

Frontal EEG Asymmetry and Regulation during Childhood

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ABSTRACT: Previous research suggests an association between frontal electroencephalographic (EEG) asymmetries and both positive and negative emotion reactivity. Specifically, right frontal EEG activation is associated with emotions of negative valence in both infants and adults, whereas left frontal EEG activation is associated with emotions of more positive valence. Relatively few studies have examined such associations in children. Moreover, research on mechanisms through which emotion reactivity is related to frontal EEG asymmetries is sparse. As one possible mechanism, we hypothesize that regulatory skills and behaviors developing rapidly during childhood play a critical role in linking frontal EEG asymmetries to emotion reactivity in children. To test the research hypothesis, 25 children were followed from early-to-middle childhood at two different points in time with a 4-year interview interval. Results show that individual variations in a number of regulatory behaviors among children are significantly associated with frontal EEG asymmetries. Our results provide support for the possibility of frontal EEG asymmetry informing the study of the development of regulation in children. The discussion of the findings is centered on potential risk for and resilience to children's emotional reactivity and regulation.

KEYWORDS: frontal EEG asymmetry; childhood regulatory behaviors; vulnerability to negative emotion

FRONTAL EEG ASYMMETRY AND REGULATION DURING CHILDHOOD

Researchers who study infants and adults have reported associations between baseline frontal electroencephalographic (EEG) asymmetries and emotion reactivity.¹⁻⁴ For instance, infants who cried in response to maternal separation

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were more likely to have right frontal EEG activation than those who did not cry in response to maternal separation.^{1,2} Psychosocially healthy adults with greater relative left hemisphere frontal EEG activation at baseline reacted to positive mood elicitors with more positive affect and those with greater relative right hemisphere frontal EEG activation at baseline reported more negative emotion to negative mood elicitors.^{5,6} These findings have provided crucial research evidence for some aspect of vulnerability to positive and negative emotion elicitors. In turn, these reports with healthy individuals have advanced our knowledge of psychophysiological correlates of mood disorders, such as depressive and anxious psychopathology.^{7,8}

Although these studies have pointed to an important association between frontal hemisphere activation and an individual's predisposition to various emotional states, the evidence linking frontal EEG asymmetry to the *regulatory* aspects of emotion is limited. Emotional regulation involves the capacity to control emotions and to adjust emotional arousal to an appropriate level of intensity to achieve one's aims.⁹ We propose that individual variations in regulatory skills may account for part of the association between emotion reactivity and frontal EEG asymmetry. It is during childhood that many regulatory skills have their foundations.¹⁰ Indeed, children must learn various strategies for managing emotional intensity in line with social rules. A great amount of individual variation in adjustment to emotional arousal during childhood involves both competent and incompetent regulation of emotions that are displayed through complex emotional expressivity and emotion-related behaviors. Unfortunately, little is known about individual differences in emotional regulation in association with frontal EEG asymmetry during this critical period. In this investigation, we followed a group of normal children from early-to-middle childhood to examine interindividual differences in the relations between frontal EEG asymmetry and regulatory behaviors.

Fifty 8-month-old infants (28 boys) and their parents were recruited from a Southwest Virginia community for a study of the effects of emotion reactivity on infant outcome.¹¹ When these children were 4 years old, there were 27 of these families still living in the local area and 25 families (14 boys) agreed to participate in a preschool study.¹² When these children were 8 years of age, all 25 families were still living in the local area and agreed to participate in a follow-up study. At both the 4-year and 8-year assessments, EEG was recorded during quiet baseline. At the 4-year assessment, trained observers coded the child's skills in a variety of effortful control regulatory tasks. At the 8-year assessment, children participated in a battery of regulatory computer tasks. At both visits, parents endorsed information on their children's reactivity and regulatory behaviors via temperament questionnaires (Rothbart's CBQ and EATQ).^{13,14} Parents observe their children in numerous settings and, thus, provide insight into their children's behaviors that are not readily observable in the research lab.

EEG was recorded at each age from 16 scalp locations and the analyses reported here focused on 6–9 Hz power for the left and right medial frontal leads (F3, F4). Young children have a dominant frequency between 6 and 9 Hz. Eyeblink and movement artifact were removed from the recording and power values calculated and normalized. Frontal EEG asymmetries were calculated using the formula *right EEG 6–9 Hz power (F4)–left EEG 6–9 Hz power (F3)*. Lower EEG power values at one hemisphere indicate greater brain activation at that hemisphere relative to the other hemisphere. For instance, greater left hemisphere frontal activation means lower left hemisphere EEG power values relative to the right hemisphere values. Thus, a positive symmetry value indicates left frontal EEG asymmetry (left hemisphere activation) and a negative asymmetry value indicates right frontal EEG asymmetry (right hemisphere activation).

Our analyses showed that frontal EEG asymmetries were related to a number of regulatory dimensions during childhood. Examining the data from a cross-sectional perspective, higher levels of parent-reported impulsivity at the age of 4 years were associated with right frontal asymmetry ($r = -0.52$; right frontal asymmetry is a negative value). In addition, children at 4 years who were better able to regulate peak distress or excitement (parent-reported falling reactivity and soothability) were more likely to present with greater left frontal asymmetry ($r = 0.63$; left frontal asymmetry is a positive value). At 8 years of age, high levels of parent-reported surgency were associated with right frontal asymmetry ($r = -0.63$). Thus, parent-reported regulatory skills (i.e., regulating peak distress) were associated with left frontal asymmetries, whereas difficulties with regulation (i.e., impulsivity, surgency) were associated with right frontal asymmetries.

Focusing on the longitudinal analyses, higher levels of parent-reported impulsivity at 4 years of age were associated with right frontal asymmetry when the children were 8 years old ($r = -0.47$). Moreover, higher levels of parent-reported low intensity pleasure in children at age 4 were associated with right frontal asymmetry at age 8 ($r = -0.72$). Children who are high in low intensity pleasure prefer quiet activities, avoiding what might be novel and fearful situations. There was also a longitudinal association between observed regulatory behavior in the research lab setting at the age of 4 years and EEG asymmetry measured at 8 years of age. Children who exhibited a higher level of controlled behavior to delay of gratification at 4 years (Kochanska's Bow task) were more likely to show left frontal asymmetries at age 8 ($r = 0.43$).¹⁵ These longitudinal associations are intriguing in that they each suggest that 4-year behavior is correlated with 8-year frontal EEG asymmetry.

Our results provide support for the possibility of frontal EEG asymmetry informing the study of regulation in children. We found right frontal asymmetry associated with less than optimal regulatory behaviors and left frontal asymmetry with more favorable regulatory skills. These findings extend our

knowledge of neurobiological patterns associated with various emotion behaviors. It is not only emotional reactivity, as shown in previous research, but also the capacity to manage reactivity that may be affected by neurobiological patterns inherent in the individual children. It should be noted, however, that exhibiting specific patterns of frontal EEG asymmetries in early childhood does not necessarily portend either difficulties or ease in developing important regulatory abilities. There is evidence for change in frontal EEG asymmetries in young children across the first 4 years of life, along with behavioral changes in temperament-related behaviors.¹⁶ Future studies need to address continuity and discontinuity in physiological patterns reflecting emotional disposition and regulatory skills and behaviors.

To our knowledge, the present investigation provides some of the first research evidence for potential risk and resilience with respect to developing regulatory abilities in childhood. Frontal EEG asymmetries were related to variations in emotion regulatory behaviors among children in cross-sectional and longitudinal analyses.

REFERENCES

1. BELL, M.A. & N.A. FOX. 1994. Brain development over the first year of life: relations between EEG frequency and coherence and cognitive and affective behaviors. *In* Human Behavior and the Development Brain. G. Dawson & K. FISCHER, Eds.: 314–345. Guilford. New York.
2. DAVIDSON, R.J. & N.A. FOX. 1989. The relation between tonic EEG asymmetry and ten-month-old infant emotional responses to separation. *J. Abnorm. Psychol.* **98**: 127–131.
3. DAVIDSON, R.J. & A.J. TOMARKEN. 1989. Laterality and emotion: an electrophysiological approach. *In* Handbook of Neuropsychology. F. Boller & J. Grafman, Eds.: 419–441. Elsevier. Amsterdam, The Netherlands.
4. HAGEMANN, D. *et al.* 2005. The latent state-trait structure of resting EEG asymmetry: replication and extension. *Psychophysiology* **42**: 740–752.
5. DAVIDSON, R.J. 1995. Cerebral asymmetry, emotion and affective style. *In* Brain Asymmetry. R.J. Davidson & K. Hugdahl, Eds: 361–387. MIT Press. Cambridge, MA.
6. WHEELER, R.E. *et al.* 1993. Frontal brain asymmetry and emotional reactivity: a neurological substrate of affective style. *Psychophysiology* **30**: 82–89.
7. ALLEN, J.B. *et al.* 2004. The stability of resting frontal electroencephalographic asymmetry in depression. *Psychophysiology* **41**: 269–280.
8. DIEGO, M.A. *et al.* 2001. CES-D depression scores are correlated with frontal EEG alpha asymmetry. *Depress. Anxiety* **13**: 32–37.
9. SROUFE, L.A. 1998. Emotional Development: the Organization of Emotional Life in the Early Years. University Press. Cambridge, UK.
10. CALKINS, S. 2004. Early attachment processes and the development of emotional self-regulation. *In* Handbook of Self-Regulation: Research, Theory, and Applications. R.F. Baumeister & K.D. Vohs, Eds.: 324–339. Guilford. New York.

11. BELL, M.A. 2006. Tutorial on electroencephalogram methodology: EEG research with infants and young children. *In* Handbook of Developmental Neuropsychology. D.L. Molfese & V.J. Molfese, Eds.: Erlbaum. Mahwah, NJ. In press.
12. WOLFE, C.D. & M.A. BELL. 2004. Working memory and inhibitory control in early childhood: contributions from electrophysiology, temperament, and language. *Dev. Psychobiol.* **44**: 68–83.
13. ROTHBART, M.K. *et al.* 2001. Investigations of temperament at three to seven years: the children's behavior questionnaire. *Child. Dev.* **72**: 1394–1408.
14. ELLIS, L.K. & M.K. ROTHBART. 2001. Revision of the early adolescent temperament questionnaire: presented at the 2001 biennial meeting of the society for research in child development. Minneapolis, MN, April.
15. KOCHANSKA, G. *et al.* 2000. Effortful control in early childhood: continuity and change, antecedents, and implications for social development. *Dev. Psychol.* **36**: 220–232.
16. FOX, N.A. *et al.* 2001. Continuity and discontinuity of behavioral inhibition and exuberance: psychophysiological and behavioral influences across the first four years of life. *Child. Dev.* **72**: 1–21.