symptoms in children may be discrepant due to the fact that children are reporting on experiences they are having internally and parents are reporting on observable behavior in children (Kolko & Kazdin, 1993; Niditch & Varela, 2011; Treutler & Epkins, 2003). Considering the fact that error sensitivity may partially be an internal process, parents may lack complete information regarding their children's internal experience of making mistakes. Moreover, parents may have more awareness of children's observable reactions to mistakes compared to the children themselves. Thereby, parents and children may both contribute accurate and non-overlapping information on this construct.

Although the ERN has been linked to "anxiety" in a broad sense in a wealth of previous studies, we believe an increased ERN in anxious individuals indexes a particular phenotypic expression of anxiety. Specifically, we propose that an increased ERN relates to concerns over making mistakes or error sensitivity. Meyer, Weinberg, Klein, and Hajcak (2012) found that the relationship between the ERN and "anxiety" in a broad sense changes across development. For example, in a sample of children between the ages of 8 and 13 years old, a larger ERN was related to increased anxiety among older children; however, among younger children, the relationship was in the *opposite* direction – a smaller ERN related to increased anxiety symptoms (Meyer et al., 2012). Additionally, in another study, temperamentally fearful children were characterized by a decreased ERN when they were 6 years old; by age 9, the same children who were fearful at the baseline assessment were now characterized by increased ERNs (Meyer et al., 2018). Hence, this developmental “flip” in the relationship between the ERN and anxiety has been demonstrated both between and within-subjects. We have interpreted these results as tracking the changing phenomenology of anxiety across development. It is possible that when measures focus on anxiety as a broad phenomenon or on general temperamental fear, younger children who score high on these measures may be more focused on external threat during the ERN assessment (e.g., the darkness of the room, the experimenter, being separated from their parent, etc.), whereas older children who score high on these measures may begin to monitor more for internal signals of threat (e.g., performing well on the task, evaluation of performance by the experimenter, etc.). However, in the current study, we examine a more specific measure of error sensitivity, as opposed to “anxiety” in a general sense, and we observed the expected relationship: *young* children higher in error sensitivity were characterized by an increased ERN, and error sensitivity mediated the relationship between the ERN and anxiety symptoms. Thus, results from the current study are consistent with the notion that the ERN is tracking the changing phenomenology of anxiety across development – i.e., sensitivity to making mistakes.

Our factor analysis suggested that the Child Error Sensitivity Index has three distinct components: 1) Social Concerns, 2) Perfectionism, and 3) Physical Reactions. Interestingly, girls had higher scores on the social concerns factor compared to the boys. This is consistent with previous findings regarding the tendency for girls to have increased social anxiety or social concerns compared to boys (Adler, Kless, & Adler, 1992; Tulkin, Muller, & Conn, 1969).

Results from the current study are novel insofar as *young* children (5–7 years old) completed a self-report measure. While there is some evidence that children as young as five years old are able to reliably and validly self-report on their health and Big Five personality traits when provided with an age-appropriate instrument (Measelle, John, Ablow, Cowan, & Cowan, 2005; Varni et al., 2007), self-report measures have primarily been validated in populations including older children and adults. Importantly, most measures related to anxiety symptoms and fears in this age range have not been validated in children younger than 7 years old. In the current investigation, we utilized a board game and scaffolding from the research assistants to keep the children engaged and attentive. Remarkably, children’s report of their error sensitivity corresponded to their neural response to errors. And, children’s report of their perfectionism (on the Child Error Sensitivity Index) related to their overall accuracy during the task. Taken together, these findings support the notion that even young children can accurately report on complex psychological constructs. Given the fact that many internalizing symptoms (including error sensitivity) may not be observable to parents, children may be the optimal reporters of these experiences and future studies should validate measures in younger populations.

This study also serves as a novel extension of previous work on the FSSC-R. To our knowledge, the FSSC-R has never been validated in children younger than 7 years old (Last, Francis, & Strauss, 1989; Ollendick, 1983). Our results show excellent overall and factor-specific internal reliability for children ages 5–7 years old. It also displayed good convergent validity in this age range through significant correlations with the Child Error Sensitivity Index.

Like other self-report measures, the Child Error Sensitivity Index has limitations. For instance, child participants might lack introspective ability or understanding of the material. In our study, while a research assistant read the statements to the child and explained when necessary, we relied solely on the report of the children and did not include multiple informants. Future studies should include other informants such as parents, teachers, peers, and lab-based observations.

It should be noted that in the current study, children completed the go/no-go task in the presence of an experimenter and a parent. While this design may increase the psychological relevance of the ERN (e.g., through social observation), it is unclear to what extent the ERN measured in the current study relates to the ERN as measured when children are alone in the room. Future work should examine whether the Child Error Sensitivity Index relates to the ERN when children complete the task in isolation.

The development of the Child Error Sensitivity Index extends previous work suggesting that increased reactivity to errors is an important risk factor for the development of anxiety across childhood. The use of a self-report measure is novel, building on previous work that has found that increased *neural* response to mistakes (i.e., the ERN) predicts new onset anxiety disorders in young children (Meyer et al., 2015). It is possible that using both self-report and neural measures of error sensitivity may result in a superior indicator of risk for anxiety. Future studies should examine if combining self-report and neural measures increases predictive ability for anxiety through a longitudinal design.

In the current study, we found that child error sensitivity mediated the relationship between the ERN and anxiety symptoms in children (as reported by parents and children). Additionally, we tested reversed causal models wherein the outcome variable and mediator were switched and found that both reversed models did not reach significance. These findings suggest that the indirect pathway from the ERN to anxiety symptoms via child error sensitivity is significant. However, deriving *causal* interpretations from mediation models tested in cross-sectional data should be done with caution. Future work should examine this model in longitudinal developmental samples, using multiple time points, to examine causal processes.

Furthermore, increased error sensitivity may be a novel *target* for intervention efforts. Using the self-report measure from the current investigation, we may begin to identify children who are at increased risk for developing anxiety and intervene before symptoms become impairing. Future studies should investigate to what extent computerized and clinical interventions may effectively reduce error sensitivity in children. Additionally, given evidence suggesting that critical or harsh parenting styles may increase error sensitivity in young children (Brooker & Buss, 2014; Meyer et al., 2014b), future interventions focusing on parents may also aim to reduce error sensitivity in children.

Notes

1. The peaks fell between a range of −25.16 ms and 98.63 ms (M = 47.24 ms).
2. The ERN, calculated as an area measure (0–100 ms after the response), was significantly correlated to the measure derived from the area around the peak, $r(80) = .96$, $p < .001$. The pattern of results was similar when analyses were conducted with the area measure (0–100 ms): the Child Error Sensitivity Index related to a larger ERN, even when controlling for other relevant variables (i.e., child age, performance on the task), $B = -.14$, $t = -2.80$, $p < .01$. Additionally, the parent-report of child error sensitivity related to an increased ERN in children, $B = -.11$, $t = -1.84$, $p = .07$, at a trend level. When the ERN was calculated using a residual-based difference score (instead of a subtraction-based difference score), the pattern of results was similar. The residual and subtraction-based difference scores were significantly correlated, $r(80) = .94$, $p < .001$. Furthermore, the Child Error Sensitivity Index related to a larger ERN, even when controlling for other relevant variables (i.e., child age, performance on the task), $B = -.107$, $t = -1.07$, $p < .05$. Additionally, the parent-report of child error sensitivity related to an increased ERN in children, $B = -1.21$, $t = -1.83$, $p = .08$, at a trend level. The split-half reliability of the ERN measured using an area measure (0–100 ms) was moderate (0.50).

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This research was not funded by an external funding agency.

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