J Abnorm Child Psychol (2015) 43:821–829
DOI 10.1007/s10802-014-9918-1

Self-Reported and Observed Punitive Parenting Prospectively Predicts Increased Error-Related Brain Activity in Six-Year-Old Children

Alexandria Meyer · Greg Hajcak Proudfit · Sara J. Bufferd · Autumn J. Kujawa · Rebecca S. Laptook · Dana C. Torpey · Daniel N. Klein

Published online: 5 August 2014

Abstract The error-related negativity (ERN) is a negative deflection in the event-related potential (ERP) occurring approximately 50 ms after error commission at fronto-central electrode sites and is thought to reflect the activation of a generic error monitoring system. Several studies have reported an increased ERN in clinically anxious children, and suggest that anxious children are more sensitive to error commission—although the mechanisms underlying this association are not clear. We have previously found that punishing errors results in a larger ERN, an effect that persists after punishment ends. It is possible that learning-related experiences that impact sensitivity to errors may lead to an increased ERN. In particular, punitive parenting might sensitize children to errors and increase their ERN. We tested this possibility in the current study by prospectively examining the relationship between parenting style during early childhood and children's ERN approximately 3 years later. Initially, 295 parents and children (approximately 3 years old) participated in a structured observational measure of parenting behavior, and parents completed a self-report measure of parenting style. At a follow-up assessment approximately 3 years later, the ERN was elicited during a Go/No-Go task, and diagnostic interviews were completed with parents to assess child psychopathology. Results suggested that both observational measures of hostile parenting and self-report measures of authoritarian parenting style uniquely predicted a larger ERN in children 3 years later. We previously reported that children in this sample with anxiety disorders were characterized by an increased ERN. A mediation analysis indicated that ERN magnitude mediated the relationship between harsh parenting and child anxiety disorder. Results suggest that parenting may shape children's error processing through environmental conditioning and thereby risk for anxiety, although future work is needed to confirm this hypothesis.

Keywords Error-related negativity · ERN · Parenting · Children · Development · Response monitoring · Anxiety

A. Meyer (✉) · G. H. Proudfit · S. J. Bufferd · A. J. Kujawa · R. S. Laptook · D. C. Torpey · D. N. Klein
Department of Psychology, Stony Brook University, 11794-2500 Stony Brook, NY, USA
e-mail: ammeyer3@gmail.com

Introduction

Among children and adolescents, anxiety disorders are the most frequently diagnosed form of psychopathology (Beesdo et al. 2009) and often continue into adulthood, resulting in chronic impairment (Beesdo 2010; Bittner et al. 2007; Kessler et al. 2005; Last et al. 1996; Pine 2007; Pine et al. 1998; Wittchen et al. 2000). For successful prevention and intervention, it may be important to identify early neural markers that distinguish pathological trajectories of development, as well as modifiable environmental factors that impact neural markers of risk.

A considerable amount of research has focused on an event-related potential (ERP) related to error monitoring as a potential neural correlate of pathological anxiety. The error-related negativity (ERN) is a negative deflection in the waveform occurring approximately 50 ms after error commission at fronto-central electrode sites and is thought to reflect the activation of a generic error monitoring system (Falkenstein et al. 1991; Gehring et al. 1993). Research suggests that the ERN is generated in the anterior cingulate cortex (Debener et al. 2005; Dehaene et al. 1994; Hoffmann and Falkenstein 2010) and is evident across a range of response and stimulus modalities (Holroyd et al. 1998; Nieuwenhuis et al. 2001).

Variation in the ERN has been related to individual differences in sensitivity to errors and defensive reactivity following mistakes (Hajcak 2012; Weinberg et al. 2012a). More specifically, an increased ERN has been associated with personality traits that characterize anxiety, such as behavioral inhibition system (BIS) sensitivity (Amodio et al. 2008), worry (Hajcak et al. 2003), high negative affect (Hajcak et al. 2004), and punishment sensitivity (Boksem et al. 2006). Moreover, an increased ERN has been observed in individuals with obsessive-compulsive disorder (OCD; Endrass et al. 2008; Gehring et al. 2000; Xiao et al. 2011) and generalized anxiety disorder (GAD; Weinberg et al. 2012b; Weinberg et al. 2010).

Consistent with findings in adult populations, an increased ERN has also been found within a heterogeneous group of clinically anxious children (Ladouceur et al. 2006), children with OCD (Carrasco et al. 2013; Hajcak et al. 2008; Hanna et al. 2012), children with non-clinical symptoms of OCD (Santesso et al. 2006), children with clinical anxiety as young as 6 years old (Meyer et al. 2013a), adolescents with non-clinical anxiety symptoms (Meyer et al. 2012), in children characterized by early temperamental behavioral inhibition (McDermott et al. 2009), as well as unaffected siblings of children with OCD (Carrasco et al. 2013). In light of these findings, the ERN has been proposed as a neurobehavioral trait (Hajcak 2012) and endophenotype (Proudfit et al. 2013) that may be useful in understanding and characterizing developmental risk trajectories associated with anxiety disorders.

Although the ERN magnitude appears to be moderately heritable (Anokhin et al. 2008), a large portion of variance is unaccounted for by genetic influences (between 40–60 %), suggesting that the environment may play a substantial role in the development of the ERN. Recent work indicates that the ERN is increased when errors are punished (Meyer et al., Enhanced error-related negativity is specific to punishment condition in high trait anxiety, unpublished manuscript; Riesel et al. 2012) and that this effect persists after punishment ends. Thus, learning-related experiences surrounding error commission may impact the ERN. One important element of the *early* childhood learning environment is parenting style. Indeed, harsh parents tend to punish children's mistakes more frequently and with more intensity (Robinson et al. 2001), often resulting in children's excessive concern over making mistakes (Kawamura et al. 2002). One mechanism that may underlie an increased ERN in childhood is chronic exposure to a punitive learning environment as a result of harsh parenting.

Parenting styles characterized by high control, low support, hostility, rejection, and authoritarianism have been associated with anxiety in offspring (Barrett et al. 2002; Bögels and Brechman-Toussaint 2006; Brown and Whiteside 2008; Erozkan 2012; McLeod et al. 2007; Muris et al. 2003, 2000; Rapee et al. 2010; Viana and Rabian 2008; van der Voort et al. 2014). If punishing errors in a laboratory setting can have a persisting impact on the magnitude of the ERN, it is possible that punitive parenting styles may similarly sensitize children to errors and increase the magnitude of their ERN. Considering that an increased ERN has been found in anxious children (Hajcak et al. 2008; Ladouceur et al. 2006; Meyer et al. 2013b) and may be a risk factor preceding the development of anxiety disorders (Hajcak 2012; Hajcak et al. 2008; Meyer, Proudfit, & Klein, In preparation), a further possibility is that the relationship between punitive parenting and anxiety is mediated by such increases in the ERN.

In the current study, we examined the relationship between parenting styles and children's ERN in a longitudinal study including 295 parent and child dyads. Because the effects of early environmental influences on development may be particularly important (Ainsworth et al. 2014; Landry et al. 2001), we assessed parenting when the children were relatively young (approximately 3 years old). Initially, parents and children completed behavioral tasks that were coded by trained observers to assess hostile and supportive parenting style. Parents also completed the Parenting Styles and Dimensions Questionnaire (PSDQ). During the second assessment, when the children were approximately 6 years old, ERPs were recorded while children performed a Go/No-Go task. Based on work suggesting that the ERN is sensitive to punishment, we hypothesized that both observed hostile parenting and self-reported authoritarian parenting style at age 3 would prospectively predict an increased ERN in children at Age 6. And, considering that previous studies utilizing both observed and self-reported parenting data find only small correlations between these measures (Susan M. Bögels and Brechman-Toussaint 2006; Greco and Morris 2002; Siqueland et al. 1996), we tentatively hypothesized that PSDQ self-reported authoritarianism and observed parental hostility may contribute unique variance to child ERN. We also hypothesized that the parenting-ERN relationship would be specific to harsh forms of parenting, and would not be related to other forms of maladaptive parenting such as low support or high permissiveness. Finally, we previously found an increased ERN in children with clinical anxiety in this sample (Meyer et al. 2013a). Therefore, we explored whether children with anxiety disorders at Age 6 were characterized by more punitive parents at Age 3, and sought to test the possibility that the ERN may mediate the relationship between harsh parenting and child anxiety disorders.

Method

Participants Participants were identified through a commercial mailing list. An initial assessment was completed when children were approximately 3 years of age, wherein a primary caretaker brought their child into the laboratory to complete a

series of tasks. At this assessment, the primary parent completed self-reports regarding parenting style and both the child and parent participated in a modified version of the Teaching Tasks battery that provided an observational measure of hostile and supportive parenting style. Three years later, when children were approximately 6 years of age, they returned to the laboratory for an EEG assessment and clinical interview with the parent (among a series of other tasks) were completed. As previously reported (Torpey et al. 2011), EEG data from 87 out of 413 children were not included in the analyses (69 due to committing 5 or fewer errors, 16 due to having 5 or fewer artifact-free error trials, 1 due to technical error, and 1 due to having an ERP value more than 3 standard deviations from the overall mean).[1] Of the 326 children with adequate EEG data from the Age 6 assessment, 295 had completed the Teaching Tasks battery and 280 had completed self-report questionnaires regarding parenting style. For analyses including only the teaching task data, all 295 participants were utilized and for analyses including both measures, 280 participants were included. Of the children who had usable data for the entire study (280, 144 female), the mean age at the first assessment was 3.51, SD=0.27, and at the second assessment was 6.11, SD=0.42. Overall, 91.5 % of the children were Caucasian, 1.7 % Asian, 8.5 % Hispanic, 1.7 % African American, and 5.4 % identified themselves as "other." Most children's parents were married (88.5 %), employed (mothers: 64.2 %, fathers: 96.5 %), and had at least one parent who graduated from college (67.6 %). The study was approved of by the Stony Brook Institutional Review Board and completed with consent of the participants.

Observed Parental Hostility and Support At the first assessment, the parent who accompanied the child to the laboratory (93 % mothers) and child participated in a session that included a modified version of the Teaching Tasks battery (Egeland et al. 1995). This battery included six standardized tasks (e.g., block-building, book-reading) that were designed to elicit various parent and child behaviors. Parental hostility was defined as a parent's expression of anger, frustration, and/or criticism towards her child and parental support was defined as parent's provision of emotional support and expression of positive regard. Coders rated behavior on a five-point scale for each task and these ratings were averaged across tasks for: parent hostility: M=1.19, SD=0.33, Range: 1.0–3.67, and parent support: M=4.48, SD=0.56, Range: 2.17–5.00. Coders were unaware of self-reported parenting style. The interrater reliability (based on 55 assessments) and internal consistency of the hostility (ICC=0.83, α=0.76) and support (ICC=0.85, α=0.88) scale were acceptable.

[1] These 87 children did not differ from the rest of the sample in age, race, or any of the parenting measures, all ps>0.20.

Self-Reported Parenting Style The primary parent also completed the Parenting Styles and Dimensions Questionnaire (PSDQ; Robinson et al. 2001) at the first assessment. The PSDQ contains 37 items. Parents rate each item on a scale from 1 (*never*) to 5 (*always*), measuring three parenting styles: authoritative (high control, high warmth), authoritarian (high control, low warmth), and permissive (low control, high warmth). The factors' internal consistencies (authoritative: α=0.82, authoritarian: α=0.75, permissive: α=0.74) were acceptable.

Diagnostic Interviewing As previously reported (Meyer et al. 2013a), the Preschool Age Psychiatric Assessment (PAPA; Egger et al. 1999) was used to assess a range of disorders from the Diagnostic Statistical Manual of Mental Disorders (DSM-IV-TR; American Psychiatric Association 2000) in children at the second assessment when they were Age 6. Anxiety disorders included specific phobia, separation anxiety disorder, social phobia, generalized anxiety disorder, obsessive-compulsive disorder, and agoraphobia. Symptoms occurring 3 months prior to the interview were rated to maximize recall. For information on the interview's psychometric properties, see Egger et al. (2006). Interviews were conducted face-to-face with parents by M.A.-level psychologists. A second diagnostician rated audiotapes of 35 interviews for reliability, oversampling for psychopathology. Kappas were the following: any anxiety disorder (0.89), separation anxiety (1.00), specific phobia (0.79), agoraphobia (1.00); the other anxiety disorders were not diagnosed in the interrater reliability sample.

EEG Task and Materials As previously described (Meyer et al. 2013a; Torpey et al. 2011), a Go/No-Go task was administered using Presentation software (Neurobehavioral Systems, Inc.). The stimuli were green equilateral triangles presented in one of four different orientations for 1,200 ms in the middle of the monitor. On 60 % of the trials, triangles were vertically aligned and pointed up, 20 % were vertically aligned and pointed down, 10 % were tilted slightly to the left, and 10 % were titled slightly to the right. Children were told to respond to upward-pointing triangles by pressing a button, and to withhold a response to all other triangles. Following the presentation of the triangle, a small gray fixation cross was displayed in the middle of the monitor for between 300–800 ms before the next trial began. Children completed four blocks of 60 trials each.

Psychophysiological Recording The Active Two system (Biosemi, Amsterdam, Netherlands) was used to acquire EEG data and 32 Ag/AgCl-tipped electrodes were used with a small amount of electrolyte gel (Signa Gel; Bio-Medical Instruments Inc., Warren, Michigan) at each electrode position. All data were sampled at 512 Hz. The ground electrode

during acquisition was formed by the common mode sense active electrode and the driven right leg passive electrode.

Data was processed offline with Brain Vision Analyzer (Brain Products, Gilching, Germany). EEG data was re-referenced to the nose and high and low pass filtered at 0.1 Hz and 30 Hz, respectively. EEG segments of 1,500 ms were extracted from the continuous EEG, beginning 500 ms prior to responses. Data was then corrected for eye-movements and blinks (Gratton et al. 1983) and artifacts were rejected if any of the following criteria were met: a voltage step of more than 50 microvolts between data points, a voltage difference of 300 microvolts within a single trial, or a voltage difference of less than 0.5 microvolts within 100 ms intervals. After this, data were visually inspected for remaining artifacts. ERP averages were created for error and correct trials and a baseline of the average activity from −500 to–300 ms prior to the response was subtracted from each data point.

ERP and behavioral results in the full sample have been previously reported (Torpey et al. 2011). The error-related negativity (ERN) and correct-related negativity (CRN) were scored as the average voltage in the window between 0 ms and 100 ms after response commission on error and correct trials, respectively; the CRN and ERN were quantified at Fz, where error-related brain activity was maximal. The delta ERN (ΔERN), thought to reflect error-specific activity, was calculated by subtracting the CRN from the ERN.

All statistical analyses were conducted using SPSS (Version 17.0) General Linear Model Software, with Greenhouse-Geisser correction applied to p values with multiple-df, repeated-measures comparisons when necessitated by violation of the assumption of sphericity. The Pearson correlation coefficient (r) was used to examine associations between parenting and error-related brain activity. A simultaneous regression analysis was also used to examine the relationships between self-reported and observed parenting with error-related brain activity.

We utilized a nonparametric bootstrapping method (MacKinnon et al. 2004) to conduct mediational analyses to explore the extent to which error-related brain activity mediated the relationship between parenting and child anxiety disorder. This approach has been shown to be more statistically powerful than other tests of mediation (MacKinnon et al. 2002). To test for mediation, we used an SPSS macro (Preacher and Hayes 2004), which provided 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 $p<0.05$ level. Direct and indirect effects were tested using 5,000 bootstrap samples.

Results

Parenting and Child Error-Related Brain Activity

As previously reported (Meyer et al. 2013b; Torpey et al. 2011; Torpey et al. 2013), the ERP response was more negative following errors than correct responses, $F(1, 294)=104.20$, $p<0.001$.[2] Table 1 shows the means, standard deviations, and correlations for error-related brain activity and all parenting variables (i.e., PSDQ factors and observed hostility and support) across the sample. An increase in both the ERN and ΔERN was related to higher self-reported authoritarian parenting (PSDQ) and observed hostile parenting. Additionally, bivariate correlations revealed that the relationship between self-reported authoritarian parenting (PSDQ) and observed hostility was small to moderate.

Table 2 presents the results of a simultaneous regression examining the associations between age at the EEG assessment, all three of the PSDQ parenting factors, observed hostility and support and the ΔERN. Children with parents who displayed increased hostility as observed in the lab at age 3 where characterized by an increased ΔERN at Age 6, after controlling for age, the PSDQ parenting factors, and observed parental support. Additionally, children whose parents reported an authoritarian parenting style at age 3 were characterized by an increased ΔERN at Age 6 (at a trend level, $p=0.08$), even when accounting for the influence of age and the other PSDQ and observed parenting factors.[3] Figure 1 presents waveforms and topographical distribution of error-related activity as a function of parenting style. For representation purposes, a median-split was performed on both authoritarian parenting style and observed hostile parenting.[4]

[2] Behavioral data for this sample has been previously reported (Meyer et al. 2013a; Torpey et al. 2011; Torpey et al. 2013). In the current sample, reaction time during correct trials, $M=625.67$, $SD=73.63$, was significantly slower than during error trials, $M=505.23$, $SD=87.69$, $F(1, 268)=992.23$, $p<0.001$. On average, children committed 15.89 errors, $SD=7.30$, and made 212.14, $SD=15.39$, correct responses. Neither reaction times during error or correct trials or accuracy was related to any of the parenting variables (observed or self-reported) in the current study, all ps>0.10.

[3] The reduction in significance between the ΔERN and authoritarianism in the regression (compared to the bivariate correlation) was due to including observed parenting in the model, not due to including the other PDSQ factors. In a model including age and all PDSQ factors predicting ΔERN, authoritarianism was related to the ΔERN, $p<0.05$.

[4] When child fear (measured observationally at Age 3), parental education, the Hollingshead Four-Factor Index of Socioeconomic Status, and maternal lifetime history of anxiety, substance abuse, or depression are added as covariates to the simultaneous regression, the pattern of results is not altered (authoritarian parenting and hostility are associated with an increased ERN in children).

Table 1 Bivariate correlations between ERPs, self-reported parenting (PSDQ) factors and observed hostile and supportive parenting as well as means and standard deviations for all measures

	1	2	3	4	5	6	Mean	SD
1. ΔERN	-						−4.93	8.30
2. ERN	0.85**	-					−0.68	8.04
3. PSDQ Factor 1: authoritative	−0.05	−0.03	-				61.44	6.68
4. PSDQ Factor 2: authoritarian	−0.10†	−0.12*	−0.23**	-			20.08	4.67
5. PSDQ Factor 3: permissive	−0.03	−0.05	−0.10†	0.42**	-		10.76	3.26
6. Observed hostility	−0.13*	−0.14*	−0.03	0.21**	0.27**	-	1.19	0.33
7. Observed support	0.06	0.10	0.05	−0.21**	−0.23**	−0.65**	4.48	0.56
8. Composite: harsh parenting	−0.14*	−0.16**	−0.07	0.37**	0.33**	0.77**	-	-

†=$p<0.09$, *=$p<0.05$, **=$p<0.01$

Parenting, Child Error-Related Brain Activity, and Child Anxiety

Table 3 includes means and standard deviations of error-related brain activity and all parenting variables for children with and without anxiety disorders at Age 6. As previously reported (Meyer et al. 2013b), children with anxiety disorders were characterized by an increased ΔERN, $F(1, 294)=6.13$, $p<0.01$.[5] Additionally, as can be seen in Table 3, parents of children with anxiety disorders were characterized by a more authoritarian parenting style at age 3, $t(273)=2.88$, $p<0.05$.

We then conducted analyses to examine whether the ΔERN mediated the relationship between harsh parenting and childhood anxiety disorders. Due to the fact that aggregate scores of parenting from multiple sources has been shown to be more consistent and generalizable (Bögels and Melick 2004), we *z*-scored and combined the PSDQ Authoritarian factor and observed hostile parenting score, to derive a score reflecting both self-reported and observed parenting (i.e., harsh parenting). Correlations for this variable are presented in Table 1. Additionally, we *z*-scored the ΔERN to produce standardized β weights. Results indicated that the mediation model was predictive of variance in childhood anxiety, at a trend level, $R^2=0.024$, $F=2.87$, $p=0.06$. Harsh parenting significantly predicted the magnitude of the ΔERN, $\beta=-0.14$, $t(279)=-2.23$, $p<0.05$, and the ΔERN in turn significantly predicted childhood anxiety disorders, $\beta=0.51$, $t(279)=2.37$, $p<0.05$. Although the aggregate measure of harsh parenting was not directly predictive of childhood anxiety disorders, $\beta=-0.03$ $t(279)=-0.16$, $p=0.88$, there was a significant indirect effect of harsh parenting, mediated through the ΔERN, on childhood anxiety disorders, $\beta=-0.08$ (95 % confidence interval [CI]: −0.19 to–0.02). As the mediator (i.e., child ERN) and dependent variable (i.e., child anxiety disorder) were assessed contemporaneously, we also examined the alternative model in which child anxiety was posited to mediate the effects of harsh parenting on ERN. The results indicated that the indirect effect of harsh parenting, mediated through child anxiety, on the ΔERN was not significant ($\beta=0.01$; 95 % confidence interval [CI]: −0.27 to 0.17).

[5] In the previous study on a subset of 48 of these participants (Meyer et al. 2013b), the ERN was maximal at Cz and scored at this site. However, in the current larger sample, the ERN was maximal at Fz. Regardless of whether the ERN is measured at Cz or Fz, in either sample, children with anxiety disorders are characterized by an increased ΔERN.

Discussion

Consistent with other work indicating that punishing errors has a lasting impact on ERN magnitude (Meyer et al., Enhanced error-related negativity is specific to punishment condition in high trait anxiety, unpublished manuscript; Riesel et al. 2012), observed parental hostility, as well as self-reported authoritarian parenting style, both prospectively predicted an increased ERN in children 3 years later. As hypothesized, these relationships were specific to harsh parenting; observed parental support and self-reported authoritative and permissive parenting did not predict child ERN. Finally, the ERN mediated the relationship between harsh parenting and

Table 2 Simultaneous regression analyses examining associations of self-reported parenting (PSDQ) factors and observed hostile and supportive parenting with the ΔERN

	ΔERN		
Variables entered	*b*	Std. error	*t*
	N=280		
Age at ERN assessment	−1.50	1.23	−1.22
PSDQ Factor 1: authoritative	−0.11	0.08	−1.44
PSDQ Factor 2: authoritarian	−0.22	0.12	−1.79†
PSDQ Factor 3: permissive	0.19	0.18	1.07
Observed hostility	−3.92	2.00	−1.96*
Observed support	-0.78	1.18	−0.66
Overall model: total *R*-squared	0.04		

†=$p<0.09$, *=$p<0.05$, **=$p<0.01$

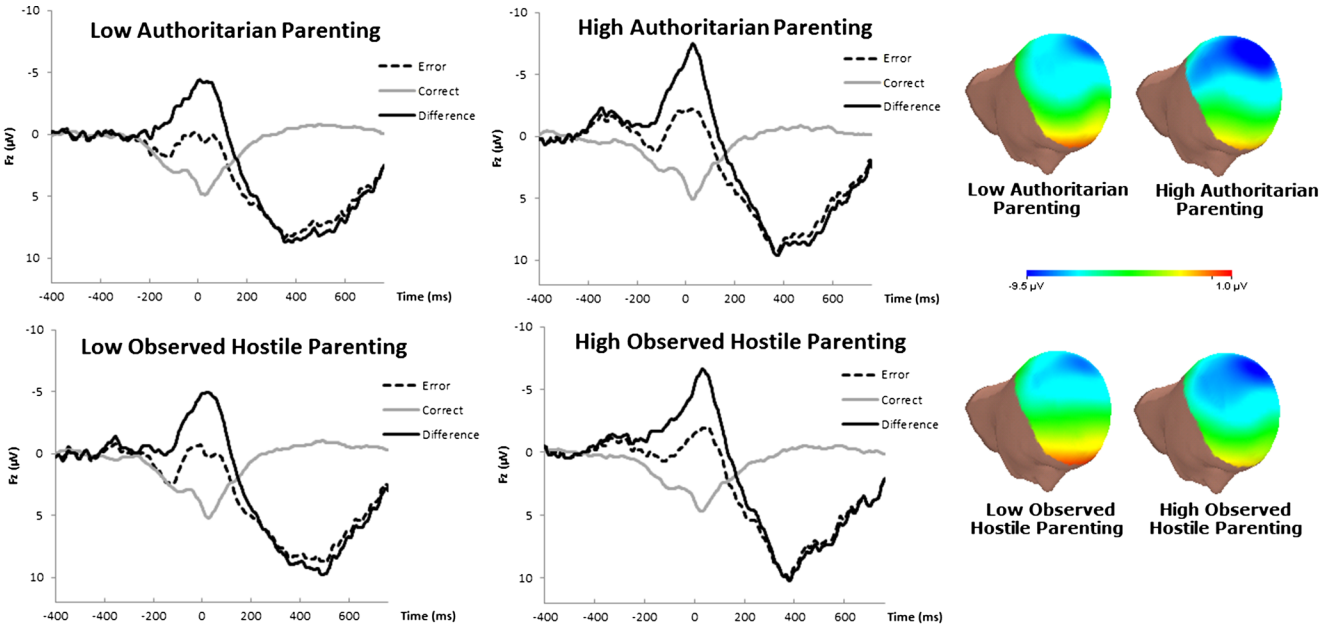

Fig. 1 On the *left*, response-locked ERP waveforms for correct and error trials, as well as the difference wave. On the *right*, topographic maps of activity (error minus correct). For representation purposes, a median-split was performed on both authoritarian parenting style (*top*) and observed hostile parenting (*bottom*)

child anxiety disorder status at Age 6, suggesting that harsh parenting may relate to subsequent risk for anxiety insofar as it potentiates children's neural response to their errors.

As expected, laboratory observations and self-reported measures of parenting were only minimally correlated. This finding is in line with previous work (Bögels and Brechman-Toussaint 2006; Greco and Morris 2002; Siqueland et al. 1996), which suggests that observation and self-reported parenting may measure somewhat different constructs. Although observational measures reduce social desirability and other biases associated with self-reports, it is difficult to determine the extent to which observations conducted in a short laboratory visit generalize to daily interactions between parents and children (Bögels and Brechman-Toussaint 2006; Epstein 1980; Greco and Morris 2002). Few studies have used both questionnaire and observational measures of parenting (and none in relation to an ERP), and it is therefore notable that in the current study both measures uniquely predicted ERN magnitude in children.

Table 3 Means and standard deviations of error-related brain activity and all parenting variables for children with and without anxiety disorders at age 6

	Anxiety diagnosis (N=43)	No anxiety diagnosis (N=260)
1. ΔERN	−7.74 (8.74) μV*	−4.49 (8.25) μV*
2. ERN	−2.07 (7.93) μV	−0.46 (8.13) μV
3. PSDQ Factor 1: authoritative	62.44 (6.39)	61.30 (6.72)
4. PSDQ Factor 2: authoritarian	22.20 (5.25)*	19.78 (4.52)*
5. PSDQ Factor 3: permissive	12.03 (3.94)†	10.57 (3.12)†
6. Observed hostility	1.23 (0.29)	1.18 (0.33)
7. Observed support	4.42 (0.62)	4.49 (0.55)

†=p<0.09, *=p<0.05, **=p<0.01

While existing EEG and ERP studies investigating the impact of parenting on brain activity have focused on extreme neglect and maltreatment (e.g., Davies 1978; Ito et al. 1998; Marshall et al. 2008; Pollak et al. 1997; Pollak et al. 2001; Shackman et al. 2007), only one previous study has investigated variation in normative parenting styles in relationship to ERPs (Euser et al. 2013), finding that parental warmth predicted an increased P300 following positive feedback. The current study contributes to this literature by relating variation in normative parenting behaviors to the ERN, a potential biomarker of risk for anxiety disorders (Hajcak 2012; Proudfit et al. 2013).

Previous human and animal studies suggest that parenting may substantially impact brain development and stress reactivity (Belsky and de Haan 2011; Caldji et al. 1998; Dougherty et al. 2011; Francis et al. 1999; Kertes et al. 2009; Kryski et al. 2013; Liu et al. 1997; Teicher et al. 2003; Teicher and Samson 2013; Whittle et al. 2009), potentially programming biological responses to threatening stimuli to allow organisms to thrive under the unique demands of their environment (Francis et al. 1999). The results of the current study fit with this proposition insofar as harsh parenting may increase the threatening nature and salience of errors, and thereby increase children's neural response to their own error commission. However, the extent to which parenting

specifically impacts the ERN relative to other measures of threat sensitivity is unknown and future work should explore this possibility.

The results from the current study support the notion that parenting may play a role in shaping children's ERN; however, it is also possible that genes influencing both parenting and children's ERN underlie this association. Previous studies have reported associations between parenting style and child functioning that are not solely genetic effects (Belsky and de Haan 2011; Boom 1994; Plomin et al. 2008). Future work might address this issue by examining both child and parent ERNs to determine if the impact of parenting on the child's ERN is independent of the parent's ERN. Additionally, it is important to consider the possibility that children with an increased ERN may elicit hostile parenting. Future developmental studies might measure both the ERN and parenting at multiple points to examine this issue.

Considering that the impact of genetic and environmental influences may shift across the lifespan, and the structural features of the anterior cingulate cortex show more environmental plasticity in adolescents compared to young children (Lenroot et al. 2009), it is possible that environmental conditions (e.g. parenting) may have a differential impact on the ERN at different developmental stages. Whereas the current study focused on a developmental period between the ages of 3 and 6 years of age, future work might explore how parenting impacts error processing across other developmental periods. Given that the association between parenting and the ERN was smaller than the association between the ERN and child anxiety, future work should consider the impact of other environmental factors (e.g. normative variation in: socioeconomic status, life stress and adversity, peer criticism) on the ERN in children.

In the current study, we wished to explore whether punitive or harsh parenting, defined broadly, would relate to the magnitude of the ERN in children. Future studies could explore whether more specific parenting styles may impact the ERN (e.g., parents who are critical of mistakes, parents who are inconsistent with feedback, parents who use physical punishment). Additionally, future studies should explore whether the current findings are generalizable to more diverse populations. Furthermore, future studies could incorporate self-report to measure children's concern about making mistakes to determine if harsh parenting is related to this construct, or related to more general processes such as increased self-awareness or vigilance.

Although exploratory, the results of the mediation analysis suggest the possibility that one pathway whereby parents confer risk for clinical anxiety to their children is through the impact of harsh parenting on children's error processing. Previous work suggests that parenting interventions may decrease anxiety in children (Rapee et al. 2010). The current study suggests that one possible mechanism through which parenting interventions decrease anxiety in children is by reducing error monitoring, as indexed by the ERN.

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

References

Ainsworth, M. D. S., Blehar, M. C., Waters, E., & Wall, S. (2014). *Patterns of attachment: A psychological study of the strange situation*: Psychology Press.

American Psychiatric Association. (2000). Diagnostic and statistical manual of mental disorders DSM-IV-TR fourth edition (text revision) author: American Psychiatr.

Amodio, D. M., Master, S. L., Yee, C. M., & Taylor, S. E. (2008). Neurocognitive components of the behavioral inhibition and activation systems: implications for theories of self-regulation. *Psychophysiology, 45*(1), 11–19. doi:10.1111/j.1469-8986.2007.00609.x.

Anokhin, A. P., Golosheykin, S., & Heath, A. C. (2008). Heritability of frontal brain function related to action monitoring. *Psychophysiology, 45*(4), 524–534.

Barrett, P., Shortt, A., & Healy, L. (2002). Do parent and child behaviours differentiate families whose children have obsessive-compulsive disorder from other clinic and non-clinic families? *Journal of Child Psychology and Psychiatry, and Allied Disciplines, 43*(5), 597–607.

Beesdo, P. D. S. L. R. W. H. (2010). Incidence and risk patterns of anxiety and depressive disorders and categorization of generalized anxiety disorder. *Archives of General Psychiatry, 67*(1), 47–57. doi:10.1001/archgenpsychiatry.2009.177.

Beesdo, K., Knappe, S., & Pine, D. S. (2009). Anxiety and anxiety disorders in children and adolescents: developmental issues and implications for DSM-V. *Psychiatric Clinics of North America, 32*(3), 483–524. doi:10.1016/j.psc.2009.06.002.

Belsky, J., & de Haan, M. (2011). Annual research review: parenting and children's brain development: the end of the beginning. *Journal of Child Psychology and Psychiatry, 52*(4), 409–428.

Bittner, A., Egger, H. L., Erkanli, A., Jane Costello, E., Foley, D. L., & Angold, A. (2007). What do childhood anxiety disorders predict? *Journal of Child Psychology and Psychiatry, 48*(12), 1174–1183.

Bögels, S. M., & Brechman-Toussaint, M. L. (2006). Family issues in child anxiety: Attachment, family functioning, parental rearing and beliefs. *Clinical Psychology Review, 26* (7), 834–856. doi: http://dx.doi.org/10.1016/j.cpr.2005.08.001

Bögels, S. M., & Melick, M. (2004). The relationship between child-report, parent self-report, and partner report of perceived parental rearing behaviors and anxiety in children and parents. *Personality and Individual Differences, 37*(8), 1583–1596.

Boksem, M. A. S., Tops, M., Wester, A. E., Meijman, T. F., & Lorist, M. M. (2006). Error-related ERP components and individual differences in punishment and reward sensitivity. *Brain Research, 1101*(1), 92–101. doi:10.1016/j.brainres.2006.05.004.

Boom, D. C. (1994). The influence of temperament and mothering on attachment and exploration: an experimental manipulation of sensitive responsiveness among lower class mothers with irritable infants. *Child Development, 65*(5), 1457–1477.

Brown, A. M., & Whiteside, S. P. (2008). Relations among perceived parental rearing behaviors, attachment style, and worry in anxious children. *Journal of Anxiety Disorders, 22*(2), 263–272.

Caldji, C., Tannenbaum, B., Sharma, S., Francis, D., Plotsky, P. M., & Meaney, M. J. (1998). Maternal care during infancy regulates the

development of neural systems mediating the expression of fearfulness in the rat. *Proceedings of the National Academy of Sciences, 95*(9), 5335–5340.

Carrasco, M., Harbin, S. M., Nienhuis, J. K., Fitzgerald, K. D., Gehring, W. J., & Hanna, G. L. (2013). Increased error-related brain activity in youth with obsessive-compulsive disorder and unaffected siblingseased error–related brain activity in youth with obsessive–compulsive disorder and unaffected siblings. *Depression and Anxiety, 30*(1), 39–46.

Davies, R. K. (1978). Incest: some neuropsychiatric findings. *The International Journal of Psychiatry in Medicine, 9*(2), 117–121.

Debener, S., Ullsperger, M., Siegel, M., Fiehler, K., von Cramon, D. Y., & Engel, A. K. (2005). Trial-by-trial coupling of concurrent electroencephalogram and functional magnetic resonance imaging identifies the dynamics of performance monitoring. *The Journal of Neuroscience, 25*(50), 11730–11737. doi:10.1523/jneurosci.3286-05.2005.

Dehaene, S., Posner, M. I., & Don, M. T. (1994). Localization of a neural system for error detection and compensation. *Psychological Science, 5*(5), 303–305.

Dougherty, L. R., Klein, D. N., Rose, S., & Laptook, R. S. (2011). Hypothalamic-pituitary-adrenal axis reactivity in the preschool-age offspring of depressed parents moderation by early parenting. *Psychological Science, 22*(5), 650–658.

Egeland, B., Weinfield, N., Hiester, M., Lawrence, C., Pierce, S., Chippendale, K., & Powell, J. (1995). Teaching tasks administration and scoring manual. *University of Minnesota*.

Egger, Ascher, B., & Angold, A. (1999). The preschool age psychiatric assessment: Version 1.1. *Unpublished Interview Schedule). Center for Developmental Epidemiology, Department of Psychiatry and Behavioral Sciences, Duke University Medical Center*.

Egger, H. L., Erkanli, A., Keeler, G., Potts, E., Walter, B. K., & Angold, A. (2006). Test-retest reliability of the preschool age psychiatric assessment (PAPA). *Journal of the American Academy of Child & Adolescent Psychiatry, 45*(5), 538–549.

Endrass, T., Klawohn, J., Schuster, F., & Kathmann, N. (2008). Overactive performance monitoring in obsessive-compulsive disorder: ERP evidence from correct and erroneous reactions. *Neuropsychologia, 46*(7), 1877–1887. doi:10.1016/j.neuropsychologia.2007.12.001.

Epstein, S. (1980). The stability of behavior: II. Implications for psychological research. *American Psychologist, 35*(9), 790.

Erozkan, A. (2012). Examination of relationship between anxiety sensitivity and parenting styles in adolescents. *Educational Sciences: Theory and Practice, 12*(1), 52–57.

Euser, A. S., Evans, B. E., Greaves-Lord, K., Huizink, A. C., & Franken, I. H. A. (2013). Parental rearing behavior prospectively predicts adolescents' risky decision-making and feedback-related electrical brain activity. *Developmental Science, 16*(3), 409–427. doi:10.1111/desc.12026.

Falkenstein, M., Hohnsbein, J., Hoormann, J., & Blanke, L. (1991). Effects of crossmodal divided attention on late ERP components. II. Error processing in choice reaction tasks. *Electroencephalography and Clinical Neurophysiology, 78*(6), 447–455. doi:10.1016/0013-4694(91)90062-9.

Francis, D., Diorio, J., Liu, D., & Meaney, M. J. (1999). Nongenomic transmission across generations of maternal behavior and stress responses in the rat. *Science, 286*(5442), 1155–1158.

Gehring, W. J., Goss, B., Coles, M. G. H., Meyer, D. E., & Donchin, E. (1993). A neural system for error detection and compensation. *Psychological Science, 4*(6), 385–390.

Gehring, W. J., Himle, J., & Nisenson, L. G. (2000). Action-monitoring dysfunction in obsessive-compulsive disorder. *Psychological Science, 11*(1), 1–6. doi:10.1111/1467-9280.00206.

Gratton, G., Coles, M. G. H., & Donchin, E. (1983). A new method for off-line removal of ocular artifact. *Electroencephalography and Clinical Neurophysiology, 55*(4), 468–484. doi:10.1016/0013-4694(83)90135-9.

Greco, L. A., & Morris, T. L. (2002). Paternal child-rearing style and child social anxiety: investigation of child perceptions and actual father behavior. *Journal of Psychopathology and Behavioral Assessment, 24*(4), 259–267.

Hajcak, G. (2012). What we've learned from mistakes. *Current Directions in Psychological Science, 21*(2), 101–106. doi:10.1177/0963721412436809.

Hajcak, G., McDonald, N., & Simons, R. F. (2003). Anxiety and error-related brain activity. *Biological Psychology, 64*(1–2), 77–90. doi:10.1016/s0301-0511(03)00103-0.

Hajcak, G., McDonald, N., & Simons, R. F. (2004). Error-related psychophysiology and negative affect. *Brain and Cognition, 56*(2), 189–197. doi:10.1016/j.bandc.2003.11.001.

Hajcak, G., Franklin, M. E., Foa, E. B., & Simons, R. F. (2008). Increased error-related brain activity in pediatric obsessive-compulsive disorder before and after treatment. *The American Journal of Psychiatry, 165*(1), 116–123. doi:10.1176/appi.ajp.2007.07010143.

Hanna, G. L., Carrasco, M., Harbin, S. M., Nienhuis, J. K., LaRosa, C. E., Chen, P., . . . Gehring, W. J. (2012). Error-Related Negativity and Tic History in Pediatric Obsessive-Compulsive Disorder. *Journal of the American Academy of Child & Adolescent Psychiatry*.

Hoffmann, S., & Falkenstein, M. (2010). Independent component analysis of erroneous and correct responses suggests online response control. *Human Brain Mapping, 31*(9), 1305–1315. doi:10.1002/hbm.20937.

Holroyd, C. B., Dien, J., & Coles, M. G. H. (1998). Error-related scalp potentials elicited by hand and foot movements: evidence for an output-independent error-processing system in humans. *Neuroscience Letters, 242*(2), 65–68. doi:10.1016/s0304-3940(98)00035-4.

Ito, Y., Teicher, M. H., Glod, C. A., & Ackerman, E. (1998). Preliminary evidence for aberrant cortical development in abused children a quantitative EEG study. *The Journal of Neuropsychiatry and Clinical Neurosciences, 10*(3), 298–307.

Kawamura, K. Y., Frost, R. O., & Harmatz, M. G. (2002). The relationship of perceived parenting styles to perfectionism. *Personality and Individual Differences, 32*(2), 317–327.

Kertes, D. A., Donzella, B., Talge, N. M., Garvin, M. C., Van Ryzin, M. J., & Gunnar, M. R. (2009). Inhibited temperament and parent emotional availability differentially predict young children's cortisol responses to novel social and nonsocial events. *Developmental Psychobiology, 51*(7), 521–532.

Kessler, R. C., Berglund, P., Demler, O., Jin, R., Merikangas, K. R., & Walters, E. E. (2005). Lifetime prevalence and age-of-onset distributions of DSM-IV disorders in the national comorbidity survey replication. *Archives of General Psychiatry, 62*(6), 593–602.

Kryski, K. R., Dougherty, L. R., Dyson, M. W., Olino, T. M., Laptook, R. S., Klein, D. N., & Hayden, E. P. (2013). Effortful control and parenting: associations with HPA axis reactivity in early childhood. *Developmental Science, 16*(4), 531–541. doi:10.1111/desc.12050.

Ladouceur, C. D., Dahl, R. E., Birmaher, B., Axelson, D. A., & Ryan, N. D. (2006). Increased error–related negativity (ERN) in childhood anxiety disorders: ERP and source localization. *Journal of Child Psychology and Psychiatry, 47*(10), 1073–1082.

Landry, S. H., Smith, K. E., Swank, P. R., Assel, M. A., & Vellet, S. (2001). Does early responsive parenting have a special importance for children's development or is consistency across early childhood necessary? *Developmental Psychology, 37*(3), 387–403. doi:10.1037/0012-1649.37.3.387.

Last, C. G., Perrin, S., Hersen, M., & Kazdin, A. E. (1996). A prospective study of childhood anxiety disorders. *Journal of the American Academy of Child and Adolescent Psychiatry, 35*(11), 1502–1510.

Lenroot, R. K., Schmitt, J. E., Ordaz, S. J., Wallace, G. L., Neale, M. C., Lerch, J. P., & Giedd, J. N. (2009). Differences in genetic and environmental influences on the human cerebral cortex associated with development during childhood and adolescence. *Human Brain Mapping, 30*(1), 163–174.

Liu, D., Diorio, J., Tannenbaum, B., Caldji, C., Francis, D., Freedman, A., & Meaney, M. J. (1997). Maternal care, hippocampal glucocorticoid receptors, and hypothalamic-pituitary-adrenal responses to stress. *Science, 277*(5332), 1659–1662.

MacKinnon, D. P., Lockwood, C. M., Hoffman, J. M., West, S. G., & Sheets, V. (2002). A comparison of methods to test mediation and other intervening variable effects. *Psychological Methods, 7*(1), 83.

MacKinnon, D. P., Lockwood, C. M., & Williams, J. (2004). Confidence limits for the indirect effect: distribution of the product and resampling methods. *Multivariate Behavioral Research, 39*(1), 99–128.

Marshall, P. J., Reeb, B. C., Fox, N. A., Nelson, C. A., & Zeanah, C. H. (2008). Effects of early intervention on EEG power and coherence in previously institutionalized children in Romania. *Development and Psychopathology, 20*(3), 861.

McDermott, J. M., Perez-Edgar, K., Henderson, H. A., Chronis-Tuscano, A., Pine, D. S., & Fox, N. A. (2009). A history of childhood behavioral inhibition and enhanced response monitoring in adolescence are linked to clinical anxiety. *Biological Psychiatry, 65*(5), 445–448. doi:10.1016/j.biopsych.2008.10.043.

McLeod, B. D., Wood, J. J., & Weisz, J. R. (2007). Examining the association between parenting and childhood anxiety: a meta-analysis. *Clinical Psychology Review, 27*(2), 155–172.

Meyer, A., Weinberg, A., Klein, D. N., & Hajcak, G. (2012a). The development of the error-related negativity (ERN) and its relationship with anxiety: Evidence from 8 to 13 year-olds. *Developmental Cognitive Neuroscience, 2*(1), 152–161. doi:10.1016/j.dcn.2011.09.005.

Meyer, A., Hajcak, G., Torpey, D. C., Kujawa, A., Kim, J., Bufferd, S., . . . Klein, D. N. (2013a). Increased error-related brain activity in six-year-old children with clinical anxiety. *Journal of Abnormal Child Psychology*, 1–10.

Meyer, A., Hajcak, G., Torpey, D. C., Kujawa, A., Kim, J., Bufferd, S., & Klein, D. N. (2013b). Increased error-related brain activity in six-year-old children with clinical anxiety. *Journal of Abnormal Child Psychology, 41*(8), 1257–1266.

Muris, P., Meesters, C., & van den Berg, S. (2003). Internalizing and externalizing problems as correlates of self-reported attachment style and perceived parental rearing in normal adolescents. *Journal of Child and Family Studies, 12*(2), 171–183.

Muris, P., Meesters, C., Merckelbach, H., & Hülsenbeck, P. (2000). Worry in children is related to perceived parental rearing and attachment. *Behaviour Research and Therapy, 38*(5), 487–497.

Nieuwenhuis, S., Ridderinkhof, K. R., Blom, J., Band, G. P., & Kok, A. (2001). Error-related brain potentials are differentially related to awareness of response errors: evidence from an antisaccade task. *Psychophysiology, 38*(5), 752–760.

Pine, D. S. (2007). Research review: a neuroscience framework for pediatric anxiety disorders. *Journal of Child Psychology & Psychiatry, 48*(7), 631–648.

Pine, D. S., Cohen, P., Gurley, D., Brook, J., & Ma, Y. (1998). The risk for early-adulthood anxiety and depressive disorders in adolescents with anxiety and depressive disorders. *Archives of General Psychiatry, 55*(1), 56–64.

Plomin, R., DeFries, J. C., McClearn, G. E., & McGuffin, P. (2008). *Behavioral genetics*. New York: WH Freeman.

Pollak, S. D., Cicchetti, D., Klorman, R., & Brumaghim, J. T. (1997). Cognitive brain event–related potentials and emotion processing in maltreated children. *Child Development, 68*(5), 773–787.

Pollak, S. D., Klorman, R., Thatcher, J. E., & Cicchetti, D. (2001). P3b reflects maltreated children's reactions to facial displays of emotion. *Psychophysiology, 38*(2), 267–274.

Preacher, K. J., & Hayes, A. F. (2004). SPSS and SAS procedures for estimating indirect effects in simple mediation models. *Behavior Research Methods, Instruments, & Computers, 36*(4), 717–731.

Proudfit, G. H., Inzlicht, M., & Mennin, D. S. (2013). Anxiety and error monitoring: the importance of motivation and emotion. *Frontiers in Human Neuroscience, 7*.

Rapee, R. M., Kennedy, S. J., Ingram, M., Edwards, S. L., & Sweeney, L. (2010). Altering the trajectory of anxiety in at-risk young children. *American Journal of Psychiatry, 167*(12), 1518–1525.

Riesel, A., Weinberg, A., Endrass, T., Kathmann, N., & Hajcak, G. (2012). Punishment has a lasting impact on error–related brain activity. *Psychophysiology, 49*(2), 239–247.

Robinson, C., Mandleco, B., Olsen, S. F., & Hart, C. (2001). The parenting styles and dimensions questionnaire (PSDQ). *Handbook of family measurement techniques, 3*, 319–321.

Santesso, D. L., Segalowitz, S. J., & Schmidt, L. A. (2006). Error-related electrocortical responses are enhanced in children with obsessive-compulsive behaviors. *Developmental Neuropsychology, 29*(3), 431–445.

Shackman, J. E., Shackman, A. J., & Pollak, S. D. (2007). Physical abuse amplifies attention to threat and increases anxiety in children. *Emotion, 7*(4), 838.

Siqueland, L., Kendall, P. C., & Steinberg, L. (1996). Anxiety in children: perceived family environments and observed family interaction. *Journal of Clinical Child Psychology, 25*(2), 225–237.

Teicher, M. H., & Samson, J. A. (2013). Childhood maltreatment and psychopathology: a case for ecophenotypic variants as clinically and neurobiologically distinct subtypes. *American Journal of Psychiatry, 170*(10), 1114–1133.

Teicher, M. H., Andersen, S. L., Polcari, A., Anderson, C. M., Navalta, C. P., & Kim, D. M. (2003). The neurobiological consequences of early stress and childhood maltreatment. *Neuroscience & Biobehavioral Reviews, 27*(1), 33–44.

Torpey, D. C., Hajcak, G., Kim, J., Kujawa, A., & Klein, D. N. (2011). Electrocortical and behavioral measures of response monitoring in young children during a Go/No-Go task. *Developmental Psychobiology*, n/a-n/a. doi:10.1002/dev.20590.

Torpey, D. C., Hajcak, G., Kim, J., Kujawa, A. J., Dyson, M. W., Olino, T. M., & Klein, D. N. (2013). Error-related brain activity in young children: associations with parental anxiety and child temperamental negative emotionality. *Journal of Child Psychology and Psychiatry*, no-no. doi:10.1111/jcpp.12041.

van der Voort, A., Juffer, F., & Bakermans-Kranenburg, M. (2014). Sensitive parenting is the foundation for secure attachment relationships and positive social-emotional development of children. *Journal of Children's Services, 9*(2), 165–175.

Viana, A. G., & Rabian, B. (2008). Perceived attachment: relations to anxiety sensitivity, worry, and GAD symptoms. *Behaviour Research and Therapy, 46*(6), 737–747.

Weinberg, A., Olvet, D. M., & Hajcak, G. (2010). Increased error-related brain activity in generalized anxiety disorder. *Biological Psychology, 85*(3), 472–480. doi:10.1016/j.biopsycho.2010.09.011.

Weinberg, A., Klein, D. N., & Hajcak, G. (2012). Increased error-related brain activity distinguishes Generalized Anxiety Disorder with and without comorbid Major Depressive Disorder. *Journal of Abnormal Psychology*. doi: 10.1037/a0028270

Weinberg, A., Riesel, A., & Hajcak, G. (2012b). Integrating multiple perspectives on error-related brain activity: the ERN as a neural indicator of trait defensive reactivity. *Motivation and Emotion, 36*, 1–17.

Whittle, S., Yap, M. B., Yücel, M., Sheeber, L., Simmons, J. G., Pantelis, C., & Allen, N. B. (2009). Maternal responses to adolescent positive affect are associated with adolescents' reward neuroanatomy. *Social Cognitive and Affective Neuroscience, 4*(3), 247–256.

Wittchen, H. U., Lieb, R., Pfister, H., & Schuster, P. (2000). The waxing and waning of mental disorders: evaluating the stability of syndromes of mental disorders in the population. *Comprehensive Psychiatry, 41*(2 Suppl 1), 122–132.

Xiao, Z., Wang, J., Zhang, M., Li, H., Tang, Y., Wang, Y., & Fromson, J. A. (2011). Error-related negativity abnormalities in generalized anxiety disorder and obsessive–compulsive disorder. *Progress in Neuro-Psychopharmacology and Biological Psychiatry, 35*(1), 265–272. doi:10.1016/j.pnpbp.2010.11.022.