Brief Report

Dagmar Kr. Hannesdóttir[1,2]
Jacquelyn Doxie[1,3]
Martha Ann Bell[1]
Thomas H. Ollendick[1]
Christy D. Wolfe[1,4]

[1]Virginia Polytechnic Institute and State University, Blacksburg, Virginia

[2]Centre for Child Development and Behaviour, Reykjavík, Iceland
E-mail: dagmar.kristin@gmail.com

[3]De Paul University, Chicago, Illinois

[4]Bellarmine University Louisville, Kentucky

A Longitudinal Study of Emotion Regulation and Anxiety in Middle Childhood: Associations with Frontal EEG Asymmetry in Early Childhood

ABSTRACT: *We investigated whether brain electrical activity during early childhood was associated with anxiety symptoms and emotion regulation during a stressful situation during middle childhood. Frontal electroencephalogram (EEG) asymmetries were measured during baseline and during a cognitive control task at 4½ years. Anxiety and emotion regulation were assessed during a stressful situation at age 9 (speech task), along with measures of heart rate (HR) and heart rate variability (HRV). Questionnaires were also used to assess anxiety and emotion regulation at age 9. Results from this longitudinal study indicated that children who exhibited right frontal asymmetry in early childhood experienced more physiological arousal (increased HR, decreased HRV) during the speech task at age 9 and less ability to regulate their emotions as reported by their parents. Findings are discussed in light of the associations between temperament and development of anxiety disorders. © 2010 Wiley Periodicals, Inc.* Dev Psychobiol 52: 197–204, 2010.

Keywords: *anxiety; children; EEG asymmetry; emotion regulation; cardiovascular arousal*

INTRODUCTION

Reactivity to stressful events and early difficulties in emotion regulation appear to have a constitutional basis and have been associated with patterns of electroencephalogram (EEG) activation (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001). Specifically, approach behaviors and positive affectivity have been associated with greater left frontal activation and withdrawal behaviors and negative affectivity have been associated with greater right frontal activation (Fox, 1994). Research has shown that infants and children who show greater right relative to left frontal EEG activation (right frontal asymmetry) are likely to be fearful and inhibited (Fox et al., 2001), have higher negative affect (Calkins, Fox, & Marshall, 1996), and show increased distress during maternal separation (Fox, Bell, & Jones, 1992; Fox & Davidson, 1987). On the other hand, left frontal asymmetry in infants has been found to predict increased sociability, approach behaviors, and better regulatory skills later in early childhood (Davidson, Jackson, & Kalin, 2000; Kim & Bell, 2006). It is unknown whether such early indicators of regulatory capabilities are predictive of later childhood adjustment. The purpose of our study was to examine early EEG asymmetry patterns in relation to symptoms of anxiety during middle childhood and to examine the children's ability to regulate their emotional state under stress at this later age.

Emotion Regulation and Anxiety

Emotion regulation can be defined as the modification of any processes, extrinsic or intrinsic, in the system that

Received 28 June 2009; Accepted 1 December 2009
Correspondence to: D. K. Hannesdóttir
Published online 28 January 2010 in Wiley InterScience (www.interscience.wiley.com). DOI 10.1002/dev.20425

generates emotion or its manifestation in behavior (e.g., facial expressions, self-soothing behaviors; Campos, Frankel, & Camras, 2004). Thus, emotion regulation can involve change or maintenance of any aspect of emotional arousal, such as physiological and neurological activation, cognitive appraisal, and attention processes (Thompson, 1994). Although certain emotion regulation strategies can be effective in reducing stress and modifying emotions in anxiety provoking situations, these strategies can become maladaptive in the long run and lead to emotion dysregulation. Cicchetti, Ackerman, and Izard (1995) noted that emotion dysregulation develops as emotions become connected to deviant cognitive and action strategies, thus leading to difficulties in preventing the elicitation of certain emotions or managing emotions and expressions once they are elicited.

Several studies have indicated that children with anxiety disorders demonstrate emotion dysregulation in a variety of ways. When anxious children find themselves in emotionally arousing situations, they appear to have limited skills to manage their emotions. In various studies, anxious children have reported experiencing emotions more intensely, had dysregulated expressions, showed less adaptive coping, had lower self-efficacy in their ability to improve their mood compared to less anxious peers (Suveg & Zeman, 2004) and have demonstrated limited knowledge in their ability to change and hide their emotions to achieve interpersonal goals (Southam-Gerow & Kendall, 2000). Anxious children also tend to become hypervigilant towards and hyperfocused on threatening stimuli (both external and internal stimuli; Vasey & MacLeod, 2001), thus showing difficulty changing their mood state by breaking their attention away from the negative mood elicitor.

Frontal EEG Asymmetry and Anxiety

When infants are exposed to stressful events in the laboratory, individual differences in reactivity are observable in both their behavior and cerebral activation patterns. Such individual differences in behavior are usually referred to as temperamental characteristics and have been demonstrated to be relatively stable throughout childhood (e.g., McManis, Kagan, Snidman, & Woodward, 2002). The temperamental construct that has received the most interest with regard to predicting the development of anxiety disorders is behavioral inhibition (Kagan, 1997; Ollendick & Hirshfeld-Becker, 2002). Behavioral inhibition is generally defined as the tendency to be silent, behaviorally restrained, or fearful in novel situations (Fox et al., 2001). Behavioral inhibition has been associated with high reactivity in infancy (motor activity and distress in response to novel stimuli) and social wariness in early childhood (Kagan, 2001). Studies have revealed that children who show consistent behavioral inhibition throughout infancy and childhood are more likely to develop anxiety disorders in later childhood (Hirshfeld et al., 1992).

These early behavioral characteristics have also been found to be associated with EEG asymmetry patterns. Right frontal EEG asymmetry in infancy has been shown to be associated with behavioral reticence and negative affectivity among preschoolers, but only for those children who remain stably inhibited throughout early childhood (Fox et al., 2001). Right frontal asymmetry has also been shown to be associated with infants' responses to various mild stressors. For example, it has been shown that infants who cried in response to maternal separation showed right frontal EEG asymmetry during a baseline recording obtained before the separation. On the other hand, infants who showed signs of interest and joy when approached by their mother showed left frontal EEG asymmetry during baseline (Fox et al., 1992; Fox & Davidson, 1987). No differences were found in activation for other scalp locations (Fox et al., 1992; Fox & Davidson, 1987), thus demonstrating the unique role of the frontal lobes in affect regulation in response to emotionally arousing events.

Despite the number of studies that exist regarding the relations between frontal EEG asymmetry and emotion reactivity and regulation in infancy, relatively few studies have assessed this relation in older children. McManis et al. (2002) examined how well temperamental qualities in infancy predicted asymmetry patterns in 10- to 12-year-old children. Supporting previous findings, children who had been highly reactive and fearful as infants were more likely to show right frontal EEG asymmetry during baseline and in response to a speech task compared to children who had not been classified as reactive when they were infants. Similarly, Kim and Bell (2006) found that right frontal EEG asymmetry in infancy predicted impulsivity and surgency at 4 and 8 years of age, whereas left frontal EEG asymmetry was associated with greater regulatory skills. Combined, these findings from studies of infants and children in early and middle childhood suggest that the differential activation patterns of the frontal areas during resting periods and in response to stressful events seem to be reliable markers and predictors of individual reactivity and emotion regulation.

Based on these longitudinal studies, children who demonstrate relative right frontal activation during infancy might be more at risk for developing internalizing disorders. Viewing increased right frontal asymmetry as a diathesis for developing clinical disorders has been suggested with regard to depression (e.g., Dawson et al.,

2003) and social anxiety (Ollendick & Hirshfeld-Becker, 2002). Such findings have been repeatedly demonstrated among adults, in which negative affectivity (i.e., depression and anxiety) is associated with increased right frontal EEG asymmetry during resting periods (e.g., Blackhart, Minnix, & Kline, 2006) and in response to anxiety provoking tasks (e.g., Davidson, Marshall, Tomarken, & Henriques, 2000). Although few studies have examined relations between internalizing symptoms and right frontal asymmetry in children, similar findings have emerged. Self-presentation anxiety in 7-year-old children was found to be associated with increased relative right frontal activation, increased heart rate (HR), and lower vagal tone or heart rate variability (HRV) in anticipation of a speech task (Schmidt, Fox, Schulkin, & Gold, 1999). In addition, infants who show consistent behavioral inhibition throughout early childhood are more likely to demonstrate right frontal asymmetry (Fox et al., 2001) and are more likely to develop anxiety disorders in middle childhood (Hirshfeld et al., 1992).

In the few studies that have directly examined EEG asymmetry and anxiety in children, only concurrent data of anxiety symptoms and patterns have been obtained. The association between behavioral inhibition and EEG asymmetry has repeatedly been demonstrated, and the association between behavioral inhibition and anxiety disorders in childhood has been suggested for children who show stable inhibition. However, we know of no studies to date which have examined whether early signs of right frontal EEG asymmetry are associated with anxiety and difficulties in emotion regulation during stressful tasks in older children. The purpose of our study was to examine early EEG asymmetry patterns in relation to symptoms of anxiety during middle childhood and to children's ability to regulate emotional state under stress.

Hypotheses

We expected frontal EEG asymmetry patterns in early childhood to be associated with adjustment in later childhood, more so than other cerebral activation sites (e.g., temporal, parietal, and occipital). Specifically, we hypothesized that children with patterns of right frontal EEG asymmetry in early childhood would have more symptoms of anxiety, demonstrate poor emotion regulation, and have prolonged cardiovascular activation in response to an anxiety provoking experimental task. Furthermore and in line with the findings of Schmidt et al. (1999), we predicted the children who showed right frontal asymmetry in early childhood would show higher HR and lower HRV during a stressful task at the age of 9.

METHODS

Participants

The children in this study were part of a longitudinal investigation of self-regulatory skills associated with attention and cognition in early development. At age 4½ years, 25 children participated in a laboratory study to examine individual differences in effortful control, EEG, and working memory (Wolfe & Bell, 2004, 2007).

For the current assessment at age 9, we focused on self-regulation during an anxiety-provoking situation. The 25 families from the 4½-year assessment were still living in the local area and 20 children (12 boys) and their parents agreed to participate in the current study, with the other 5 families reporting they were unavailable to do so. Each child received a $25 gift certificate at a local store for participating.

Procedure

For the current assessment at age 9, the children came to the laboratory with their parents. Parents and children were asked to complete questionnaires and the child was asked to engage in a short speech task while cardiovascular response was recorded. EEG was not part of the protocol for this follow-up visit.

EEG Recordings at Early Childhood. At 4½ years, baseline EEG was averaged across 60 s with eyes closed and 60 s of a Sesame Street video. Task EEG was averaged across two cognitive control tasks, the Yes/No task and the Day/Night task (Wolfe & Bell, 2004). EEG was recorded from 16 left and right scalp locations, referenced to Cz, using an Electro-Cap. Recommended procedures regarding EEG data collection with young children were followed (Pivik et al., 1993). Electrode impedances were measured and accepted if they were below 5K ohms. The electrical activity from each lead was amplified using separate SA Instrumentation Bioamps and bandpassed from 1 to 100 Hz. The EEG signal was digitized on-line at 512 samples per second for each channel so that the data were not affected by aliasing. EOG was digitized along with the EEG channels and used for subsequent artifact editing. The acquisition software was Snapshot-Snapstream (HEM Data Corp; Southfield, MI) and the raw data were stored for later analyses.

The EEG data were examined and analyzed using EEG Analysis System software by James Long Company (Caroga Lake, NY). First, the data were re-referenced via software to an average reference configuration (Lehmann, 1987) and then artifact scored for eye and gross motor movements. EEG data were artifact scored for eye movements using a peak-to-peak criterion of 100 μV or greater. Transfer of eye movements is reported to be significant in a frequency band from 0 to 6 Hz and transfer for eye blinks occurs as high as adult alpha band (8–13 Hz) frequencies (Gasser, Sroka, & Mocks, 1985). However, blink artifacts were readily identified via visual inspection of the EEG and artifact scored. An EOG correction algorithm was not used because algorithms remove power across the entire scalp across all frequency bands (Somsen & van Beek, 1998), thus filtering out some of the maturational change in frontal EEG power. Selecting artifact-free data yielded a more accurate portrayal of the EEG developmental record (Somsen & van Beek, 1998). The criterion for scoring movement artifact was a potential greater than 200 μV peak-to-peak. These artifact-scored epochs were eliminated from all subsequent analyses.

The data were then analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-s width and 50% overlap. Power was computed for the 6–9 Hz frequency band (Marshall, Bar-Haim, & Fox, 2002). The power was expressed as mean square microvolts and the data transformed using the natural log (ln) to normalize the distribution. An asymmetry score was calculated by subtracting left EEG power from right EEG power. Thus, a positive number indicated left asymmetry and a negative number indicated right asymmetry. Data from the frontal areas (F_1, F_2, F_3, F_4, F_7, and F_8) were specifically examined in this study and compared with recordings from other scalp sites (see Buss et al., 2003). Although resting state EEG is the traditional measure for examination of frontal asymmetries, we also examined nonresting EEG to explore whether EEG asymmetry during cognitive processing was correlated with later emotion regulation and anxiety. The amount of artifact-free EEG data during baseline was approximately 32 s per child, whereas the amount of artifact-free EEG data during cognitive processing was approximately 52 s per child.

Questionnaire Measures at Middle Childhood. Parents completed two questionnaires about their child's behavior and emotional state. The *Child Behavior Checklist* (CBCL; Achenbach, 2001), which focuses on internalizing and externalizing problems for children 6–16 years of age, and the *Emotion Regulation Questionnaire* (ERC; Shields & Cicchetti, 1997). This is a 24-item adult-report questionnaire on children's emotion regulation that measures two factors: Lability/Negativity (e.g., "Displays flat affect") and Emotion Regulation (e.g., "Can say when s/he is feeling sad, angry or mad, fearful or afraid"). Items are scored on a scale from 1 to 4 with higher total scores on the ERC reflecting better emotional regulation. In this study, only the total score on the ERC was used in the analyses. The children also completed two questionnaires. The *Multidimensional Anxiety Scale for Children* (MASC; March, 1997) assesses child and adolescent symptoms of anxiety (e.g., social anxiety, panic, etc.) and the *Childhood Depression Inventory* (CDI; Kovacs, 1992) assesses children's depressive symptoms (e.g., negative mood, anhedonia, etc.). All questionnaire results, except the ERC and the CDI, are provided in *T*-scores.

Speech Task and Cardiovascular Arousal/Recovery at Middle Childhood. To examine how well the children were able to regulate their emotional arousal, they were asked to complete an anxiety provoking task individually. The speech task was based on previous studies in the anxiety arena (cf. Cartwright-Hatton, Hodges, & Porter, 2003) in which the children were asked to talk about themselves for 2 min in front of a video camera. Such speech tasks have previously been shown to be anxiety provoking for children, as well as adults, even in nonanxious samples (e.g., Cartwright-Hatton et al., 2003; Schmidt et al., 1999). The children were fitted with three electrodes on the chest and connected to an ambulatory monitoring system (AMS, Vrije Universitat). This system measured HR and HRV. The mean inter beat intervals (IBI), quantified as the average time between successive R-spikes on the ECG, was used as a cardiac chronotropic measure (Berntson, Cacioppo, & Quigley, 1995). Spectral analysis was used to quantify HRV in the current study but respiration was not recorded.

The children were asked to complete a 5-min baseline before the speech task during which they watched a cartoon. They were then asked to wait for 30 s before going into the room where they would be videotaped (anticipatory anxiety phase). Before going into the room with the camera they were asked to give their *Subjective units of distress* (SUDS before speech) on a scale from 0 to 8, the highest value indicating a great amount of anxiety. The task lasted for 2 min, or however long the children were willing to talk in front of the video camera. After the speech, the children were asked how much distress they felt during the task (SUDS during speech) and then returned to another room for a 5-min recovery period.

Calculation of recovery time after the speech task was based on a previous study by Fredrickson and Levenson (1998). Average HR and confidence interval were obtained for the baseline measure and recovery time (in seconds) was defined as the time that passed from the beginning of the speech task until the child had reached baseline levels of HR and stayed within that confidence interval for at least five of six consecutive seconds. At that point, the child was considered to have recovered, whether this occurred while the child was still talking in front of the video camera or after the speech during the recovery phase. Complete data were available for 18 of the 20 children at age 9. One child refused to do the speech task and another child refused to wear the electrodes necessary to measure HR/HRV. Due to the small sample size, the current findings are exploratory.

RESULTS

Self and Parent Reports at Age 9

Examination of the questionnaire data revealed normal overall adjustment for this sample of 9-year-old children, although there was some variability in anxiety symptoms and internalizing problems. The average CBCL internalizing scale reported by the mothers and the MASC total scores reported by the children were below the clinical range ($T = 65$), although the scores of two children were in the clinical range on the CBCL and one child reported clinical levels of anxiety symptoms on the MASC (see means in Tab. 1). No gender differences emerged for any of the questionnaire measures. In addition, no associations were found between the amount of artifact-free EEG data and any of the dependent variables.

Speech Task and Physiological Arousal/ Recovery at Age 9

We examined children's physiological response during the speech task designed to elicit anxiety. First, a manipulation check revealed that the children showed

Table 1. Correlations Between Child and Parent Report Measures and Cardiovascular Outcomes During Speech Task at Age 9

	CBCL-I	ERC	MASC	CDI	SUDS Before Speech	SUDS During Speech	HR—Baseline	HR—Speech Task	HRV—Baseline	HRV—Speech Task
Means (SD)	49.95 (9.8)	80.10 (7.5)	49.20 (9.4)	5.53 (4.9)	3.10 (2.3)	3.63 (2.29)	85.89 (11.9)	101.04 (10.56)	54.49 (38.4)	34.36 (19.2)
CBCL-I										
ERC	−.67** (20)									
MASC	−.28 (20)	.37 (20)								
CDI	.58* (17)	−.30 (17)	.23 (17)							
SUDS before speech	.12 (20)	.04 (20)	.47* (20)	.50* (17)						
SUDS during speech	.12 (19)	−.18 (19)	.28 (19)	.36 (16)	.16 (19)					
HR—baseline	−.01 (18)	−.11 (18)	−.06 (18)	−.18 (15)	−.05 (18)	.49* (17)				
HR—speech task	−.01 (18)	−.08 (18)	.02 (18)	−.12 (15)	−.12 (18)	.54* (17)	.88** (18)			
HRV—baseline	.18 (17)	.03 (17)	−.31 (17)	−.03 (15)	−.11 (17)	−.58* (16)	−.85** (17)	−.84** (17)		
HRV—speech task	−.01 (18)	.09 (18)	.02 (18)	−.17 (15)	.01 (18)	−.58* (17)	−.67** (18)	−.78** (18)	.90** (17)	
HR—recovery rate	−.35 (16)	.42 (16)	.44$^+$ (16)	−.04 (13)	−.05 (16)	.22 (16)	−.11 (16)	−.06 (16)	.01 (15)	.09 (16)

Number of observations are in parentheses next to each correlation.

CBCL-I, Child Behavior Checklist-Internalizing problems (mother report); ERC, Emotion Regulation Checklist (mother report); MASC, Multidimensional Anxiety Scale for Children (child report); CDI, Childhood Depression Inventory (child report); SUDS, subjective units of distress; HR, heart rate; HRV, heart rate variability.

$^+p < .10$.

$^*p < .05$.

$^{**}p < .01$.

an increase in HR (t (1,17) = 11.4, $p < .001$) and a decrease in HRV (t (1,17) = 3.8, $p < .001$) between baseline and the speech task. This pattern of cardiovascular arousal may indicate that the children experienced tension/anxiety, which is in line with their reports of feeling somewhat anxious on the SUDS scale both prior to and during the task (see means in Tab. 1).

Self/Parent Reports and Speech Task Physiology at Age 9

Of the questionnaire data at age 9, only the scores on the MASC were correlated (marginally) with heart rate recovery after the speech task. Children who reported more anxiety on the MASC took longer to recover after the task. Significant correlations emerged for child reported internalizing symptoms (MASC, CDI) and anticipatory anxiety before the speech (SUDS) (see Tab. 1). On the other hand, child reported SUDS during the speech were significantly correlated with their HR and lowered HRV. The more anxiety reported, the greater the physiological response (see Tab. 1).

4½-Year Frontal EEG and 9-Year Outcome Measures

Several significant correlations emerged for 9-year outcomes and frontal EEG data obtained at 4½ years, especially for the cognitive control task and scalp area F_1/F_2. Frontal asymmetry during the task was positively correlated with emotion regulation as reported by mothers at age 9 (see Tab. 2). Thus, children with greater left frontal asymmetry (a positive number) were reported to have better emotion regulation skills, and vice versa for children with right frontal asymmetry. The 4½-year task frontal asymmetry score ($F_2 - F_1$) therefore predicted 26% of the emotion regulation variance at age 9 (see Tab. 2). Task frontal asymmetry (and borderline significant baseline asymmetry) was negatively correlated with HR and positively correlated with HRV before (at resting baseline) and during the speech task at age 9. Thus, children with greater right frontal asymmetry (a negative number) at 4½ years exhibited increased HR at age 9 ($r^2 = 62\%$; see Tab. 2), and decreased HRV prior to and during the speech task in middle childhood. Conversely, children with greater left frontal EEG task asymmetry (a positive number) demonstrated lower HR and greater HRV at age 9 during baseline and the speech task (see Tab. 2). This pattern was not observed at any other cerebral site, except one correlation was significant for the T_3/T_4 area, where greater left asymmetry was associated with faster recovery after the speech task. Overall, the data are generally consistent with the notion that relative right frontal asymmetry is associated with increased negative

Table 2. Correlations Between Child and Parent Report Measures at Age 9 and Frontal EEG Asymmetry During Early Childhood

	CBCL Intern.	ERC	MASC	CDI	SUDS Before Speech	SUDS During Speech	HR—Baseline	HR—Speech Task	HRV—Baseline	HRV—Speech Task	HR—Recovery Rate
$4\frac{1}{2}$ years frontal asymmetry											
Baseline											
$F_2 - F_1$	−.34 (15)	.24 (15)	.09 (15)	.08 (14)	.29 (15)	−.04 (14)	$-.48^{+}$ (13)	−.38 (13)	.37 (12)	.38 (13)	.11 (11)
$F_4 - F_3$	.41 (16)	$-.48^{+}$ (16)	−.39 (16)	−.13 (15)	−.17 (16)	−.24 (15)	.06 (14)	.20 (14)	−.01 (13)	−.07 (14)	−.52 (12)
$F_8 - F_7$	.01 (16)	.26 (16)	.02 (16)	.34 (15)	.05 (16)	−.30 (15)	−.22 (14)	.07 (14)	.15 (13)	−.06 (14)	.11 (12)
$T_4 - T_3$	.21 (16)	.07 (16)	.00 (16)	−.08 (15)	.01 (16)	−.02 (15)	−.25 (14)	−.20 (14)	.14 (13)	.12 (14)	−.63* (12)
$P_4 - P_3$	.10 (16)	.17 (16)	.13 (16)	.14 (15)	−.02 (16)	.09 (15)	.14 (14)	−.03 (14)	−.14 (13)	.25 (14)	.33 (12)
$O_2 - O_1$	−.40 (16)	.02 (16)	−.03 (16)	−.37 (15)	−.04 (16)	.12 (15)	.32 (14)	.22 (14)	−.31 (13)	−.18 (14)	−.35 (12)
CC task											
$F_2 - F_1$	−.32 (15)	.51* (15)	$.45^{+}$ (15)	.10 (14)	$.50^{+}$ (15)	−.15 (14)	−.65 (13)	−.79** (13)	.48 (12)	.67* (13)	.32 (11)
$F_4 - F_3$	.43 (15)	−.40 (15)	$-.44^{+}$ (15)	−.28 (14)	−.08 (15)	−.19 (14)	.18 (13)	.27 (13)	.00 (12)	−.21 (13)	−.57 (11)
$F_8 - F_7$	.20 (15)	.11 (15)	−.21 (15)	.31 (14)	−.02 (15)	−.63 (14)	−.14 (13)	−.07 (13)	.24 (12)	.07 (13)	−.12 (11)
$T_4 - T_3$	−.11 (15)	.10 (15)	.37 (15)	−.08 (14)	.15 (15)	−.17 (14)	−.16 (13)	−.17 (12)	−.17 (12)	.08 (13)	−.50 (11)
$P_4 - P_3$	.29 (15)	−.04 (15)	−.23 (15)	.15 (14)	.06 (15)	.04 (14)	.12 (13)	.06 (13)	−.02 (12)	−.06 (13)	−.07 (11)
$O_2 - O_1$	−.45 (14)	.10 (14)	.31 (14)	−.21 (13)	.02 (14)	.29 (13)	−.06 (12)	−.03 (12)	−.16 (11)	.09 (12)	.18 (10)

Number of observations are in parentheses next to each correlation.

CC Task, Cognitive control task; CBCL-I, Child Behavior Checklist-Internalizing problems (mother report); ERC, Emotion Regulation Checklist (mother report); MASC, Multidimensional Anxiety Scale for Children (child report); CDI, Childhood Depression Inventory (child report); SUDS, subjective units of distress; HR, heart rate; HRV, heart rate variability.

F, frontal areas 1,2,3,4,7, and 8, *T*, temporal areas 3 and 4, *P*, parietal areas 3 and 4, and O, occipital areas 1 and 2. Left frontal asymmetry, a positive increasing value; right frontal asymmetry, a negative decreasing value.

$^{+}p < .10$.

$*p < .05$.

$**p < .01$.

emotions, including fear and anxiety, and poorer emotion regulation, especially when measured during a cognitive control task.

DISCUSSION

The findings of this study suggest that the pattern of frontal asymmetry in early childhood may be associated with fear, anxiety, and emotion regulation in later childhood. Although limited by the small sample of children, these longitudinal data add to the mounting evidence that the early psychobiology of temperament is associated with later childhood adjustment.

Overall, the parent report data of child anxiety at middle childhood were not correlated with EEG asymmetries from early childhood. However, emotion regulation skills reported by parents were positively related with frontal asymmetry. The more left frontal asymmetry at age 4½ years, the better the emotion regulation skills in middle childhood. In previous research, children who showed right frontal asymmetry in infancy were reported to have more internalizing problems later on.

The HR/HRV data during the stressful task at 9 years and frontal EEG asymmetries from early childhood were consistently related, however. Children who demonstrated left frontal EEG asymmetry in early childhood experienced less arousal (lower HR, higher HRV) during the speech task. Conversely, children with right frontal EEG asymmetry in early childhood experienced greater arousal (higher HR, lower HRV) during the speech task. Significant correlations mainly emerged for the frontal asymmetry (F_1/F_2 area) that occurred during the cognitive control task at age 4½ years and the physiological measures at age 9, as opposed to the baseline asymmetry pattern or patterns obtained at other cerebral sites (temporal, parietal, or occipital lobes). In line with previous studies (e.g., Calkins, 1997), these patterns suggest that cognitive control tasks better predict regulation skills and physiological responses to stress at age 9 than more temperament-related baseline measures at age 4½ years.

Despite the small sample size, certain associations were found between patterns of brain electrical activity and cardiovascular arousal obtained several years later in developing children. To some extent, it is remarkable that cerebral activation patterns obtained during early development can predict physiological responses to a stressful task at 9 years of age. According to these findings, right frontal asymmetry in early childhood is associated with increased fear and anxiety during tasks that require regulation and verbal fluency and spontaneity where the child risks being evaluated negatively by others. This indicates that despite environmental shaping that occurs in this first decade of the child's life, temperamental influences reflected in cerebral activation patterns remain significantly associated with a child's reaction and performance during a stressful task. Environmental shaping and parental influences may on the other hand greatly affect whether children with such a disposition develop anxiety disorders and affective problems or whether they learn to manage their fears and overcome obstacles along the way.

NOTES

The authors are grateful for the dedication of the families to this longitudinal study. Data collection during early childhood was supported by a Millennium Grant from the College of Arts and Sciences at Virginia Tech. Data collection during middle childhood was supported by the Clinical Child Research Fund at Virginia Tech and the Memorial Fund of Margrét Björgúlfsdóttir in Iceland.

REFERENCES

Achenbach, T. M. (2001). *Child Behavior Checklist*. Achenbach System of Empirically Based Assessment.

Berntson, G. G., Cacioppo, J. T., & Quigley, K. S. (1995). The metrics of cardiac chronotropism: Biometric perspectives. Psychophysiology, 32, 162–171.

Blackhart, G. C., Minnix, J. A., & Kline, J. P. (2006). Can EEG asymmetry patterns predict future development of anxiety and depression? A preliminary study. Biological Psychology, 72, 46–50.

Buss, K. A., Malmstadt, J., Dolski, I., Kalin, N., Goldsmith, H., & Davidson, R. (2003). Right frontal brain activity, cortical, & withdrawal behavior in 6 months old infants. Behavioral Neuroscience, 117, 11–20.

Calkins, S. D. (1997). Cardiac vagal tone indices of temperamental reactivity and behavioral regulation in young children. Developmental Psychobiology, 31, 125–135.

Calkins, S. D., Fox, N. A., & Marshall, T. R. (1996). Behavioral and physiological antecedents of inhibited and uninhibited behavior. Child Development, 67, 523–540.

Campos, J. J., Frankel, C. B., & Camras, L. (2004). On the nature of emotion regulation. Child Development, 75, 377–394.

Cartwright-Hatton, S., Hodges, L., & Porter, J. (2003). Social anxiety in childhood: The relationship with self and observer rated social skills. Journal of Child Psychology and Psychiatry, 44, 737–742.

Cicchetti, D., Ackerman, B. P., & Izard, C. E. (1995). Emotions and emotion regulation in developmental psychopathology. Development and Psychopathology, 7, 1–10.

Davidson, R. J., Jackson, D. C., & Kalin, N. H. (2000). Emotion, plasticity, context, and regulation: Perspectives from affective neuroscience. Psychological Bulletin, 126, 890–909.

Davidson, R. J., Marshall, J. R., Tomarken, A. J., & Henriques, J. B. (2000). While a phobic waits: Regional brain electrical and autonomic activity in social phobics during anticipation of public speaking. Biological Psychiatry, 47, 85–95.

Dawson, G., Ashman, S. B., Panagiotides, H., Hessl, D., Self, J., Yamada, E., & Embry, L. (2003). Preschool outcomes of children of depressed mothers: Role of maternal behavior, contextual risk, and children's brain activity. Child Development, 74, 1158–1175.

Fox, N. A. (1994). Dynamic cerebral processes underlying emotion regulation. Monographs of the Society for Research in Child Development, 59, 152–166.

Fox, N. A., Bell, M. A., & Jones, N. A. (1992). Individual differences in response to stress and cerebral asymmetry. Developmental Neuropsychology, 8, 161–184.

Fox, N. A., & Davidson, R. J. (1987). Electroencephalogram asymmetry in response to the approach of a stranger and maternal separation in 10-month old infants. Developmental Psychology, 2, 233–240.

Fox, N. A., Henderson, H. A., Rubin, K. H., Calkins, S. D., & Schmidt, L. A. (2001). Continuity and discontinuity of behavioral inhibition and exuberance: Psychophysiological and behavioral influences across the first four years of life. Child Development, 72, 1–21.

Fredrickson, B. L., & Levenson, R. W. (1998). Positive emotions speed recovery from the cardiovascular sequelae of negative emotions. Cognition & Emotion, 12, 191–220.

Gasser, T., Sroka, L., & Mocks, J. (1985). The transfer of EOG activity into the EEG for eyes open and close. Electroencephalography and Clinical Neurophysiology, 61, 181–193.

Hirshfeld, D. R., Rosenbaum, J. F., Biederman, J., Bolduc, E. A., Faraone, S. V., Snidman, N., et al. (1992). Stable behavioral inhibition and its association with anxiety disorder. Journal of the American Academy of Child and Adolescent Psychiatry, 31, 103–111.

Kagan, J. (1997). Temperament and the reactions to unfamiliarity. Child Development, 68, 139–143.

Kagan, J. (2001). Temperamental contributions to affective and behavioral profiles in childhood. In: S. G. Hofman, D. M. DiBartolo, & P. Marten (Eds.), From social anxiety to social phobia: Multiple perspectives (pp. 216–234). Needham Heights: Allyn & Bacon.

Kim, K. J., & Bell, M. A. (2006). Frontal EEG asymmetry and regulation during childhood. In: B. M. Lester, A. Masten, & B. McEwen (Eds.), Resilience in children (pp. 308–312). New York: The New York Academy of Sciences Press.

Kovacs, M. (1992). Childhood depression inventory. Cheektowaga: Multi-Health Systems Inc.

Lehmann, D. (1987). Principles of spatial analysis. In: A. S. Gevins & A. Remond (Eds.), Handbook of electroencephalography and clinical neurophysiology, rev. ser. Vol. 1: Methods of analysis of brain electrical and magnetic signals (pp. 309–354). Amsterdam: Elsevier.

March, J. (1997). Multidimensional Anxiety Scale for Children. Cheektowaga: Multi-Health Systems Inc.

Marshall, P. J., Bar-Haim, Y., & Fox, N. A. (2002). Development of the EEG from 5 months to 4 years of age. Clinical Neurophysiology, 113, 1199–1208.

McManis, M. H., Kagan, J., Snidman, N. C., & Woodward, S. A. (2002). EEG asymmetry, power, and temperament in children. Developmental Psychobiology, 41, 169–177.

Ollendick, T. H., & Hirshfeld-Becker, D. R. (2002). The developmental psychopathology of social anxiety disorder. Biological Psychiatry, 51, 44–58.

Pivik, R. T., Broughton, R. J., Coppola, R., Davidson, R. J., Fox, N. A., & Nuwer, M. R. (1993). Guidelines for the recording and quantitative analysis of electroencephalographic activity in research contexts. Psychophysiology, 30, 547–558.

Schmidt, L. A., Fox, N. A., Schulkin, J., & Gold, P. W. (1999). Behavioral and psychophysiological correlates of self-presentation in temperamentally shy children. Developmental Psychobiology, 35, 119–135.

Shields, A., & Cicchetti, D. (1997). Emotion regulation among school-age children: The development and validation of a new criterion Q-sort scale. Developmental Psychology, 33, 906–917.

Somsen, R., & van Beek, B. (1998). Ocular artifacts in children's EEG: Selection is better than correction. Biological Psychology, 48, 281–300.

Southam-Gerow, M. A., & Kendall, P. C. (2000). A preliminary study of the emotion understanding of youths referred for treatment of anxiety disorders. Journal of Clinical Child Psychology, 29, 319–327.

Suveg, C., & Zeman, J. (2004). Emotion regulation in children with anxiety disorders. Journal of Clinical Child and Adolescent Psychology, 33, 750–759.

Thompson, R. A. (1994). Emotion regulation: A theme in search of definition. Monographs of the Society for Research in Child Development, 59, 25–52.

Vasey, M. W., & MacLeod, C. (2001). Information-processing factors in childhood anxiety: A review and developmental perspective. In: M. W. Vasey & M. R. Dadds (Eds.), The developmental psychopathology of anxiety (pp. 253–277). Oxford: Oxford University Press.

Wolfe, C. D., & Bell, M. A. (2004). Working memory and inhibitory control in early childhood: Contributions from electrophysiology, temperament, and language. Developmental Psychobiology, 44, 68–83.

Wolfe, C. D., & Bell, M. A. (2007). The integration of cognition and emotion during infancy and early childhood: Regulatory processes associated with the development of working memory. Brain and Cognition, 65, 3–13.