Event-related potential measures of emotion regulation in early childhood

Marc D. Lewis[a], Rebecca M. Todd[a] and Michael J.M. Honsberger[b]

[a]Department of Human Development and Applied Psychology, University of Toronto, Toronto, Ontario and [b]Department of Psychology, McGill University, Montreal, Quebec, Canada

Correspondence and requests for reprints to Professor Marc D. Lewis, PhD, Department of Human Development and Applied Psychology, University of Toronto, 252 Bloor Street West, Toronto, Ontario, Canada M5S 1V6
Tel: + 1 416 923 6641 ext. 2443; e-mail: mlewis@oise.utoronto.ca

Sponsorship: This study was supported by the Natural Sciences and Engineering Research Council of Canada.

Received 31 August 2006; accepted 5 September 2006

Emotion regulation in adults may be mediated by frontal cortical activities that adjust attention in response to challenging emotions. We examined event-related potentials across emotional conditions to assess normative patterns and individual differences in cortical mechanisms of emotion regulation in 4–6-year-olds. The children viewed pictures of angry, neutral, and happy faces during a Go/No-go task. Angry faces generated the greatest (fronto-central) N2 amplitudes and fastest N2 latencies, and happy faces produced the smallest amplitudes and slowest latencies. Frontal electrodes showed larger N2s to angry faces in the Go condition. The P3b was also largest for angry faces. More fearful children showed faster latency N2s to angry faces. These results are interpreted in terms of early-developing mechanisms for regulating anxiety and processing emotional information. *NeuroReport* 18:61–65 © 2007 Lippincott Williams & Wilkins.

Keywords: early child development, emotion faces, emotion regulation, event-related potentials, temperament

Introduction

The study of emotion regulation is currently of great interest to developmental psychologists. Developmentalists are concerned not only with age-specific mechanisms of emotion regulation but also with individual differences in their recruitment. In neuroscience, emotion regulation is often viewed in terms of frontal cortical activities that mediate cognitive control in the presence of emotional stimuli (e.g. [1]). Children's cognitive functions are, however, mediated by cortical regions that are more variable, more diffuse, or simply different from those of adults (e.g. [2,3]). Thus, we know little about the role of cortical activity in young children's emotion regulation.

When negative or disturbing emotions arise, people attempt to regulate their appraisals, their behavior, or the felt quality of the emotions themselves. According to both developmental psychologists (e.g. [4]) and neuroscientists (e.g. [5]), all of these activities require executive control of attention and/or action. An important milestone in 'effortful control' is reached during the fourth year of life, perhaps owing to the increased recruitment of the anterior cingulate cortex (ACC) for the regulation of impulsive behavior [6]. Individual differences in temperament can also be recorded at this age [6].

Event-related potential (ERP) research into cognitive self-regulation or effortful attention has focused on medial-frontal ERPs, such as the N2, associated with response inhibition and effortful attention [7,8]. Whereas later ERPs such as the P3b are associated with ongoing information processing, effortful control tapped by the frontal N2 may be essential for emotion regulation, and there is some direct evidence linking the N2 with negative emotional evaluations [9,10]. Moreover, anatomical correlates of the N2, including the ACC [8,11,12] and, less commonly, the orbitofrontal cortex [11,13] are thought to mediate links between attention and emotion [14,15]. Only a few studies have, however, examined the frontal N2 in children [12,13,16,17], and even fewer have investigated it in children as young as 4 years.

To look at the N2 as an index of emotion regulation in young children, we required a simple task that demanded effortful attention and an age-appropriate emotion-induction procedure. For the task, we chose a Go/No-go procedure adapted for young children. For the emotion induction, we used on-screen pictures of adult actors displaying emotion faces (angry, neutral, happy). Facial emotion induces emotional responses in both children and adults, and young children's ERPs vary with different emotion face stimuli, including larger midline negativities to angry than happy faces [18]. Children's responses also differ according to affective style or temperament, including faster response times for anxious children [19] and larger ERP amplitudes to angry faces for abused children [20].

The present study used ERP methods to determine whether frontocortical activity, hypothetically associated with emotion regulation, increases when children view anxiety-eliciting (e.g. angry) faces. Secondarily, we examined correlations of N2 magnitude and timing with individual differences in child temperament. We were interested in the N2 induced by both the face and the

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

response cue, because the emotional impact of the face was expected to modulate both the N2 tapping the initial appraisal and the N2 tapping the response control. We also examined the P3b after face presentation to determine whether early self-regulatory efforts would be followed by increased information processing of negative emotional stimuli [20]. We predicted that angry faces would trigger higher amplitude or more rapid N2s than happy faces, suggesting effortful emotion regulation, followed by larger P3bs, suggesting increased information processing. We also predicted that more fearful children would show higher amplitude or more rapid N2s to angry but not happy faces.

Methods

Participants

Participants were 18 English-speaking children aged 4–6 years (11 boys and seven girls), with normal or corrected-to-normal vision, all part of a larger study conducted at the University of Oregon. All participants belonged to an Anglo-American, middle-class, and urban community, and none were suspected of psychiatric difficulties of any kind. The families were paid US$20, or US$10 plus a toy for participation. Ethical approval was granted by the Human Subjects Review Board of the University of Oregon and informed consent was obtained from all the participants. Data from five children were excluded from analysis because of insufficient artifact-free trials in two or more stimulus conditions (see below).

Procedure

The testing protocol was carried out in a dark, sound-attenuated booth, where the child sat on his/her mother's lap in front of the computer monitor. A chin-rest and response pad were used. An examiner remained in the booth during the task to monitor the child's behavior and coach when needed.

Go versus No-go trials were cued by the gender of the face (counterbalanced across participants). In the No-go condition, children were instructed to 'wait' rather than not respond at all, to maintain engagement. Children were instructed as follows: 'When the frame appears, if the picture is a man (woman), press the button right away. If the picture is a woman (man), don't press the button until after the frame goes away' (see Fig. 1). Children were given an initial practice block of 10 faces, repeated if necessary. A second block of 16 angry and happy faces provided additional exposure and practice.

Angry, neutral, and happy faces (28 of each) were then presented in pseudo-randomized order. Pictures (1.5×1.8 inches) were black and white frontal head shots of adult amateur actors (50% men, 50% women), from the Karolinska Directed Emotional Faces Series [21]. The pictures were controlled for brightness, shading, and size of the head. A white frame appeared around the picture following a random interval of 1000–2000 ms. In the Go condition, the child's button-press terminated picture and frame simultaneously (after a 200-ms delay). In the Wait condition, the frame disappeared within 1000–1500 ms (randomized) following its onset. Then, the child's button-press terminated the picture (after a 200-ms delay). The ratio of Go-to-Wait trials was 50/50 for each face type.

After the task, parents were given a modified version of the Child Behavior Questionnaire [22] to complete. Only one scale, fear (anxiety), comprising 12 items (α=0.69), was used for the present analysis. The scale description for fear (anxiety) is the 'amount of negative affect, including unease, worry or nervousness related to anticipated pain or distress and/or potentially threatening situations'.

Event-related potential acquisition and scoring

Electroencephalogram was recorded from scalp electrodes using the 128-channel Geodesic Sensor Net (EGI, Eugene, Oregon, USA). All recordings were referenced to Cz, and electrode impedances were kept below 80 kΩ. Signals were sampled at 250 Hz. Raw electroencephalogram was filtered using a 1–40-Hz band-pass filter, then segmented into epochs from 200 ms before to 1000 ms after the presentation of both face and frame stimuli. Trials with blink and eye movement artifacts, and trials on which 20 or more channels exceeded 200 μV (absolute) or 100 μV (sample to sample) were excluded. Artifact-free trials were averaged for each participant, for each emotion face, and each response condition ($3 \times 2 = 6$ values each for face and frame presentation). The data were average-referenced and baseline-corrected (baseline beginning 200 ms before face onset and 100 ms before frame onset).

The N2 was scored 220–550 ms after face presentation, and 220–500 ms after frame presentation. Peak negative amplitudes within this time window were scored at midline frontal site 11 (approximately Fz) and at site 6 (approximately FCz). The P3b was scored 500–1000 ms ($M = 794$ ms)

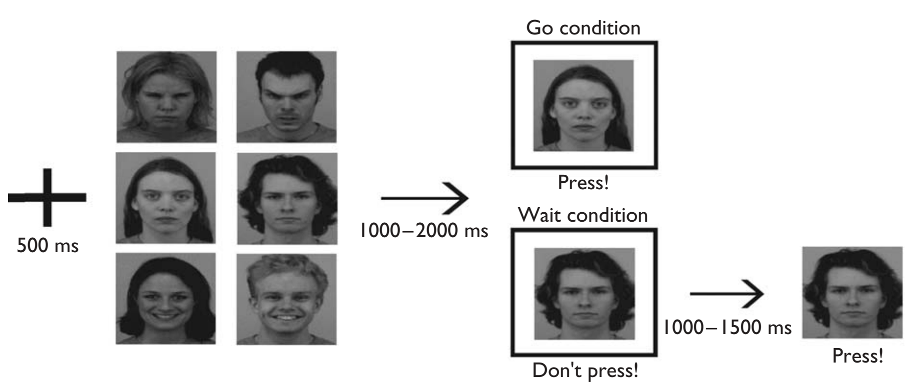

Fig. 1 A fixation cross lasting 500 ms was followed by a picture of a face with a happy, angry, or neutral expression. After 1000–2000 ms, a frame appeared around the face, and the child was instructed to 'Go' (press a button immediately) or 'Wait' (withhold a button press), depending on the gender of the face. In the Wait condition, the child was instructed to press the button after the frame disappeared (1000–1500 ms after onset).

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

after face presentation at site 55 (immediately posterior to Cz).

Movement artifacts, participant deletion, and power considerations

With preschool-aged children, movement artifacts are very difficult to control. Young children simply move about a great deal, even when they are 'sitting still', and this was true despite ongoing coaching by the parent and/or examiner. Five out of 18 children had 50% or more of their trials discarded in two or more stimulus conditions owing to movement artifacts, and these participants were removed from the sample. The remaining 13 children constituted a relatively small sample, but one sufficiently large to achieve statistical significance given moderate to large effect sizes. We calculated partial η^2 statistics to specify effect size for all analyses of variance (ANOVAs) involving ERPs. Note that this statistic is roughly equivalent to R^2 in multiple regression models as it represents the amount of variance accounted for by each independent variable.

Manipulation check

A second group of 4–6-year-old children ($n = 6$) rated all the angry faces and a selection of neutral and happy faces (12 and 8, respectively). Three-point scales were used to designate how 'angry' and 'scary' the faces appeared (1 = not at all, 2 = a little bit, 3 = very). Angry faces received mean angry ratings between 2 and 3, M = 2.15, SD = 0.33 and mean scary ratings between 2 and 3, M = 2.22, SD = 0.10. The happy faces received angry and scary ratings of 1. Neutral faces fell in between, with mean angry ratings of 1.32 (SD = 0.40) and mean scary ratings of 1.39 (SD = 0.34).

Results

Behavioral analyses

Response time was measured from frame onset for Go trials and from frame offset for Wait trials. For Go trials, response time was fastest for happy faces, medium for neutral faces, and slowest for angry faces, Ms = 1596.68, 1841.95, and 1908.59 ms, respectively. A repeated-measures ANOVA indicated a linear trend [$F(1,12) = 4.31$, $P = 0.06$]. For Wait trials, means were all in the low-middle sector of this range (1634.74–1799.48 ms) and did not approach significant differences. Thus, children tended to respond more quickly to happy faces and more slowly to angry faces. Regarding response accuracy, errors of omission on Go trials were rare because the task was not speeded, M = 0.92, SD = 1.75. Errors of commission on Wait trials were more frequent, but still within an acceptable range, M = 7.0, SD = 3.46. These values indicate that the children were quite capable of performing the task.

Event-related potential analyses

Response to faces

The grand-averaged waveform in response to the face showed distinct N1, P2, and N2 components at both frontal sites (Fig. 2), despite considerable latency jitter (variability in timing – not surprising for young children). We conducted separate repeated-measures ANOVAs on peak N2 amplitudes at each site. The site was not entered as a factor because we anticipated inconsistency in the location of peak ERP amplitudes in such young children [23]. A significant main effect was seen for emotion face (angry, neutral, happy) at FCz [$F(2,11) = 4.00$, $P = 0.05$, partial $\eta^2 = 0.42$]. As shown in Fig. 3, Go and Wait conditions showed very similar profiles, and planned contrasts revealed greater amplitudes for angry than happy faces, as predicted [$F(1,12) = 7.17$, $P = 0.02$, partial $\eta^2 = 0.37$]. At Fz, we found an interaction effect between emotion face and response (Go, Wait) conditions [$F(2,11) = 4.11$, $P < 0.05$, partial $\eta^2 = 0.43$]. Emotion faces differed significantly in the Go condition only [$F(2,11) = 4.81$, $P = 0.03$], in which Bonferroni-adjusted pairwise comparisons revealed greater amplitudes for angry than happy faces (mean difference: 2.96 μV, $P = 0.04$). Finally, an additional repeated-measures ANOVA revealed a significant multivariate effect for the

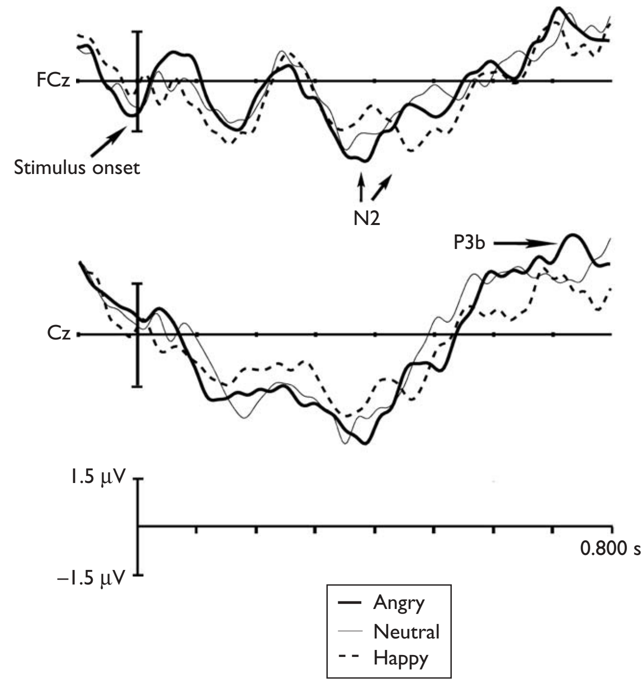

Fig. 2 Grand-average waveforms elicited by angry, neutral, and happy faces (100 ms before stimulus onset to 800 ms following onset) showing the N2 at FCz and the P3b at Cz.

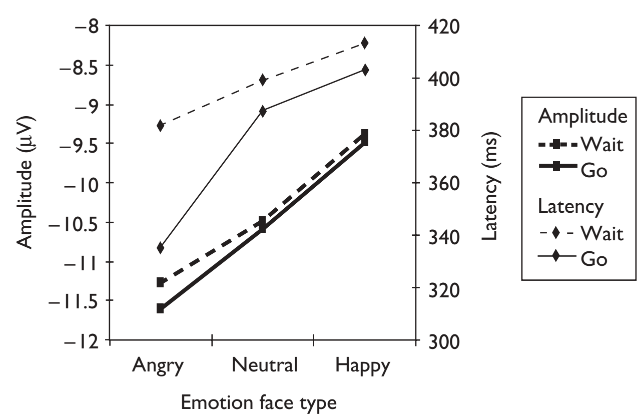

Fig. 3 Mean N2 amplitudes (μV) and latencies (ms) after face onset by emotion face type. Angry faces produced greater N2 amplitudes and faster latencies than happy faces, with neutral faces in between.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

P3b [F(2,11) = 3.90, $P = 0.05$, partial $\eta^2 = 0.42$]. This effect was accounted for by a linear trend showing greatest amplitudes for angry faces (M = 12.88 μV), as predicted, compared with happy (M = 11.04 μV) and neutral (M = 11.02 μV) faces [F(1,12) = 6.62, $P = 0.02$, partial $\eta^2 = 0.36$].

Not only were N2 amplitudes greater for angry than happy faces, but they also appeared earlier. At Fz, there was a main effect of emotion face on N2 latencies [F(1,12) = 5.06, $P = 0.04$, partial $\eta^2 = 0.30$]. As shown in Fig. 3, fastest latencies corresponded with angry faces and slowest with happy faces, as predicted, with the greatest differences seen in the Go condition. No significant effects were found at FCz, and P3b latencies showed no significant differences either.

Response to frame

The grand-averaged waveforms time-locked to frame (response cue) onset were even more smeared than to face onset, but the N2 component was still clearly visible. Separate repeated-measures ANOVAs were conducted on peak N2 amplitudes as before. At Fz, there was a main effect for response type, with greater mean amplitudes in the Wait condition, as predicted [F(1,11) = 4.76, $P = 0.05$, partial $\eta^2 = 0.30$]. Planned contrasts, however, revealed an unpredicted interaction effect between emotion face and response type at the level of a trend [F(1,11) = 4.22, $P = 0.07$] with a significant difference between Go and Wait conditions for neutral faces only [F(1,11) = 4.77, $P = 0.05$]. The same difference was evident at FCz [F(1,11) = 4.97, $P < 0.05$]. In both cases, neutral faces induced the smallest amplitudes in the Go condition and the greatest in the Wait condition. No other effects, including latency differences, approached significance.

Associations with temperament

An initial inspection of the data revealed that N2 latencies, and not amplitudes, correlated with fearfulness scores. To cut down the number of correlations tested, it was necessary to choose a particular site for analysis. A comparison of mean differences in amplitude between angry and happy faces revealed consistently greater angry–happy differences at Fz following face presentation and consistently greater angry–happy differences at FCz after frame presentation, so these sites were used. There were two significant correlations out of the eight that were tested. More fearful children showed more rapid N2s to angry faces when they appeared in the Go condition, $r = -0.65$, $P = 0.02$. In response to the frame (response cue), more fearful children showed more rapid N2s to angry faces in the Wait condition, $r = -0.85$, $P < 0.001$. Scatterplots representing these correlations revealed coherent distributions without obvious outliers (see Fig. 4), a crucial test for small N correlations. No correlations approached significance for the happy face condition following either face or frame presentation.

Discussion

The frontal N2 has been associated with effortful attention or response control in challenging conflictual situations as well as negative emotional evaluations. In this study, we hypothesized that anxiety-producing stimuli (angry faces) would enhance the amplitude or speed of this component in young children, tapping effortful emotion regulation, with

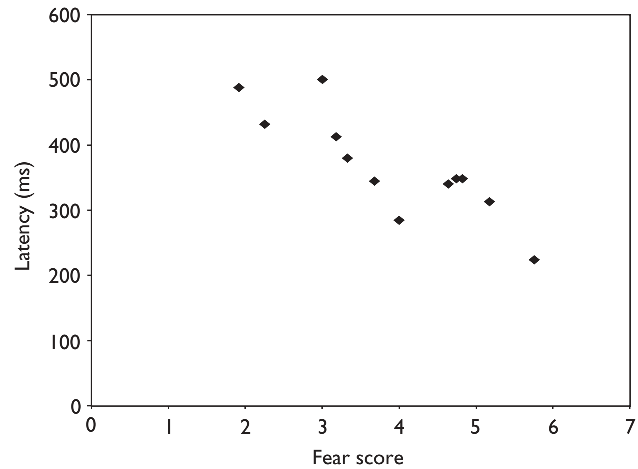

Fig. 4 Scatterplot illustrating the correlation ($r = -0.85$) between N2 latencies (time-locked to the frame) and fear scores after angry face presentation. Children with higher fear scores had significantly faster N2 latencies following angry faces after both face and frame presentation.

greatest enhancement for temperamentally fearful children. Indeed, the presentation of angry faces produced both higher amplitude and more rapid N2 responses than happy faces, with neutral faces falling in between. No main effect was seen for emotion face type in the response to the frame presentation. Thus, only when children initially encountered the angry face, and when no response was immediately required, was their cortical response enhanced.

Both higher amplitude and faster frontocortical responses could reflect more urgent recruitment of attentional processes needed to regulate anxiety during stimulus appraisal. Consistent with this interpretation, response times for button-pressing (in the Go condition) were slowest following angry faces. Greater attentional regulation in the presence of anxiety could have slowed response times owing to increased vigilance, self-inhibition, or other processes such as interference.

These results are consistent with the findings of larger medial-frontal negativities when adults are presented not only with negatively balenced stimuli [9,10] but also with Nelson and Nugent's [18] finding of increased frontocentral negativities in 4–6-year-old children in response to angry (but not happy) faces. Does this imply that preschoolers use the same cortical mechanisms as adults to regulate their emotions? We [17] recently showed that, from 5 to 16 years, frontal midline ERPs after negative emotion induction steadily decrease in amplitude, consistent with other N2 research, and become more localized to frontal cortical sources indicative of the ACC. Thus, although children's neural response to negative emotion resembles that of adults, emotion regulation networks or cortical systems involved in response inhibition, more generally, probably become more efficient and better integrated as the prefrontal cortex matures [24]. Longitudinal research using the present design would be important for examining these changes within individual children.

We also found unpredicted interaction effects in response to the face. At Fz, amplitude (and latency) differences for angry vs. happy faces were greatest in the Go condition. Response time differences were also suggested ($P = 0.06$) for the Go condition only. These findings point to the increased

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.

impact of angry faces associated with a Go command. This effect may be explained in terms of task demands, which may have been more urgent in the Go condition. Alternatively, angry faces associated with a Go command may have produced response conflict – an interpretation consistent with van Veen and Carter's [8] account of the frontal N2.

The P3b was also largest for angry faces. This component is thought to tap the allocation of cortical resources to stimuli that require ongoing cognitive processing. These results are consistent with Pollak and colleagues' [20] demonstration of larger P3b amplitudes in maltreated children, compared with normal controls, in response to angry faces. Like these authors, we assume that angry faces required ongoing attentional engagement because they elicited greater concern. We, however, see this allocation as a follow-up to initial efforts at self-regulation tapped by the N2. The P3b might thus reflect a second phase of emotion regulation.

As predicted, fearful temperament correlated with more rapid N2s to angry faces in response to both face and frame presentation. An association between medial-frontal negativities (such as the error-negativity) and anxiety has been documented in adult studies (e.g. [25]). Our results suggest that neural processes tapped by medial-frontal negativities already differ in individual styles of self-regulation by the preschool years [6]. Speeded N2s may correspond with the rapid registration of negative emotional content that characterizes the vigilant appraisal style of anxious children – perhaps a first step in self-regulation.

Conclusion

This experiment represents a novel approach to studying the neural correlates of emotion regulation in preschool children, an area that has literally not been examined by previous investigators. Our relatively small sample size, however, necessitates replication of the findings before firm conclusions can be drawn. Nevertheless, relatively large η^2 values indicated robust effect sizes for all of our key findings. These results suggest that young children, like adults, recruit cortical mechanisms of emotion regulation tapped by ERPs associated with effortful control (or response inhibition) and information processing. They also suggest that differential recruitment of these mechanisms contributes to personality or temperament differences in the preschool period.

Acknowledgements

We are very grateful to Liesel-Ann Meusel for her valuable comments on a previous draft of this manuscript.

References

1. Ochsner KN, Ray RD, Cooper JC, Robertson ER, Chopra S, Gabrieli JDE, *et al.* For better or for worse: neural systems supporting the cognitive down- and up-regulation of negative emotion. *Neuroimage* 2004; **23**:483–499.
2. Bunge SA, Dudukovic NM, Thomason ME, Vaidya CJ, Gabrieli JDE. Immature frontal lobe contributions to cognitive control in children: evidence from fMRI. *Neuron* 2002; **33**:301–311.
3. Luna B, Thulborn K, Munoz DP, Merriam EP, Garver KE, Minshew NJ, *et al.* Maturation of widely-distributed brain function subserves cognitive development. *Neuroimage* 2001; **13**:786–793.
4. Cole PM, Martin SE, Dennis TA. Emotion regulation as a scientific construct: methodological challenges for child development research. *Child Dev* 2004; **75**:317–333.
5. Gross JJ. Emotion regulation: affective, cognitive, and social consequences. *Psychophysiology* 2002; **39**:281–291.
6. Posner MI, Rothbart MK. Developing mechanisms of self-regulation. *Dev Psychopathol* 2000; **12**:427–441.
7. Gehring WJ, Knight RT. Prefrontal–cingulate interactions in action monitoring. *Nat Neurosci* 2000; **3**:516–520.
8. van Veen V, Carter CS. The timing of action-monitoring processes in the anterior cingulate cortex. *J Cogn Neurosci* 2002; **14**:593–602.
9. Luu P, Tucker DM, Derryberry D, Reed M, Poulsen C. Electrophysiological responses to errors and feedback in the process of action regulation. *Psychol Sci* 2003; **14**:47–53.
10. Tucker DM, Luu P, Desmond RE Jr, Hartry-Speiser A, Davey C, Flaisch T. Corticolimbic mechanisms in emotional decisions. *Emotion* 2003; **3**: 127–149.
11. Bokura H, Yamaguchi S, Kobayashi S. Electrophysiological correlates for response inhibition in a Go/No-go task. *Clin Neurophysiol* 2001; **112**:2224–2232.
12. Falgatter AJ, Mueller TJ, Strik WK. Age-related changes in the brain electrical correlates of response control. *Clin Neurophysiol* 1999; **110**: 833–838.
13. Plizska SR, Liotti M, Woldorff M. Inhibitory control in children with attention-deficit/hyperactivity disorder: event-related potentials identify the processing component and timing of an impaired right-frontal response-inhibition mechanism. *Biol Psychiatry* 2000; **48**:238–246.
14. Barbas H. Anatomic basis of cognitive-emotional interactions in the primate prefrontal cortex. *Neurosci Biobehav Rev* 1995; **19**:449–510.
15. Lane RD, Fink GR, Chau PML, Dolan RJ. Neural activation during selective attention to subjective emotional responses. *Neuroreport* 1997; **8**:3969–3972.
16. Davis EP, Bruce J, Snyder K, Nelson C. The X-trials: neural correlates of an inhibitory control task in children and adults. *J Cogn Neurosci* 2003; **13**:432–443.
17. Lewis MD, Lamm C, Segalowitz SJ, Stieben J, Zelazo PD. Neurophysiological correlates of emotion regulation in children and adolescents. *J Cogn Neurosci* 2006; **18**:430–443.
18. Nelson CA, Nugent KM. Recognition memory and resource allocation as revealed by children's event-related potential responses to happy and angry faces. *Dev Psychol* 1990; **26**:171–179.
19. Hadwin JA, Donnelly N, French CC, Richards A, Watts A, Daley D. The influence of children's self-report trait anxiety and depression on visual search for emotional faces. *J Child Psychol Psychiatry* 2003; **44**:432–444.
20. Pollak SD, Klorman R, Thatcher JE, Cicchetti D. P3b reflects maltreated children's reactions to facial displays of emotion. *Psychophysiology* 2001; **38**:267–274.
21. Lundqvist D, Flykt A, Öhman A. *The Karolinska Directed Emotional Faces [Photo database]*. Sweden, Stockholm: Karolinska Institute; 1998.
22. Rothbart MK, Ahadi SA, Hershey KL, Fisher P. Investigations of temperament at three to seven years: the children's behavior questionnaire. *Child Dev* 2001; **72**:1394–1408.
23. Taylor MJ, Baldeweg T. Application of EEG, ERP and intracranial recordings to the investigation of cognitive functions in children. *Dev Sci* 2002; **5**:318–334.
24. Casey BJ, Giedd JN, Thomas KM. Structural and functional brain development and its relation to cognitive development. *Biol Psychol* 2000; **54**:241–257.
25. Gehring WJ, Himle J, Nisenson LG. Action monitoring dysfunction in obsessive–compulsive disorder. *Psychol Sci* 2000; **11**:1–6.

Copyright © Lippincott Williams & Wilkins. Unauthorized reproduction of this article is prohibited.