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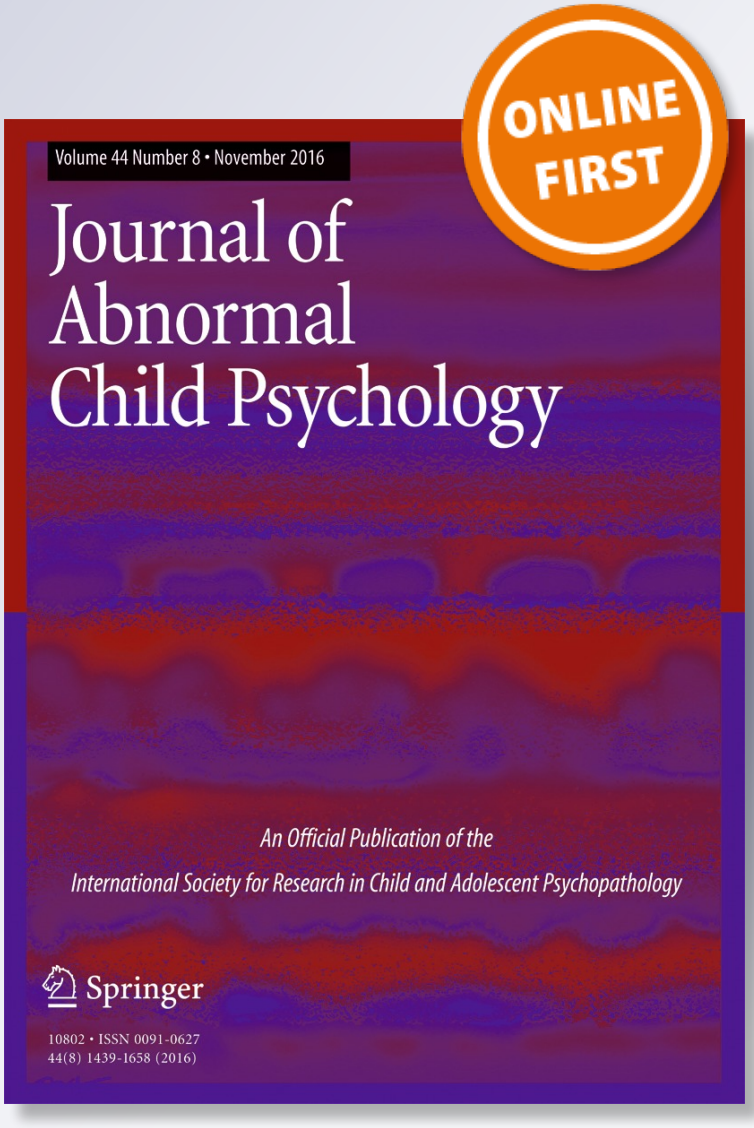


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# Associations between Disorder-Specific Symptoms of Anxiety and Error-Monitoring Brain Activity in Young Children

**Sharon L. Lo**[1] · **Hans S. Schroder**[1] · **Megan E. Fisher**[1] · **C. Emily Durbin**[1] · **Kate D. Fitzgerald**[2] · **Judith H. Danovitch**[3] · **Jason S. Moser**[1]



**Abstract** Anxiety disorders are among the earliest emerging disorders and most common mental health problem across the lifespan. A common characteristic of individuals with anxiety is poor attentional and cognitive control. Therefore, researchers are interested in how cognitive functioning relates to anxiety in young children. In particular, research has demonstrated associations between anxiety and electrophysiological markers of cognitive control skills such as the error-related negativity (ERN). The nature of the anxiety-ERN relationship is not well understood, however. The purpose of the present study was to examine: 1) the association between the ERN and diagnostically-defined symptoms of different anxiety disorders; and 2) the extent to which disorder-specific symptoms of anxiety moderated the association between ERN and behavioral performance on a Go/No-Go task in a sample of 139 children 5–8 years of age (70 females and 69 males). Results suggest that more separation anxiety disorder (SAD) symptoms are associated with a smaller ΔERN, even after controlling for other anxiety disorder symptoms. Children with more SAD symptoms showed higher error rates and failed to exhibit the expected association between ΔERN and behavioral performance, suggesting ineffective error-monitoring in young children with SAD problems.

**Keywords** Error-related negativity · Children · Separation anxiety · Behavioral Performanc

Anxiety disorders are the most common mental health problem in the United States with the earliest age of onset (Kessler et al. 2005), and are associated with substantial burdens to both individuals and society due to diminished work productivity and high medical care use (Greenberg et al. 1999; Hoffman et al. 2008). Clinical anxiety in childhood is associated with poor long-term outcomes related to academic, social, and emotional functioning (e.g., Copeland et al. 2015). Longitudinal studies further indicate that anxiety disorders in childhood confer significant risk for anxiety disorders in adulthood (e.g., Biederman et al. 2007; Pine et al. 1998). Extensive research indicates that poor self-regulation and cognitive control skills characterize children experiencing problematic anxiety (e.g., Derryberry and Reed 2002; Eisenberg et al. 2009; Lonigan et al. 2004). Understanding how cognitive control deficits relate to anxiety in children may therefore pave the way for novel, mechanistically-based strategies to treat and prevent anxiety from its earliest stages.

An increasing number of studies have used event-related brain potentials (ERPs) to examine relationships between anxiety and cognitive control processes, such as error-monitoring. The error-related negativity (ERN) is perhaps the most well-studied ERP related to performance errors, peaks at approximately 50 ms following an error, and is thought to index anterior cingulate cortex (ACC)-mediated cognitive control functions (Gehring et al. 1993, 2012). There is substantial evidence in adulthood showing that a larger ERN is associated with anxiety-related problems (e.g., Moser et al. 2013;

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Weinberg et al. 2012), perhaps indicating an overinvestment of frontally-mediated control processes among anxious adults (Eysenck and Derakshan 2011; Moser et al. 2013).

Important to the current study aims, however, are findings indicating that the anxiety-ERN relationship may be moderated by age. Although larger ERN has been observed in children 8 years or older with higher levels of anxiety (Hajcak et al. 2008; Ladouceur et al. 2006; Meyer et al. 2012), others have found the reverse association in younger children. For instance, Meyer et al. (2012) found a modest association between a smaller ERN and higher levels of parent-reported anxiety in younger children in their sample. Similarly, Torpey et al. (2013) found that a smaller ERN characterized 6-year-olds who displayed fearful behaviors. Consistent with these results, we recently reported an association between a smaller ERN and higher defensive reactivity, as indexed by a larger startle magnitude to aversive stimuli, in a sample of 3–7 year olds (Lo et al. 2015). Nonetheless, the evidence in young children remains limited because there are no investigations examining the relationship between the ERN and concurrent diagnostically-defined symptoms of anxiety disorders using a parent-reported measure that captures the full spectrum of severity across multiple dimensions of anxiety.

The functional significance of the anxiety-ERN relationship in children is further obscured because few consider the relationship in the context of behavioral performance (Schroder and Moser 2014). Behavioral performance can refer to different aspects of task performance such as task accuracy, reaction time, and number of errors. Existing research has focused on ERN amplitude differences between anxious and non-anxious populations, and thus less is known about how anxiety affects the relationship between the ERN and behavior. Research in healthy adults suggests that a larger ERN is related to better behavioral performance, namely higher accuracy and fewer errors (Gehring et al. 1993; Maier et al. 2011), supporting theories that propose the ERN serves critical cognitive control functions involved in adaptive behavioral adjustments and error correction (Botvinick and Cohen 2014). Of the few studies in children that have provided data on the association between the ERN and performance, results confirm that a larger ERN is associated with higher accuracy and fewer errors (e.g., Grammer et al. 2014; Lo et al. 2015).

Anxious adults, on the other hand, exhibit a larger ERN but do not demonstrate improved performance compared to non-anxious peers (e.g., Hajcak 2012; Moser et al. 2013). We have characterized this phenomenon as reflecting inefficient performance in anxiety because greater cognitive resources are allocated for no apparent behavioral gain (Eysenck et al. 2007; Moser et al. 2013; Moser et al. 2014). Similar to adults, research in children has suggested that healthy subjects and their anxious peers do not differ in terms of behavioral performance (Meyer et al. 2013). However, studies of young children have not fully characterized the nature of the anxiety-ERN relationship because they have yet to consider how anxiety may moderate the relationship between the ERN and behavioral performance.

The present study sought to address this gap by examining: 1) the associations between a range of disorder-specific symptoms of anxiety, the ERN, and behavioral performance in young children; and 2) the extent to which anxiety symptoms moderate the association between the ERN and behavioral performance. Children were sampled from the community across a wide range of anxiety severity and symptom manifestations. Given that there is no research on the association between diagnostically-defined symptoms of different anxiety disorders and the ERN in this age range, we took an exploratory approach as to which anxiety type would show the largest association with ERN. Regardless, given previous work in this age group (Lo et al. 2015; Meyer et al. 2012; Torpey et al. 2013), we expected higher levels of anxiety to be related to a smaller ERN. Moreover, we predicted that anxiety would moderate the relationship between the ERN and number of errors such that children with higher levels of anxiety would demonstrate no relationship between the ERN and number of errors, indicative of ineffective functioning. In contrast, we hypothesized that their low-anxiety counterparts would exhibit a relationship between a larger ERN and better performance, indicative of optimal functioning.

## Method

### Participants

Participants were 139 young children between 5 and 8 years of age ($M$ = 7.02 years, $SD$ = 0.74; 70 females and 69 males) and their parents ($M$ age = 37.02, $SD$ = 5.47, range 21–56; 118 females and 19 males) recruited as part of a larger project examining relations between parenting attitudes and children's cognitive processes. Families were recruited from a mid-size Midwestern city through advertisements and a laboratory database. Consistent with the demographic makeup of the area, families were 82.7% Caucasian, 3.6% African American, 2.9% Asian American, and 9.4% bi−/multiracial (categories do not sum to 100% since one subject chose not to disclose this information); 8.6% of families identified as Hispanic. All parents had completed high school, and most had completed college (95.4%). Participants received a $50 gift card for their participation. All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. Informed consent was obtained from all individual participants included in the study.

Of the 139 children who participated in the study, 1 was excluded from analysis since the subject opted to not complete the neurophysiological portion of the study, 3 were excluded due to poor quality EEG recording during task completion, and data from 2 participants were excluded who committed fewer than 6 errors (Olvet and Hajcak 2009). In total, 133 children were included in analyses using behavioral and ERP data from the Go/No-Go task.

### Parent-Report Measure

Parents completed the Revised Child Anxiety and Depression Scale—Parent Version (RCADS-P; Ebesutani et al. 2010) to assess their perception of their child's internalizing behaviors. The RCADS-P is a 47-item parent-reported measure that assesses symptomatology of both anxiety disorders and depression in accordance with DSM-IV nosology. The RCADS–P asks parents to rate items according to how often each applies to their child on a 4-point Likert scale from 0 (*never*) to 3 (*always*). RCADS–P subscale scores have demonstrated good convergent and discriminant validity in clinical and school-based samples of children aged 6–18 (Ebesutani et al. 2010). In this study, we were interested in relationships with disorder-specific symptoms of anxiety. Therefore, we focused on anxiety subscales in analyses. Internal consistency for subscales were: $\alpha = 0.73$ for separation anxiety disorder (SAD), $\alpha = 0.84$ for social phobia, $\alpha = 0.82$ for generalized anxiety, $\alpha = 0.61$ for panic disorder, and $\alpha = 0.67$ for obsessive-compulsive disorder.

### Task

Children completed a Go/No-Go task (Grammer et al. 2014) and were asked to help a zookeeper capture animals that had escaped their cages by pressing the spacebar quickly and accurately to the presentation of each animal (Go stimuli). No-Go stimuli consisted of three different orangutans that were helping the zookeeper, and therefore did not need to be captured. Children were instructed to withhold pressing the spacebar when they saw No-Go stimuli. On each trial, an animal was presented at a central location on the computer monitor for 750 ms. Before the stimulus was presented, a fixation cross appeared on the screen for 750 ms. The intertrial interval between stimulus offset and fixation cross onset was 500 ms.

The task began with a practice block consisting of 12 trials (9 Go trials and 3 No-Go trials). The practice block was repeated until the child demonstrated an understanding of the task. Then, children completed 8 blocks that consisted of 40 trials each (30 Go trials and 10 No-Go trials), totaling to 320 trials and lasting approximately 20 min. Novel sets of animal images (Go stimuli) balanced for animal size, color, and type were used in each block.

### Procedure

Parents completed questionnaires and children completed electrophysiological tasks in separate rooms. The experimenter was present in the child testing room throughout the tasks to ensure task and behavioral compliance, providing feedback and encouragement between task blocks. Children sat approximately 17 in. from a 21-in. computer monitor.

Children were instructed to place equal emphasis on accuracy and speed on the Go/No-Go task. Children were given specific performance feedback after each block of the Go/No-Go task if their accuracy was below 65% ("Remember to watch out for the orangutan friends"), or higher than 95% ("Remember to try and catch the animals even faster next time!"). Children received feedback regarding their task progress. Before the beginning of the task and after blocks 2, 4, 6, 7, and 8, children saw their current location on the "Zoo Map".

### Neurophysiological Recording, Data Reduction, and Analysis

All EEG recordings were taken from 64 Ag-AgCl electrodes using the Active Two Biosemi System (BioSemi, Amsterdam, The Netherlands). For EEG data acquisition, electrodes were placed in a stretch-lycra cap according to the 10/20 system with two additional electrodes placed on the left and right mastoids. Electrooculogram activity from eye movements and blinks were recorded at FP1 and three additional electrodes placed 1 cm from the pupil, one placed directly beneath the left pupil and the remaining two placed on the left and right outer canthi. In accordance with BioSemi's design specifications, the Common Mode Sense active electrode and Driven Right Leg passive electrode served as the reference during data acquisition. All EEG signals were digitized with a sampling rate of 512 Hz using ActiView software (BioSemi).

Offline, EEG data were re-referenced to the numeric mean of the mastoids and band-pass filtered with cutoffs of 0.1 and 30 Hz (12 dB/oct rolloff). All trials were also corrected for eye movements and blinks according to methods outlined by Gratton et al. (1983). A computer-based algorithm was used to detect physiological artifacts such that individual trials were rejected if there was a voltage step greater than 50 μV between sampling points, a voltage difference of more than 200 μV within a trial, or a maximum voltage difference less than 0.5 μV within a trial. Trials with reaction times occurring outside of a 200–1300 ms window were removed from analyses.

Based on visual inspection of the grand average ERNs and previous ERN studies in young samples (e.g., Grammer et al. 2014; Lo et al. 2015), the ERN and its correct-response negativity (CRN) counterpart were quantified as the average amplitude in the 0-100 ms post-response time window relative to

a − 200 to 0 ms pre-response baseline. The average amplitude in the 0-100 ms post-response time window were quantified across following five midline electrode sites: Fz (frontal), FCz (fronto-central), Cz (central), CPz (central-parietal), and Pz (parietal).

We also explored the role of sex as a variable in subsequent analyses given research in adults suggesting sex differences in the magnitude of the ERN (Larson et al. 2011) and the magnitude of relationship between the ERN and anxiety (Moser et al. 2016).

## Results

### Parent-Reported Measures

Descriptives and correlations between the RCADS-P scales are presented in Table 1. Children's total anxiety scores on the RCADS-P spanned the full range of scores from normative to clinically elevated, *T*-scores range: 41 *T* – 88 *T*. One-way ANOVAs were conducted to test all sex differnences. There were no significant sex differences in the total anxiety score or internalizing scale on the RCADs, $0.07 < p < 0.12$. Additionally, there were no significant sex differences in anxiety subscale scores, $.06 < p < 0.85$ with the exception of the OCD scale such that parent-reported OCD symptoms were higher in males compared to females, $F(1, 136) = 4.97$, $p = 0.03$.

### Behavioral Measures

As expected, children were significantly faster in responding on error No-Go trials relative to correct Go trials, $t(136) = 26.07$, $p < 0.001$, $d = 1.69$. There was evidence that post-error slowing, or the increase in reaction time after an error, relative to corrects, was present, $t(136) = 7.00$, $p < 0.001$, $d = 0.44$. In terms of post-error accuracy, children exhibited higher accuracy after committing a No-Go error, $M = 0.89$, $SD = 0.08$, compared to a correct Go response, $M = 0.88$, $SD = 0.04$; $t(135) = 2.04$, $p = 0.04$, $d = 0.16$. Behavioral performance descriptive statistics are presented in supplementary materials (Online Supplemental Table 1). No significant sex differences were observed in reaction time on No-Go trials, $F(1, 136) = 1.64$, $p = 0.20$, reaction time on Go trials, $F(1, 136) = 1.19$, $p = 0.28$, post-error accuracy after a No-Go error, $F(1, 135) = 0.00$, $p = 0.99$, post-error accuracy after a correct Go response, $F(1, 135) = 2.22$, $p = 0.14$, and total accuracy, $F(1, 136) = 1.55$, $p = 0.22$.

### ERP Measures

The response-locked waveforms can be seen in Fig. 1. A five (Site: Fz, FCz, Cz, CPz, and Pz) x two (error versus correct) repeated measures ANOVA was conducted to assess the presence of the ERN. There was greater negativity on No-Go errors compared to correct Go trials, $F(1, 134) = 338.48$, $p < .001$, $\eta_p^2 = 0.72$, and a main effect of electrode site, $F(1, 134) = 7.27$, $p < 0.001$, $\eta_p^2 = 0.05$. The site X trial type interaction was also significant, $F(4, 536) = 125.46$,

**Table 1** Bivariate correlations between RCAD scales, ERPs and error rates

| Variable | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Age | -- | | | | | | | | | | |
| 2. SAD | -0.02 | -- | | | | | | | | | |
| 3. GAD | 0.20* | 0.59** | -- | | | | | | | | |
| 4. PD | 0.20* | 0.51** | 0.56** | -- | | | | | | | |
| 5. SoP | 0.21* | 0.38** | 0.46** | 0.39** | -- | | | | | | |
| 6. OCD | 0.05 | 0.47** | 0.65** | 0.53** | 0.38** | -- | | | | | |
| 7. Total Anxiety | 0.17* | 0.78** | 0.82** | 0.71** | 0.77** | 0.72** | -- | | | | |
| 8. ERN FCz | –0.12 | 0.11 | 0.08 | 0.04 | -0.08 | 0.02 | 0.03 | -- | | | |
| 9. CRN FCz | –0.06 | –0.16† | –0.06 | –0.01 | –0.02 | –0.10 | -0.09 | 0.37** | -- | | |
| 10. ΔERN FCz | –0.09 | 0.23** | 0.12 | 0.05 | -0.07 | 0.09 | 0.09 | 0.78** | –0.30** | -- | |
| 11. Error No-Go Trials | –0.04 | 0.20* | 0.12 | 0.05 | -0.02 | 0.10 | 0.11 | 0.14 | –0.20* | 0.27** | -- |
| M | 7.02 | 4.29 | 4.25 | 1.52 | 7.65 | 1.57 | 3.45 | –5.68 | 4.79 | –10.5 | 32.1 |
| SD | 0.74 | 3.42 | 2.71 | 1.76 | 4.48 | 1.90 | 3.11 | 5.65 | 3.74 | 5.49 | 10.6 |

*Note*. *SAD* Separation Anxiety Disorder, *GAD* Generalized Anxiety Disorder, *PD* Panic Disorder, *SoP* Social Phobia, *OCD* Obsessive-Compulsive Disorder, *ERN* Error-Related Negativity, *CRN* Correct-Related Negativity, *ΔERN* Error-Related Negativity Difference

† $p \leq 0.10$

* $p \leq 0.05$

** $p \leq 0.01$

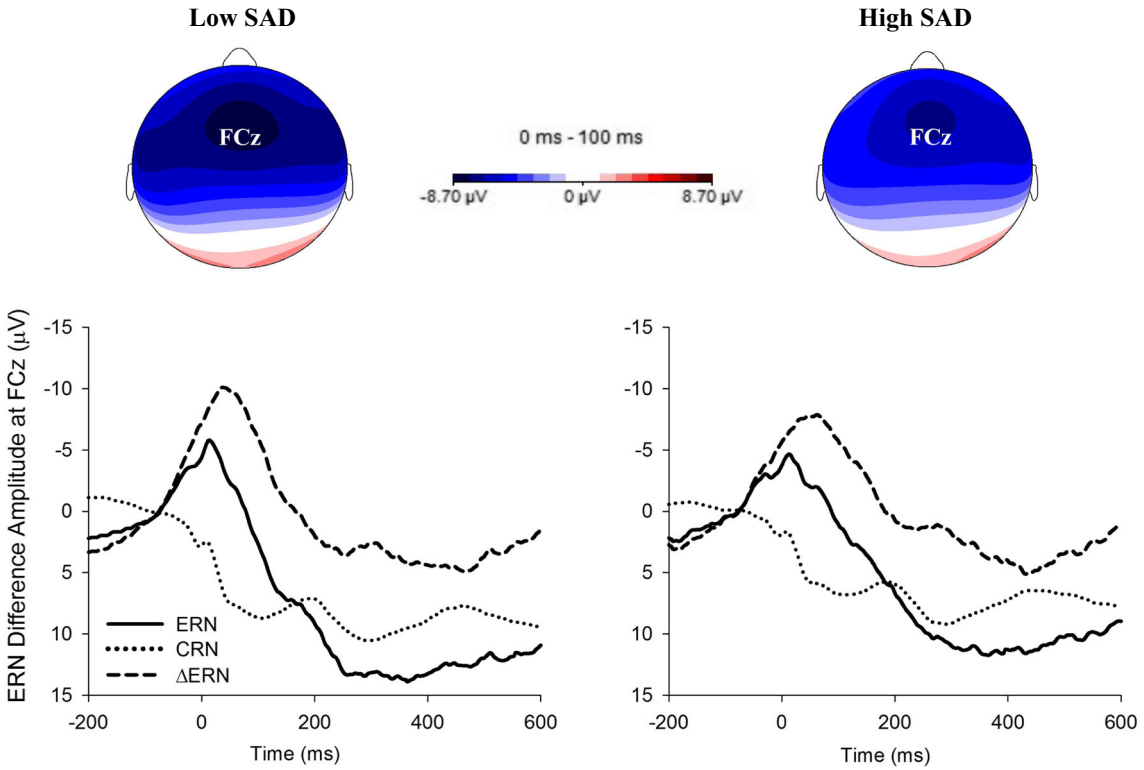


**Fig. 1** Scalp topographies depicting voltages of the ΔERN, quantified as the average activity in the first 100 ms after the response, for low SAD group (*upper left*) and high SAD group (*upper right*). Response-locked, grand-average ERP waveforms elicited during Go/No-Go task for low parent-reported SAD (lower left) and high parent-reported SAD (*lower right*). Time 0 represents response onset for both corrects and errors. A significantly smaller (i.e., less negative) ΔERN is observed in the high parent-reported SAD group compared to the low parent-reported SAD group. FCz = Frontocentral; SAD = Separation Anxiety Disorder; ERN = Error-related Negativity; CRN = Correct-related Negativity, ΔERN = Error-related Negativity Difference

$p < 0.001$, $\eta_p^2 = 0.48$, indicating a larger error vs. correct (ΔERN) difference at frontocentral recording sites. Confirming expectations and consistent with previous work (e.g., Falkenstein et al. 2000; Luu et al. 2003), follow-up t-tests indicated that the ΔERN was most negative at FCz compared to Fz, $t(134) = 2.83$, $p = 0.005$, Cz, $t(134) = 7.07$, $p < 0.001$, CPz, $t(134) = 9.65$, $p < 0.001$, and Pz, $t(134) = 8.88$, $p < 0.001$. Therefore, further analyses focused on FCz. No sex differences were observed for the ERN, $F(1, 134) = 1.57$, $p = 0.21$, CRN, $F(1, 134) = 2.08$, $p = 0.15$, or the ERN difference, $F(1, 134) = 0.06$, $p = 0.81$. Descriptive statistics for ERP measures are presented in supplementary materials (Online Supplemental Table 2).

## Links between Children's Anxiety Symptoms, Behavior, and ERPs

Associations between No-Go errors and ERP measures are presented in Table 1. Results indicated that fewer No-Go errors were significantly associated with a smaller CRN, and larger ΔERN. No significant associations between reaction times and ERP measures were observed, however, $rs = -0.02$ to 0.12, $ps = 0.15$ to 0.89.

Relations between anxiety symptoms, behavioral performance, and ERP measures are presented in Table 1. Overall, RCAD-P scales were highly intercorrelated. SAD symptoms were significantly associated with behavioral performance and ERP measures. Specifically, higher levels of SAD were significantly related to more No-Go errors and smaller ΔERN. The reduced ΔERN in children with higher levels of SAD (defined as 1 SD above the mean) compared to lower levels of SAD (defined as 1 SD below the mean) is depicted in Fig. 1.

Given that the RCAD scales were highly intercorrelated, partial correlations were conducted to examine the unique variance shared by SAD, behavior, and ERP measures controlling for other parent-reported anxiety symptoms. Partial correlations revealed that SAD remained significantly associated with a smaller ΔERN, $r = 0.23$, $p = 0.01$; the association with more errors was somewhat attenuated, $r = 0.15$, $p = 0.09$.

## Moderating Effects of SAD Symptoms and Sex on Brain-Behavior Relationships

Given that the association between SAD, ERN, and No-Go errors were robust after controlling for other parent-reported

anxiety symptoms, Hayes (2013) PROCESS macro for SPSS was used to test the extent to which SAD symptoms and sex moderated the association between the ΔERN and number of No-Go errors. Age was entered as a co-variate.

Results indicated a main effect of ΔERN and a main effect of SAD such that a smaller ΔERN, $b = 0.48$, $SE_b = 0.16$, $p < 0.01$, and higher SAD, $b = 0.59$, $SE_b = 0.27$, $p = 0.03$, were significant predictors of more No-Go errors (see Fig. 2). Consistent with our hypothesis, we found evidence for a moderating role of SAD symptoms in the association between ΔERN and No-Go errors, $b = -0.10$, $SE_b = 0.04$, $p = 0.02$. The moderating effect of SAD accounted for an additional 4% of variance explained by the model, $R^2$ change =0.04, $p = 0.02$. Simple slopes for the association between ΔERN and number of No-Go erorrs were tested for low (−1 *SD* below the mean) and high (+1 *SD* above the mean) levels of SAD symptoms (Fig. 3). Simple slope tests confirmed hypotheses that for children with fewer SAD symptoms, a larger ΔERN was associated with fewer No-Go errors, $b = 0.82$, $SE_b = 0.23$, $p < .001$, LLCI =0.37, ULCI =1.27, whereas there was no association between ΔERN and No-Go errors at high levels of SAD, $b = 0.14$, $SE_b = 0.21$, $p = 0.49$, LLCI = −0.27, ULCI =0.56.

Sex was also considered as a moderator in the association between ΔERN and behavioral performance. Results indicated a trend-level moderating effect of sex on the relationship between ΔERN and number of No-Go errors, $b = 0.55$, $SE_b = 0.33$, $p = 0.09$. Specifically, boys demonstrated a stronger relationship between a larger ΔERN and fewer No-Go errors, $b = 0.71$, $SE_b = 0.22$, $p = .002$, LLCI =0.27, ULCI =1.14, compared to girls, who exhibited no relationship between ΔERN and behavioral performance, $b = 0.15$, $SE_b = 0.24$, $p = 0.54$, LLCI = − 0.33, ULCI =0.64. Sex did not moderate the association between SAD symptoms and No-Go errors, $b = -0.01$, $SE_b = 0.61$, $p = 0.99$. Moreover, sex did not further modify the moderating effect of SAD symptoms on the association between ΔERN and number of No-Go errors, $b = 0.04$, $SE_b = 0.09$, $p = 0.41$.

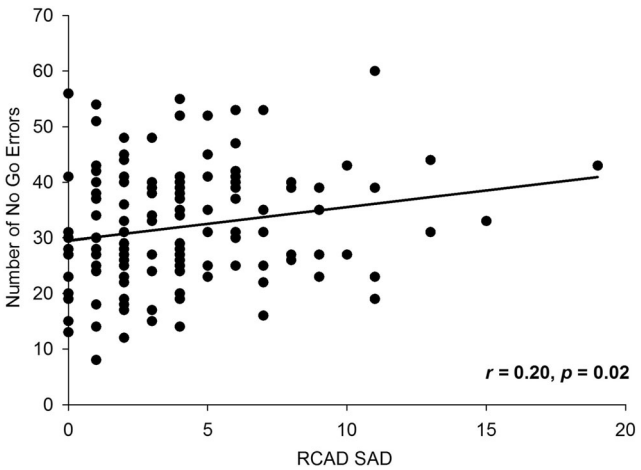


**Fig. 2** Scatterplot of the association between separation anxiety disorder (SAD) symptoms and number of No-Go errors

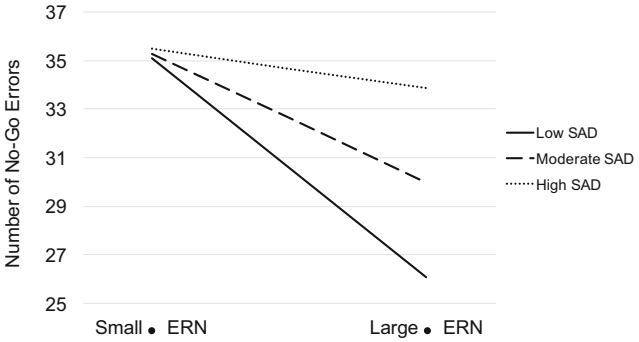


**Fig. 3** Plot depicting simple-slope analyses for the moderating role of SAD on the relationship between ΔERN and number of No-Go Errors. Results indicate that children with higher parent-reported SAD symptoms fail to exhibit the expected association between ΔERN and number of No-Go errors, suggesting ineffective error-monitoring in young children with SAD problems

## Discussion

The present study sought to examine associations between disorder-specific symptoms of anxiety and the ERN in a sample of young children. As a secondary aim, the extent to which disorder-specific symptoms of anxiety moderated the association between the ERN and behavioral performance was evaluated. Results suggested that the ERN-anxiety relationship in children 5–8 years of age were specific to SAD symptoms such that a smaller ERN was significantly associated with higher levels of SAD symptoms and higher error commission. Symptoms of SAD significantly moderated the relationship between the ERN and number of No-Go errors such that at low levels of SAD, the expected relationship between larger ERN and fewer No-Go errors was observed, but this relationship was not present at high levels of SAD. These results suggest that children with higher levels of SAD symptoms do not exhibit an ERN-behavior pattern that is indicative of effective error-monitoring functioning.

### Relationships between Disorder-Specific Symptoms of Anxiety and ERN

Extensive evidence in adults suggests that GAD (Weinberg et al. 2010, 2012) and OCD (Gehring et al. 2000; Xiao et al. 2011) are most robustly related to a larger ERN. In contrast, less is known about how the ERN relates to diagnostically-defined childhood anxiety disorder symptoms in young children. Of the studies that have examined disorder-specific symptoms, none have explored the ERN-anxiety relationship across multiple dimensions of anxiety and most have focused on pediatric OCD in adolescence ($M$ = 13.46 years,

*SD* = 0.95) (Carrasco et al. 2013). Results suggest that similar to adults, older children with OCD symptoms exhibit a larger ERN compared to healthy controls (Carrasco et al. 2013). Other investigations in children have suggested that a larger ERN is associated with higher levels of anxiety in children 8 years or older (Ladouceur et al. 2006; Meyer et al. 2012), but that the relationship is opposite in younger children (Lo et al. 2015; Torpey et al. 2013).

Results from the present study suggested that the ERN-anxiety relationship was specific to SAD even after accounting for symptoms of other disorder-specific anxiety symptoms. Specifically, a smaller ΔERN was associated with more SAD symptoms. This is consistent with previous research in younger children, supporting hypotheses that a smaller ERN may index poor cognitive control skills, which are linked to internalizing problems. These skills are involved in the ability to control one's attention and focus flexibly. Research from developmental and cognitive psychology literatures indicate that children who exhibit poor cognitive control skills have more problems with anxiety because they experience difficulties shifting their attention away from threatening stimuli and using voluntary attention to engage in self-regulatory strategies (e.g., Derryberry and Reed 2002; Eisenberg et al. 2009; Lonigan et al. 2004).

There are several possible explanations for the specificity of the ERN-anxiety association to SAD. First, the peak age of onset for SAD is between 7 and 9 years of age, which coincides with the mean age of the present sample, and is the most common childhood anxiety disorder (Carlson and Siroky 2016; Costello and Angold 1995). Therefore, SAD may be particularly relevant to cognitive functioning for this age range given that it is most commonly observed during this time. Research also supports that SAD may be particularly important during this developmental period as it is the most commonly identified childhood disorder that predicts later psychopathology, specifically increased risk for experiencing a range of internalizing disorders (Biederman et al. 2005; Biederman et al. 2007). Second, estimates suggest that nearly 50% of 8-year-old children endorse sub-threshold SAD symptoms that do not cause clinically significant impairment (Figueroa et al. 2012). Given that the present study is drawn from a community sample, it is likely that the sample demonstrated higher prevalence and variation in SAD symptoms compared to other anxiety disorder symptoms. The present finding that a smaller ΔERN is associated with more SAD symptoms thus corroborates the saliency and importance of SAD in this developmental period, and clarifies the ERN-anxiety relationship in young children. Specifically, the link between SAD symptoms and the ERN may reflect the association between anxiety and poor cognitive control skills.

In terms of the role of sex, the present results suggested no sex differences in SAD symptoms, ERN, or number of No-Go errors. Existing findings are mixed in terms of sex differences in anxiety in young children. Some studies have suggested greater anxiety symptoms in girls only, boys only, and others find no sex differences (e.g., Compton et al. 2000; Lewinsohn et al. 1998). The present finding that boys exhibited more OCD symptoms compared go girls in this sample is consistent with research suggesting that OCD is more prevalent in boys than girls during childhood (Walitza et al. 2011). However, not all studies have confirmed this statistic (i.e., Chabane et al. 2005). Research suggests that prevalence rates of anxiety disorders by sex in young children may be impacted by sample differences (i.e., clinical versus community) and type of measure used (informant-report versus self-report).

### Moderating Role of SAD Symptoms and Sex in the ERN-Behavior Relationship

In order to better understand the functional significance of the anxiety-ERN relationship, it is critical to examine the role of anxiety and the ERN in the context of behavioral performance. No study to date has examined the moderating role of diagnostically-defined symptoms of anxiety on the relationship between the ERN and behavioral performance in children or adults.

We recently investigated potential mechanisms to explain the disconnect between a larger ERN and the failure of anxious adults to adaptively change their behavioral performance (Moran et al. 2015). Findings suggested that this disconnect was a result of decreased theta band synchrony, indicative of reduced connectivity between medial frontal and lateral prefrontal regions associated with the generation of the ERN. Importantly, these findings support a proposed mechanism detailing how anxiety impacts the communication within neural networks involved in cognitive control that then results in inefficient behavioral performance. Results from the present study suggest a developmental difference in the relationship between anxiety and cognitive control-related error-monitoring processes. Specifically, unlike adults with anxiety, children with higher levels of SAD symptoms in this study demonstrated smaller (not larger) ΔERN and poorer (not comparable) behavioral performance. Moreover, SAD symptoms significantly moderated the relationship between the ERN and behavioral performance such that children with more SAD symptoms did not exhibit a relationship between ΔERN and behavior. In contrast, children with fewer SAD symptoms demonstrated the expected association between a larger ΔERN and fewer number of No-Go errors. Together, the present findings suggest insufficient error-monitoring in children with higher SAD symptoms results in ineffective behavioral performance perhaps because the reduced error-monitoring signal fails to adaptively regulate behavior in these children.

The current findings suggest a novel developmental picture of the relationship between anxiety and cognitive control

related error-monitoring. First, it is important to note that a significant portion of children with high levels of SAD will not go on to develop clinical anxiety problems. This may result in part because such children will likely improve in their cognitive control abilities over time, as reflected by an increased ERN and capacity to reestablish a functional relationship between the ERN and behavior. Children with high levels of SAD who go on to develop clinical anxiety problems in adulthood may also improve in their cognitive control skills with age, but a significantly larger ERN may act more as compensatory effort (Moser et al. 2013) that may remain uncoupled from behavioral regulation.

A trend-level effect of sex on the association between ΔERN and number of No-Go errors was observed such that boys demonstrated a stronger ERN-behavior association compared to girls. Research in adults suggest that the ERN-anxiety relationship is stronger in females compared to males (Moser et al. 2016). Notably, the observed trend for sex differences is similar to the moderating role of SAD symptoms in the current study; specifically, both girls and children who have higher symptoms of SAD do not demonstrate the expected ERN-behavior relationship. Given the large body of literature suggesting that anxiety disorders are not only more prevalent in women, but also more debilitating (e.g., Kessler et al. 2012; McLean et al. 2011), it is important for future research to investigate the moderating role of both sex and anxiety on the ERN-behavior relationship across development.

## Limitations

There are several limitations to address in future research. First, disorder-specific symptoms of anxiety were assessed using a parent-reported instrument. Several lines of research have highlighted the disadvantages of parent-report methods such as systematic bias based on parental characteristics (De Los Reyes and Kazdin 2005), including maternal psychopathology (e.g., Boyle and Pickles 1997; Durbin and Wilson 2012; Gartstein et al. 2009), parental stress (Foley et al. 2005) and low socioeconomic status (Duhig et al. 2000).[1] Second, while children in this sample exhibited a wide range of disorder-specific symptoms of anxiety, future studies need to extend these findings in clinical samples. Existing research investigating the ERN in clinical samples has generally included children older than those in our sample. Data from these studies suggest that a larger ERN is observed in children with clinical anxiety disorders (e.g., Ladouceur et al., 2006). Given that a majority of our sample was between the ages of 6 and 7 years, it will be important for future studies to determine if existing findings in children older than 8 years differ from those in the present study because of developmental age or clinical status. Lastly, the parent-reported instrument did not include any cut-off criterion, so low and high SAD groups were defined as one standard deviation below, and above the mean, respectively. However, given the dimensional nature of clinical anxiety symptoms, we can anticipate that children with a clinical diagnosis likely have higher parent-reported symptoms of SAD and therefore results may be generalizable for those populations.

[1] Parents also completed the Penn State Worry Questionnaire (PSWQ; Meyer et al. 1990) to measure their own trait level of worry. After accounting for variance shared with parent self-reported worry, parent-reported SAD remained significantly associated with a smaller ΔERN ($r = 0.23$, $p = 0.01$).

## Conclusions

Despite these limitations, findings significantly contribute to our understanding of the function of the anxiety-ERN relationship in young children. Results suggest that in children aged 5–8 years, higher SAD symptoms are associated with a smaller ΔERN, and the ERN-SAD relationship is robust even after controlling for other disorder-specific symptoms of anxiety. Children with more SAD symptoms also show higher error rates and fail to exhibit the expected association between larger ΔERN and better behavioral performance. Together, findings suggest insufficient and ineffective error-monitoring in young children with SAD problems, which may occur because of a disconnect between neural substrates involved in signaling need for control and implementation of adaptive behavior.

### Compliance with Ethical Standards

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**Conflict of Interest** The authors declare that they have no conflict of interest.

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