This article was downloaded by: *[Dennis, Tracy A.]*
On: *17 February 2009*
Access details: *Access Details: [subscription number 907776298]*
Publisher *Psychology Press*
Informa Ltd Registered in England and Wales Registered Number: 1072954 Registered office: Mortimer House, 37-41 Mortimer Street, London W1T 3JH, UK

Developmental Neuropsychology
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t775653638

Emotional Face Processing and Emotion Regulation in Children: An ERP Study

Tracy A. Dennis [a]; Melville M. Malone [b]; Chao-Cheng Chen [a]
[a] Department of Psychology, Hunter College of The City University of New York, New York, New York [b] Department of Psychology, Vanderbilt University, Nashville, Tennessee

Online Publication Date: 01 January 2009

To cite this Article Dennis, Tracy A., Malone, Melville M. and Chen, Chao-Cheng(2009)'Emotional Face Processing and Emotion Regulation in Children: An ERP Study',Developmental Neuropsychology,34:1,85 — 102

To link to this Article: DOI: 10.1080/87565640802564887

URL: http://dx.doi.org/10.1080/87565640802564887

PLEASE SCROLL DOWN FOR ARTICLE

Full terms and conditions of use: http://www.informaworld.com/terms-and-conditions-of-access.pdf

This article may be used for research, teaching and private study purposes. Any substantial or systematic reproduction, re-distribution, re-selling, loan or sub-licensing, systematic supply or distribution in any form to anyone is expressly forbidden.

The publisher does not give any warranty express or implied or make any representation that the contents will be complete or accurate or up to date. The accuracy of any instructions, formulae and drug doses should be independently verified with primary sources. The publisher shall not be liable for any loss, actions, claims, proceedings, demand or costs or damages whatsoever or howsoever caused arising directly or indirectly in connection with or arising out of the use of this material.

DEVELOPMENTAL NEUROPSYCHOLOGY, *34*(1), 85–102
Copyright © 2009 Taylor & Francis Group, LLC
ISSN: 8756-5641 print / 1532-6942 online
DOI: 10.1080/87565640802564887

Psychology Press
Taylor & Francis Group

Emotional Face Processing and Emotion Regulation in Children: An ERP Study

Tracy A. Dennis
Department of Psychology
Hunter College of The City University of New York, New York, New York

Melville M. Malone
Department of Psychology
Vanderbilt University, Nashville, Tennessee

Chao-Cheng Chen
Department of Psychology
Hunter College of The City University of New York, New York, New York

Emotion regulation is a critical component of healthy development, yet few studies examine neural - correlates of emotion regulation in childhood. In the present study, we assessed whether children's neurophysiological responses to salient and socially significant emotional distracters—emotional faces—were related to broader emotion regulation capacities. Emotion regulation was measured as attention performance following emotional distracters and as maternal report of child emotional dysregulation. Electroencephalography was recorded while participants (15 children aged 5–9) performed an attention task. Scalp-recorded event related potentials (ERPs) were time-locked to emotional distracters (fearful, sad, and neutral faces) and reflected a range of rapid attentional and face processing operations (P1, N1, N170, and Nc). P1 latencies were faster whereas N1 amplitudes were reduced to fearful compared to sad faces. Larger P1 and Nc amplitudes to fearful and sad faces were correlated with more effective emotion regulation. Results are discussed in terms of mechanisms in emotion regulation and the use of ERPs to detect early risk for psychopathology and inform intervention efforts.

Although there is no single agreed-on definition of emotion regulation, broadly speaking emotion regulation refers to the ability to monitor, evaluate, and modify the intensity and temporal dynamics of emotional reactions (Thompson, 1994). Among the core capacities that support emotion regulation is the ability to control attention in emotionally demanding contexts (Cole, Martin, & Dennis, 2004; Lewis, Lamm, Segalowitz, Stieben, & Zelazo, 2006b). For example, children who are emotionally distressed during a delay of gratification task, but who can shift attention away from a tempting prohibited item, are better able to comply, wait, and resist temptation (Cole, 1986;

Correspondence should be addressed to Tracy Dennis, Ph.D., Assistant Professor of Psychology, Hunter College of The City University of New York, 695 Park Avenue, New York, NY 10065. E-mail: tracy.dennis@hunter.cuny.edu

This research was supported by NIH Grants 5T34 GM007823, 5K01 MH075764-02, and 5S06GM060654-04, the latter two awarded to T.D. This research was also made possible by Grant RR03037 from the National Center for Research Resources (NCRR), a component of the NIH.

Putnam, Spritz, & Stifter, 2002), and show better parent-reported ability to manage negative emotions during adolescence (Shoda, Mischel, & Peake, 1990). Conversely, increased attention toward distracting negative or ambiguous emotional information has been associated with mood and anxiety problems (Compton, 2003; Derryberry & Reed, 2002) and may deplete the resources available for voluntary aspects of emotion regulation (Bishop, Duncan, Brett, & Lawrence, 2004; Hare, Tottenham, Davidson, Glover, & Casey, 2005; Kieras et al., 2000; Simpson et al., 2000). These findings are consistent with research showing that maturation of attention systems, which are highly interconnected with limbic and frontal motivational systems, support self-and emotion regulation (Bush, Luu, & Posner, 2000; Derryberry & Rothbart, 1997; Posner & Rothbart, 2000).

However, previous studies have only begun to address how attentional processing of emotional stimuli relates to complex regulatory capacities. For example, studies using scalp-recorded event related potentials (ERPs) show that increased neural activity during a negative mood induction is associated with better social–emotional functioning (Lewis, Granic, & Lamm, 2006a; Lewis et al., 2006b) whereas neuroimaging studies suggest that children's difficulties in regulating behavior in emotional context might be associated with competition between emotional processing and cognitive control systems (Hare et al., 2005; Hare et al., 2008). Thus, it may be that increased attention-related neural activity in emotional contexts reflects the allocation of cognitive resources in the service of regulatory control (Gray et al., 2005; Lewis et al., 2006b; Luu, Tucker, & Makeig, 2004). However, relatively few studies have examined direct associations between ERPs related to emotional processing and emotion regulation capacities in children. Identifying neurophysiological correlates of emotion regulation in children has the potential to provide an important adjunct to behavioral measures of emotion regulation by revealing mechanisms in emotion regulation, shedding light on the time course of emotional processing in relation to emotion regulation, and providing a potential marker for regulatory difficulties that can inform early detection and intervention efforts.

The goal of the current study was to examine whether enhanced neurophysiological responses to distracting emotional stimuli—emotional faces—are associated with more adaptive emotion regulation in children. This was tested by examining links between ERPs reflecting attention and face processing and two measures of emotion regulation in children: attention performance following the emotional distracters and maternal report of emotion regulation. ERPs provide a powerful way to measure attention to emotional stimuli at a high temporal resolution. In the present study, emotional faces were chosen as distracter stimuli because they are salient and motivationally significant, and because they have been the target of a significant number of ERP studies with children and adults (Batty & Taylor, 2006; Eimer & Holmes, 2002; Pizzagalli, Regard, & Lehmann, 1999; Sato, Kochiyama, Yoshikawa, & Matsumura, 2001; Taylor, Batty, & Itier, 2004).

A growing body of evidence documents that across the lifespan, emotional faces are perceived and evaluated extremely rapidly, with reliable ERP differences between emotional and neutral faces being reported beginning around 90–120 msec after stimulus onset (Batty & Taylor, 2003; Eimer & Holmes, 2002, 2007). For example, the P1, which is maximal in posterior recording sites around 100 msec, emerges in children and adults in response to faces and is sensitive to changes in face processing demands (Batty & Taylor, 2003; Eimer & Holmes, 2007; Itier & Taylor, 2004; Taylor et al., 2004). Although adult studies have reported that the P1 is sensitive to the emotional expression of faces (Batty & Taylor, 2003; Eger, Jedynak, Iwaki, & Skrandies, 2003; Eimer & Holmes, 2007; Pourtois, Grandjean, Sander, & Vuilleumier, 2004) only two studies to our knowledge have examined the P1 in response to emotional faces in normatively developing preschool to school-aged children (Batty & Taylor, 2006; Todd, Lewis, Meusel, & Zelazo, 2008). One study found that negative compared to neutral or positive emotions elicited later P1 latencies in 4–6 year olds but not older children or adults (Batty & Taylor, 2006), whereas a study with children in the same age range (Todd et al., 2008) revealed no significant amplitude or latency effects for the P1 due to the familiarity or emotional expression of faces. These findings, although mixed, suggest the possibility that information related to emotion may be processed before more detailed perceptual processing is completed, particularly in young children (Batty & Taylor, 2006; Vuilleumier & Pourtois, 2007).

Importantly, the P1 has traditionally been studied in relation to sensory gain control and selective attention. The P1 is enhanced for attended versus unattended (or valid versus invalid) stimuli in normative and clinical populations (Hillyard et al., 1999; Mangun & Hillyard, 1995; Tendolkar et al., 2005). This P1 effect is therefore thought to reflect a mechanism whereby sensory signals to attended stimuli are enhanced relative to unattended stimuli to avoid interference, and have a beneficial effect on speeded performance tasks. Reductions in the P1 to unattended stimuli reflect attention suppression of these stimuli (Luck, 2006; Luck & Hillyard, 1995). The N1, a negative potential following the P1, also emerges during visual processing but is thought to be more closely related to attentional facilitation of attended inputs, such as target enhancement and discrimination, rather than attention suppression (Luck, 2006; Mangun & Hillyard, 1995; Näätänen & Picton, 1987). There is some evidence that the N1 may be sensitive to facial characteristics (Bentin, Allison, Puce, & Perez, 1996; Campanella et al., 2002; Eimer & Holmes, 2002). For example, in one study with adults, a negative component in frontocentral electrodes with a latency around 115 msec was reduced to fearful versus neutral faces (Eimer & Holmes, 2002). These early and relatively automatic mechanisms of selective attention reflected by the P1 and N1 may not only support attentional processing of emotional faces, but may be related to the ability to modulate reactions to such emotional stimuli. Associations between these components and emotion regulation, however, have never to our knowledge been examined.

In summary, although results have been mixed, previous studies suggest that the P1 and N1 are sensitive to facial emotion in children. If increased attention-related neural activity in emotional contexts supports regulatory control (Lewis et al., 2006b) then enhanced attentional ERPs, particularly the P1 which is implicated in attention suppression and selective attention to emotional stimuli, may be associated with more effective emotion regulation.

It is also unclear whether slightly later ERPs related to face processing are sensitive to emotional expression and are relevant to emotion regulation. The N170 is a posterior negative potential around 170 msec that is thought to reflect the structural encoding of faces (Batty & Taylor, 2003; Bentin et al., 1996; Eger et al., 2003; Pizzagalli et al., 1999; Righart & de Gelder, 2006). Although some studies have shown that the N170 is faster or of greater amplitude for emotional faces (Batty & Taylor, 2003; Eger et al., 2003; Palermo & Rhodes, 2007; Vuilleumier & Pourtois, 2007), other studies suggest that the N170 is not sensitive to emotion (Eimer & Holmes, 2002; Herrmann et al., 2002; Pizzagalli et al., 2002). Moreover, research examining the neural substrates of face and emotional processing shows that face-specific neural responses may also be enhanced to ambiguous stimuli such as neutral faces (Adams & Kleck, 2005; Fox, Russo, & Dutton, 2002; Garner, Mogg, & Bradley, 2006; Haneda, Nomura, Iidaka, & Ohira, 2003; Kleinhans et al., 2007). In children, although studies are relatively few, there is some evidence that by the preschool years, the N170 occurs in posterior recording sites at latencies up to 300 msec (Taylor, McCarthy, Saliba, & Degiovanni, 1999) and is sensitive to configural changes in faces (Itier & Taylor, 2004; Taylor et al., 2004). It appears that the N170 may not be sensitive to emotional faces in preschool to school-aged children (Batty & Taylor, 2006), although one study found that a posterior negative component around 300 msec was larger to fearful compared to neutral faces in 3–4 year olds (Dawson, Webb, Carver, Panagiotides, & McPartland, 2004).

Face processing in children has also been associated with a frontocentral negative deflection around 200–700 msec, referred to as the Nc. Thought to be equivalent to the N400 in adult studies of face processing (Bentin & McCarthy, 1994), the Nc is sensitive to facial familiarity in infants (Carver et al., 2003; de Haan & Nelson, 1997) and typically developing preschoolers (Carver et al., 2003; Dawson et al., 2002) and may also index stimulus salience and memory recognition (de Haan & Nelson, 1997; Nelson & Nugent, 1990).

On the other hand, studies examining face processing in the context of emotion processing and emotion regulation have also referred to a negative-going ERPs with the same timing and scalp location of the Nc as frontal negativities . These frontal negativities are generated from areas of the medial frontal cortex, such as the anterior cingulate cortex, and have been linked to more deliberate attentional and cognitive control processes (Gehring & Willoughby, 2002; Luu, Flaisch, & Tucker, 2000; Parasuraman, 1998; Potts, Martin, Burton, & Montague, 2006; Yeung, Holroyd, & Cohen, 2005). For example, the N2 is a frontal negativity that is enhanced during tasks requiring monitoring of “crosstalk,” or conflicting information and response options, and is thought to signal the extent to which attentional control is required (Nieuwenhuis, Yeung, Van Den Wildenberg, & Ridderinkhof, 2003; van Veen & Carter, 2002). Frontal negativities may thus reflect a “gating” mechanism in the medial frontal cortex through which motivationally significant information gains access to cognitive and attentional control systems (Potts et al., 2006). Such action monitoring supports emotion regulation by guiding behavior and emotions to be in line with goals .

This frontal negativity interpretation of the Nc is consistent with a small body of research with children showing that the latency of the Nc is more rapid in anxious children (Lewis, Todd, & Honsberger, 2007) and that the Nc is sensitive to facial emotion: Nc amplitudes are larger and latencies faster in response to negative facial emotion compared to happy faces in children (Batty & Taylor, 2006; Lewis et al., 2007; Nelson & Nugent, 1990; Todd et al., 2008). The Nc may thus be related to both increased attention to emotional faces and the ability to regulate responses elicited by emotional faces. The Nc has not been examined in response to a range of emotional faces and in relation to emotion regulation. In the present study, we will examine whether the Nc is sensitive to negative emotional faces (fearful and sad) compared to neutral faces. In addition, because the Nc may be related to the recruitment of frontally mediated cognitive control processes, we will examine whether enhanced Nc amplitudes to negative emotional faces are associated with more effective emotion regulation, particularly measured in terms of the ability to complete a frontally mediated executive function task in an emotional context.

In summary, early-emerging ERPs related to relatively automatic and controlled attention to emotional information may reflect the recruitment of attentional and cognitive control in the service of emotion regulation. It remains unclear, however, whether these neurophysiological responses predict independent measures of emotion regulation, particularly in young children. Previous research suggests that among children, enhanced ERPs in response to emotional stimuli may reflect greater regulatory capacity (Lewis et al., 2006a; Lewis et al., 2006b). To examine this possibility, ERPs to emotional distracters were measured and examined in relation to two measures of emotion regulation: attention performance following the emotional distracters and maternal report of child emotion regulation. Attention was measured in three domains, alerting, orienting, and executive attention, in order to explore specific associations between ERPs and frontally mediated executive attention versus other attention processes.

Fearful and sad emotional faces were chosen as distracter stimuli because they are salient and motivationally significant. Neutral faces were also included, alternating with either fearful or sad faces, in order to clarify whether processing of emotional versus non-emotional but socially significant information is related to emotion regulation. Faces are processed extremely rapidly while competing for attention resources; thus, early-occurring ERPs (0–500 msec) related to attentional processing of faces and attentional control were targeted. Children aged 5 to 9 were targeted in order capture a range of ages within early childhood during which cortical maturation is rapidly progressing.

It was predicted that children will show larger amplitude ERPs stimulus-locked to distracting emotional versus neutral faces, although N1 amplitudes may be reduced to emotional versus neutral faces (Eimer & Holmes, 2002). Previous studies provide mixed results concerning whether the latency of ERPs will vary between emotional versus neutral faces, and thus we will also explore whether facial emotion modulates the latency of these ERPs. It was also predicted that larger ERP amplitudes to distracting emotional faces will be correlated with more effective emotion regulation in children: measured as more efficient attention performance (i.e., better regulation of attention) following emotional distracters and more effective regulation of emotional arousal as reported by mothers. These effects were expected to be enhanced for ERPs related to attentional suppression and control (P1 and Nc) compared to those reflecting relatively automatic attentional enhancement and face processing (N1, N170).

METHOD

Participants

Participants were 15 children between the ages of 5 and 9 (*M* age in months = 81.80, *SD* = 19.06 months; Median = 77 months; 7 females). Participants and their mothers were recruited through fliers and online advertising in New York City. Children were screened for identified psychological or neurological impairments through maternal interview. Maternal report of child's race/ethnicity was as follows: 7 Caucasian, 4 African American, 2 Hispanic, 1 Asian, 1 "Other." Participants spent approximately 2 hours in the laboratory. All participants' families were paid $50 for their participation.

Procedures and Measures

Maternal report of child emotion regulation. Mothers completed the Emotion Regulation Checklist (Shields & Cicchetti, 1995). This 24-item questionnaire concerns children's reactions to emotional challenges and regulation of a wide range of emotions. Two subscales were calculated based on measure developers' guidelines, which have been shown to converge with other measures of emotion regulation (Shields & Cicchetti, 1998): *emotion dysregulation* ($\alpha = .72$), which was comprised of items including "is prone to angry outbursts/tantrums easily" and "exhibits wide mood swings"; and *positive regulation* ($\alpha = -.22$), comprised of items including "can say when s/he is feeling sad, angry or mad, fearful or afraid." Items were rated on a 1–4 scale. Only the emotion dysregulation subscale (*M* = 1.76, *SD* = 0.75) showed adequate internal consistency, and thus is used in analyses reported later in the article.

Attention performance following emotional distracters. EEG was recorded while participants were administered a modified version of the Attention Network Test–Child Version (Rueda et al., 2004). The task was presented via E-Prime software (Psychological Software Tools, Pittsburgh, PA) on an IBM personal computer running Window XP, presenting to a 14-inch IBM monitor. Participants viewed the screen from a distance of 65 cm, and responses were collected via two buttons on the mouse.

The ANT is a cued flanker paradigm (valid cues only) that has been shown to provide reliable estimates of three distinct attention functions: alerting, orienting, and executive attention (Fan, McCandliss, Sommer, Raz, & Posner, 2002; Fossella et al., 2002). The task was modified by briefly presenting emotional faces (200 msec) as distracter stimuli before each trial of the task (Dennis & Chen, 2007a, 2007b). This stimulus duration of 200 msec was chosen to capture rapid encoding of faces before attention is likely to shift away.

Figure 1 illustrates that the task combines a cued reaction time and flanker task (Eriksen & Eriksen, 1974). Cue types are no cues, double cues (circle appears above and below the fixation), center cues (circle appears superimposed over the fixation), and spatial cues (circle appears above or below the fixation to indicate the upcoming location of the subsequent target). All cues are valid, and modulate whether subjects are alerted to the impending stimulus, and whether subjects are oriented ahead of time to the location of the target. Flanker stimuli were fishes, rockets, mice, and birds chosen because they are more engaging to young children than the arrows used in the adult version of the task. Congruent flankers point in the same direction as the central stimulus and

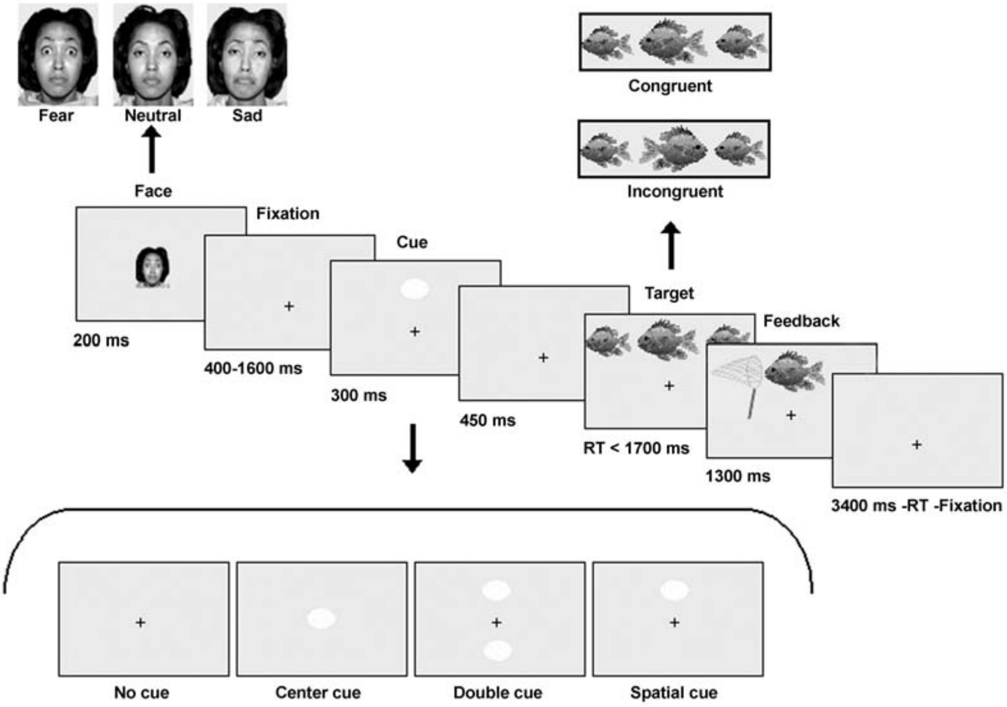

FIGURE 1 Diagram of the experimental design (based on Rueda et al., 2004)

incongruent flankers point in the opposite direction. Participants indicate with one of two alternative button presses whether the central stimulus points left or right.

As depicted in Figure 1, each trial consisted of seven events: (1) faces (fear, sad, or neutral; 200 msec); (2) fixation period (variable 400–1600 msec); (3) cue condition (no cue, center cue, double cue, spatial cue; 300 msec); (4) fixation period (450 msec); (5) simultaneously presented target and flanker stimuli (one stimulus type per block (e.g., bird) randomly selected; display terminated after 1700 msec); (6) response feedback (1300 msec); and (7) post-feedback fixation period (variable, based on the first fixation duration minus the reaction time for that trial; 3400 msec - 1st fixation - RT). Each trial lasted for 5650 msec.

The experiment consisted of a 6-trial practice block followed by two blocks of experimental trials (64 trials per block). There was a brief break in-between blocks. Each block included exactly two types of stimuli: One block contained a random mix of fearful or neutral faces (subsequently referred to as neutral-f faces) and the other block contained a random mix of sad or neutral faces (subsequently referred to as neutral-s faces). Faces were randomly presented without replacement within each block so that each stimulus type was presented for 50% of the trials within a block. Block order was counterbalanced across subjects. Throughout the experiment, the faces were distracters as they were completely unrelated and uninformative for performance on the primary attention task.

Efficiency of the three attention networks, alerting, orienting, and executive attention, is determined by measuring how response times (RT) to the flanker displays are influenced by alerting cues, spatial cues, and flanker type (see Fan et al., 2002 for additional details). *Alerting* is calculated as RT following no cue – RT following double cue. *Orienting* is calculated as RT following center cue – RT following spatial cue. *Executive attention* is calculated in terms of conflict interference: RT to incongruent flankers – RT to congruent flankers. Although higher scores for alerting and orienting indicate greater efficiency, higher conflict scores indicate greater conflict interference or less efficient executive attention.

Emotional faces. Emotion stimuli were fearful, sad, and neutral faces taken from a battery developed by the Research Network on Early Experience and Brain Development (Tottenham, Borscheid, Ellertsen, Marcus, & Nelson, 2002, April). This battery of 646 facial expression stimuli was posed by actors of varying ethnicities. Selected faces were matched for gender and ethnicity. Stimuli were presented centrally in the location of the fixation cross preceding each trial of the attention task. The order of the pictures was block randomized by emotion for each subject. The faces used in this study were selected based on normative ratings of the faces for fearful, sad, and neutral facial expressions, and representation of gender and ethnicity.

Children had difficulty understanding the task of subjectively rating faces in terms of valance and arousal properties. In a study using the same stimuli (Dennis & Chen, 2007b), however, adult participants rated each face using the Self-Assessment Mannequin technique (Lang, Bradley, & Cuthbert, 1998). Faces were rated on a 1–5 scale for arousal, with 5 indicating highly arousing (reverse scored from original rating), and a 1–5 scale for valence, with 1 being very positive and 5 being very negative. Neutral and sad faces were rated as less arousing than fearful faces, $t(37) = 3.41$, $p < .01$ and $t(37) = 4.68$, $p < .001$ (neutral $M = 1.27$, $SD = 0.79$; sad $M = 1.32$, $SD = 0.81$; fearful $M = 1.63$, $SD = 0.89$). Neutral and fearful faces were rated as more positive than sad faces, $t(37) = 5.17$, $p < .001$ and $t(37) = 6.04$, $p < .001$ (neutral $M = 3.11$, $SD = 0.15$; fearful $M = 3.19$, $SD = 0.51$; sad $M = 3.56$, $SD = 0.59$). In summary, sad faces were perceived as more negative than neutral and fearful faces, but both sad and neutral faces were rated as less arousing than fearful faces.

Psychophysiological Recording and Data Analysis

EEG activity was recorded continuously via 64 Ag/AgCl active scalp electrodes embedded in an elasticized nylon ECI cap and from two electrodes placed on the right and left mastoids. Eye movements were monitored by electro-oculogram (EOG) signals from electrodes placed approximately 1 cm above and below the left eye and from electrodes 1 cm lateral to each eye. As per BioSemi system design, the ground electrode during acquisition was formed by the Common Mode Sense active electrode and the Driven Right Leg passive electrode.

EEG and EOG signals were sampled at 512 Hz and amplified with a band pass of .16–100 Hz by the ActiveTwo amplifier (BioSemi, Amsterdam NL). All data were re-referenced offline to an average reference and filtered with a high pass frequency of .2 Hz and a low pass frequency of 30 Hz. ERPs were time-locked to faces, and were segmented into epochs from 200 msec before to 500 msec after stimulus onset; the baseline of 200 msec was used for baseline correction. The raw EEG epochs were passed through a computerized artifact scan batch to correct artifacts using Brain Electrical Source Analysis version 5.1 (BESA; MEGIS Software GmbH, Munich, Germany). After artifact correction, trials that still included EEG or EOG activity with a voltage step of more than 50 µV between sampling points, or trials with voltages remaining above ± 100 µV were excluded from further analysis. Given these criteria, trial acceptance rates ranged from 67% to 94%.

Data reduction and ERP components. ERPs emerging during the first 500 msec following presentation of faces were targeted. There were four primary deflections: P1 (maximal at 125 msec at occipital leads O1, Oz, and O2), N1 (maximal at 130 msec at central-parietal leads CP3, CPz, and CP4), N170 (maximal at 190 msec at parietal occipital leads PO7, POz, and PO8), and Nc (maximal at 335 msec at central leads C3, Cz, and C4). Figure 2 shows scalp topography and representative waveforms for each component of interest. Waveforms were calculated as the difference between the immediately preceding peak of opposite polarity and the peak of interest. The positive peak was always subtracted from the negative peak in order to obtain the absolute value for each waveform per emotion. Patterns of findings resulting from analyses conducted with mean amplitude scores did not differ from those reported later using peak difference scores.

RESULTS

Descriptive Statistics

Table 1 presents ERP amplitudes and attention scores for correct trials only (*M* accuracy = 92%, *SD* = 7%, range = 78%–99%). There were no age differences in accuracy between younger and older children (based on a median split at 77 months: younger accuracy = 90% versus older accuracy = 95%) and accuracy did not differ among emotional face conditions. Logarithmic transformations were applied to correct for positively skewed distributions of attention scores. All analyses were conducted both with transformed and untransformed values. Because results did not differ, untransformed values are reported for ease of interpretation.

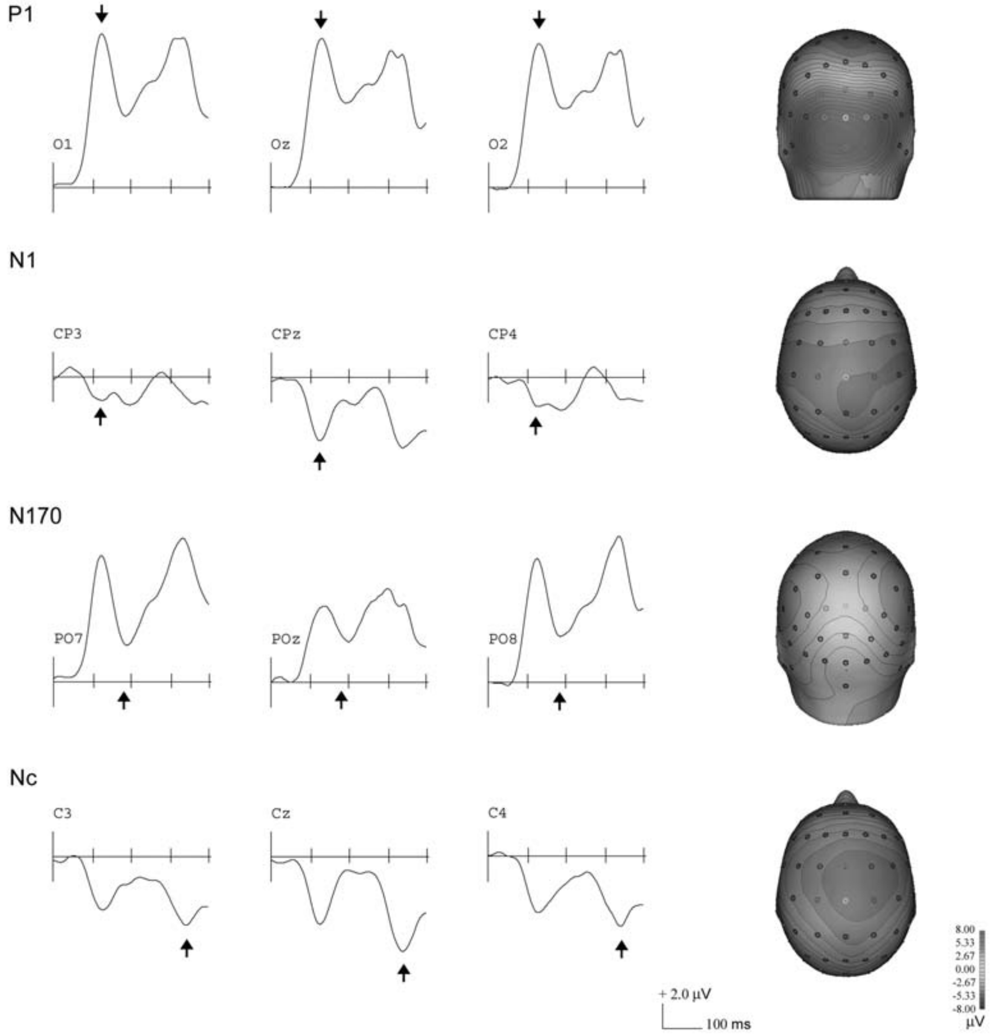

FIGURE 2 Grand-averaged waveforms and scalp topography for each ERP stimulus-locked to faces. Contour lines are spaced every 0.50 µV.

Attention Performance: Behavioral Data

It was first tested whether emotional face context alone influenced attention performance. There were two emotional faces (fearful and sad faces) and two neutral faces types (neutral faces alternating with fearful faces, or neutral-f, and neutral faces alternating with sad faces, or neutral-s). These neutral faces thus were embedded in broader emotional contexts. We conducted three 2 (Gender) × 4 (fearful, sad, neutral-f, neutral-s) repeated measure ANOVAs (attention perfor-

TABLE 1
Descriptive Statistics for Attention Performance Scores

	Emotion				
	Fearful M (SD)	*Sad M (SD)*	*Neutral-f M (SD)*	*Neutral-s M (SD)*	*Total M (SD)*
Alerting	31.68 (90.24)	30.14 (109.42)	28.47 (167.53)	–27.84 (146.94)	34.17 (33.46)
Orienting	60.05 (106.06)	71.02 (95.78)	151.28 (135.71)	65.25 (87.72)	80.33 (28.22)
Executive Attention	53.96 (84.52)	47.22 (57.60)	73.80 (93.14)	62.27 (96.44)	58.24 (50.16)

The negative alerting score indicated reduced efficiency. *M* accuracy = 92%, *SD* = 7%, range = 78%–99%.

mance: alerting, orienting, and executive attention separately). There was one significant effect of Emotion on orienting, $F(3,11) = 4.02$, $p < .05$, partial $\eta^2 = .52$. Orienting performance was better (reaction times faster after orienting cues) following neutral-f compared to neutral-s faces, $t(14) = 2.27$, $p < .05$. Therefore, the fear context (neutral faces alternating with fearful faces) but not fear faces per se were associated with facilitation of orienting. No significant effects of Gender emerged.

ERP Amplitudes Time-Locked to Distracting Faces

To test whether ERP amplitudes in response to distracting faces are greater for emotional versus neutral faces, four 2 (Gender) × 4 (Emotion: fear, sad, neutral-f, neutral-s) × 3 (Electrode Region: right, midline, left electrodes) repeated-measure ANOVAs were conducted, one for each ERP component—P1, N1, N170, Nc. Greenhouse-Geisser corrections were inspected but did not differ from uncorrected values. Significant effects were followed with Bonferroni tests or paired *t*-tests. Table 2 presents mean peak amplitudes for each component for left, right, and midline electrodes and Figure 2 shows grand-averaged waveforms and scalp topographies for each component.

TABLE 2
Descriptive Statistics for ERPs Following Distracting Emotional Faces

		Emotion				
	Region	*Fearful M (SD)*	*Sad M (SD)*	*Neutral-f M (SD)*	*Neutral-s M (SD)*	*Total M (SD)*
P1	O2	14.68 (4.34)	15.85 (5.42)	15.40 (4.86)	15.85 (5.42)	15.36 (4.33)
	O1	13.92 (5.20)	15.73 (7.96)	15.73 (7.41)	15.73 (7.96)	14.88 (6.37)
	Oz	14.80 (5.32)	15.66 (7.07)	15.54 (6.96)	15.66 (7.07)	15.21 (5.84)
N1	CP4	6.70 (3.04)	7.42 (2.48)	6.91 (1.91)	7.05 (2.93)	7.02 (1.91)
	CP3	7.13 (2.76)	6.77 (3.02)	7.54 (2.38)	6.91 (2.69)	7.09 (1.58)
	CPz	6.97 (2.58)	8.30 (4.19)	8.50 (2.41)	8.08 (4.40)	7.96 (2.40)
N170	PO8	11.24 (4.47)	12.93 (5.03)	11.17 (5.55)	12.06 (7.13)	11.85 (5.00)
	PO7	11.29 (7.25)	11.26 (6.14)	12.10 (6.86)	11.57 (8.82)	11.56 (6.53)
	POz	11.68 (4.69)	10.50 (6.43)	11.35 (5.73)	9.02 (4.74)	10.64 (4.84)
Nc	C4	9.01 (3.07)	8.09 (4.09)	9.70 (3.63)	8.49 (9.18)	8.82 (3.00)
	C3	8.41 (3.33)	7.50 (3.03)	9.18 (3.35)	8.39 (3.21)	8.37 (2.76)
	Cz	9.77 (4.36)	8.24 (4.21)	10.11 (3.72)	9.52 (8.49)	9.41 (3.45)

The main effects of Electrode for N170, $F(2,12) = 6.48$, $p < .05$, partial $\eta^2 = .59$, and Nc, $F(2,12) = 11.93$, $p < .05$, partial $\eta^2 = .68$, confirmed visual inspection of Figure 2 showing that amplitudes were maximal at lateral electrodes for N170 and maximal at electrode Cz for Nc.

There was a significant Emotion × Electrode effect for N1, $F(6,8) = 5.61$, $p < .05$, partial $\eta^2 = .81$. N1 peak amplitudes at right electrode CP4 were greater to sad versus fearful faces, $t(14) = –2.31$, $p < .05$. This finding provided only limited support for the first hypothesis, that N1 amplitudes would be greater to emotional versus neutral faces. Recall that in adults viewing these same facial stimuli, sad faces were rated as more negative than fearful faces.

ERP Latencies Following Distracting Faces

To test the hypothesis that ERP latencies would be shorter to emotional versus neutral faces, four 2 (Gender) × 4 (Emotion: fear, sad, neutral-f, neutral-s) repeated-measure ANOVAs were conducted, one for each ERP component—P1, N1, N170, and Nc. Peak latencies at midline electrodes (except for N170 in which the average of the lateral electrodes was used) were the dependent variables. Greenhouse-Geisser corrections were inspected but did not differ from uncorrected values. Significant effects were followed with paired *t*-tests.

There was a significant Emotion effect for the latency of P1, $F(3,11) = 4.18$, $p < .05$, partial $\eta^2 = .29$: Latencies were faster to fearful versus sad faces (fearful $M = 125.98$, $SE = 7.44$ versus sad $M = 144.46$, $SE = 10.61$; $t(14) = -2.54$, $p < .05$). Contrary to the first hypothesis, latencies for neutral faces (neutral-f $M = 133.04$ and neutral-s $M = 133.66$) did not significantly differ from each other or from sad or fearful faces.

Association Between ERPs and Emotion Regulation

It was predicted that larger amplitude ERPs to emotional distracters would be positively correlated with adaptive emotion regulation (reduced emotional dysregulation and more efficient attention regulation in an emotional context), in particular for ERPs reflecting relatively rapid (P1) and deliberate (Nc) attentional control. Correlations were conducted between P1, N1, N170, and Nc amplitudes to fearful and sad faces at midline electrodes (except for N170 in which the average of the lateral electrodes was used) and emotion regulation—alerting, orienting, and executive attention (conflict interference) scores across all face conditions and maternal report of emotion dysregulation. Because neural responses may change with age (Segalowitz & Davies, 2004), age was entered as a covariate. ERPs were absolute values to aid in interpretation of correlations.

As predicted, as P1 amplitudes to fearful and sad faces increased, maternal report of dysregulation was reduced ($r(15) = –.70$, $p < .01$ and $r(15) = –.68$, $p < .01$, respectively), whereas as Nc amplitudes to fearful faces increased, executive attention improved (that is, conflict was reduced; $r(15) = –.62$, $p < .05$). In addition, P1 and N170 amplitudes were specifically associated with alerting following distracting sad faces: as P1 and N170 amplitudes increased, a child's ability to maintain attentional alertness improved ($r(15) = .64$, $p < .05$ and $r(15) = .63$, $p < .05$, respectively). Correlations between ERPs to neutral faces and emotion regulation did not reach significance.

DISCUSSION

By identifying ERP correlates of child emotion regulation, there is great potential to identify children at risk for problems with dysregulation, including mood problems and disrupted attentional processes. Results of the present study were consistent with the hypothesis that ERP responses to emotional faces may reflect mechanisms in emotion regulation. That is, larger amplitude ERPs to negative emotional faces, particularly those indexing attention selection and cognitive control processes (P1 and Nc), were correlated with more efficient attention performance following emotional distracters and reduced maternal report of emotion dysregulation. Therefore, results suggest that children who devote more resources to emotional distracters may be recruiting attentional control resources in the service of emotion regulation. That is, larger ERPs may reflect greater use of attentional resources to ignore the distracting faces and complete the target task accurately and quickly. However, these results are preliminary and should be interpreted as a first step in pursuit of a larger goal: continued testing, replication, and refinement of a model of ERP markers for affective and attentional control mechanisms in emotion regulation.

This study also added to the growing body of research documenting that preschool-age children show a range of ERP responses evident in the adult literature on emotional face processing: those reflecting selective attention (P1 and N1), those related more specifically to faces and social stimuli (N170), and those linked to relatively deliberate cognitive control processes (Nc). Consistent with previous studies with children, the N170 was not sensitive to facial emotion (Batty & Taylor, 2006). However, the latency of the P1 was faster and the amplitude of the N1 smaller following fearful versus sad faces, suggesting that emotional facial expressions are analyzed at some of the earliest stages of attention processing, even before the structural encoding of the face, as reflected in the N170.

Moreover, these findings are interesting because they document that ERPs are differentially sensitive to two faces of negative valence, not only emotional versus neutral faces. The finding that P1 latencies were faster to fearful faces also adds to the accumulating evidence that the P1 is sensitive to facial emotion, although this finding contrasts with a previous study showing that negative compared to neutral or positive facial emotions elicited later P1 latencies in 4–6-year- old children (Batty & Taylor, 2006). Given that among adults, the fearful faces used in this study were rated as more arousing but less negative than sad faces, it may be that fearful faces were more quickly detected via early attention selection processes that serve to reduce interference (P1), following which attentional engagement was reduced (amplitude of N1). This interesting dissociation may be related to the adaptive function of fear and threat detection—rapid detection followed by attentional avoidance (Compton, 2003; Derryberry & Reed, 2002). Indeed, the finding that N1 amplitudes were reduced to fearful faces is consistent with a previous study with adults (Eimer & Holmes, 2002). N1 amplitudes were not related to subsequent attention performance, however. Clearly, more research is needed on the sensitivity of early attention components to emotional faces and their implications for attention selection processes. Future research should also examine how children process emotional information in more salient or intense emotional contexts and those that systematically increase task demands. Future research should also compare negative emotional face processing to happy face processing in order to strengthen the inference that findings of the present study are specifically related to negative emotional information and not simply attention processing of salient stimuli.

Associations between ERPs and measures of emotion regulation suggested that neural responses to emotional distracters may reflect mechanisms in emotion regulation. Larger Nc amplitudes to fearful faces were associated with better executive attention (reduced conflict interference). In a threat-relevant context, a child's ability to recruit greater attention resources may support the ability to ignore emotional distracters and bolster attention performance. Fearful faces may also prompt greater vigilance and thus "jump-start" attention focus (Koster, Crombez, Verschuere, & De Houwer, 2004; Putman, Hermans, & van Honk, 2006; Schulkin & Rosen, 1999). P1, on the other hand, showed distinct correlations with measures of emotion regulation: larger P1 amplitudes following fearful and sad faces were associated with reduced maternal report of child dysregulation and with greater alerting efficiency (following sad faces only). In addition, N170 following sad faces was associated with better alerting. Thus, although emotional faces themselves had little differential impact on attention performance (examining behavioral measures only), ERPs to these distracting emotional faces were related to the regulation of attention in emotional contexts (fearful or sad faces) and to broader emotion regulation ability as reported by the mother.

The specificity of these ERP-emotion regulation effects raises several intriguing possibilities. As predicted, the Nc, thought to reflect frontally mediated cognitive control, was specifically related to performance on a conflict monitoring task (the flanker task)—but only following fearful faces. As noted earlier, arousing fearful face may have jump-started attentional control mechanisms related to threat (Compton, 2003), thus bolstering the ability to resolve cognitive control dilemmas (i.e., the flanker task). In contrast, the P1 following both negative emotional face types was related to reductions in child dysregulation. This is particularly interesting given that one might expect that the Nc, reflective of more deliberative attentional and cognitive control processes as well as being a neural basis for cognition-emotion integration, would be related to the broader regulatory capacities that mothers report about their children. It was instead the P1 to negative emotional faces that was associated with maternal report of dysregulation. The P1 is related to sensory gain control and selective attention (Hillyard et al., 1998); enhanced P1 amplitudes reflect correctly directed attention whereas reduced P1 amplitudes reflect suppression of unattended stimuli (Luck, 2006), but are linked to face processing in adults and children (Batty & Taylor, 2003, 2006). This finding therefore draws attention to the possibility that relatively automatic attention toward arousing and negative emotional information may be a basic marker for a child's ability to recruit attentional resources that influence later, more controlled cognitive processes that modulate emotional arousal (Bishop et al., 2004; Fox et al., 2002). Indeed, given the relative immaturity of the prefrontal cortex, young children may utilize more posteriorly mediated control processes compared to adults (Casey, Giedd, & Thomas, 2000). Findings are also consistent with previous research documenting that ERP responses in arousing and negative rather than positive or neutral emotional contexts predict social–emotional competencies or difficulties (Lewis et al., 2006b).

Findings of the current study were also notable because ERPs were early-emerging and emotional stimuli were only mildly competitive: faces were extremely brief and presented well before the target task. Future work should systematically vary the duration of faces and other emotional stimuli to tap the affective chronometry of attention processing. Faces of longer duration may strengthen interference effects because they are more salient. On the other hand, attention toward faces of longer duration may have been more easily intentionally shifted away, thus reducing emotional distraction effects. In addition, consideration of later emerging ERPs, such as the late positive potential, may reveal distinct and more deliberative processes related to emotion regulation (Hajcak, Moser, & Simons, 2006).

Findings may have implications for normative and disrupted cognitive processes related to emotional disorders (Compton, 2003; Gray, 2004; Gray & Burgess, 2004) and underscore the need to use measures that capture rapid stages of cognitive processing. In addition, by identifying ERP correlates of emotion regulation, these measures may serve as markers of risk for dysregulated emotion and thus have potentially important implications for early detection and treatment of a range of problems related to emotion regulation. Limitations of the current study include sample size, which prevented examination of individual differences, such as child age and temperament. Results should be interpreted in the context of the experimental design, combining an attention task with irrelevant emotional distracters, although this task has the benefit of eliciting emotional processing as well as attention inhibition of distracters. Future research should use experimental designs in which emotional distracters are more relevant to the target attention task (e.g., are cues). In addition, an observation-based assessment of emotion regulation would have increased the potential clinical relevance of findings and enhanced understanding of the specificity of the links between ERPs and specific aspects of emotion regulation and dysregulation—such as distinct regulatory strategies or mood disturbances. Finally, examining ERPs to other components of the task, such as non-affective cues, flankers, or errors has the potential to reveal other important stages of attention processing and conflict monitoring relevant to individual differences in emotion regulation (Lewis et al., 2006a).

Despite limitations, this study is among the few documenting that distinct neural responses reflecting attention toward and cognitive processing of emotional distracters are differentially correlated with independent measures of emotion regulation in children. Moreover, findings suggest that enhanced neural activation under emotional conditions is related to more adaptive emotion regulation. Integrating both physiological and behavioral measures provides a more complete picture of the role of attentional and cognitive control in child social–emotional development. Future research should continue to use psychophysiological measures of distinct cognitive processes in relation to multiple measures of emotion regulation. Such specificity and integration of observed behavior with physiological measures may lead to new ways for assessing regulatory competence and risk for distinct patterns of emotion dysregulation and mood disturbances.

REFERENCES

Adams, R. B., Jr., & Kleck, R. E. (2005). Effects of direct and averted gaze on the perception of facially communicated emotion. *Emotion, 5*, 3–11.

Batty, M., & Taylor, M. J. (2003). Early processing of the six basic facial emotional expressions. *Cognitive Brain Research, 17*, 613–620.

Batty, M., & Taylor, M. J. (2006). The development of emotional face processing during childhood. *Developmental Science, 9*, 207–220.

Bentin, S., Allison, T., Puce, A., & Perez, E. (1996). Electrophysiological studies of face perception in humans. *Journal of Cognitive Neuroscience, 8*, 551–565.

Bentin, S., & McCarthy, G. (1994). The effects of immediate stimulus repetition on reaction time and event-related potentials in tasks of different complexity. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 20*, 130–149.

Bishop, S., Duncan, J., Brett, M., & Lawrence, A. D. (2004). Prefrontal cortical function and anxiety: Controlling attention to threat-related stimuli. *Nature Neuroscience, 7*, 184–188.

Bush, G., Luu, P., & Posner, M. I. (2000). Cognitive and emotional influences in the anterior cingulate cortex. *Trends in Cognitive Science, 4*, 215–222.

Campanella, S., Gaspard, C., Debatisse, D., Bruyer, R., Crommelinck, M., & Guerit, J. M. (2002). Discrimination of emotional facial expressions in a visual oddball task: An ERP study. *Biological Psychology, 59*, 171–186.

Carver, L. J., Dawson, G., Panagiotides, H., Meltzoff, A. N., McPartland, J., Gray, J., et al. (2003). Age-related differences in neural correlates of face recognition during the toddler and preschool years. *Developmental Psychobiology, 42*, 148–159.

Casey, B. J., Giedd, J. N., & Thomas, K. M. (2000). Structural and functional brain development and its relation to cognitive development. *Biological Psychology, 54*, 241–257.

Cole, P. M. (1986). Children's spontaneous control of facial expression. *Child Development, 57*, 1309–1321.

Cole, P. M., Martin, S. E., & Dennis, T. A. (2004). Emotion regulation as a scientific construct: Methodological challenges and directions for child development research. *Child Development, 75*, 317–333.

Compton, R. J. (2003). The interface between emotion and attention: A review of evidence from psychology and neuroscience. *Behavioral and Cognitive Neuroscience Reviews, 2*, 115–129.

Dawson, G., Carver, L., Meltzoff, A. N., Panagiotides, H., McPartland, J., & Webb, S. J. (2002). Neural correlates of face and object recognition in young children with autism spectrum disorder, developmental delay and typical development. *Child Development, 73*, 700–717.

Dawson, G., Webb, S. J., Carver, L., Panagiotides, H., & McPartland, J. (2004). Young children with autism show atypical brain responses to fearful versus neutral facial expressions of emotion. *Developmental Science, 7*, 340–359.

de Haan, M., & Nelson, C. A. (1997). Recognition of the mother's face by six-month-old infants: A neurobehavioral study. *Child Development, 68*, 187–210.

Dennis, T. A., & Chen, C. (2007a). Emotional face processing and attention performance in three domains: Neurophysiological mechanisms and moderating effects of trait anxiety. *International Journal of Psychophysiology, 65*, 10–19.

Dennis, T. A., & Chen, C. (2007b). Neurophysiological mechanisms in the emotional modulation of attention: The balance between threat sensitivity and attentional control. *Biological Psychology, 76*, 1–10.

Derryberry, D., & Reed, M. A. (2002). Anxiety-related attentional biases and their regulation by attentional control. *Journal of Abnormal Psychology, 111*, 225–236.

Derryberry, D., & Rothbart, M. K. (1997). Reactive and effortful processes in the organization of temperament. *Development & Psychopathology, 9*, 633–652.

Eger, E., Jedynak, A., Iwaki, T., & Skrandies, W. (2003). Rapid extraction of emotional expression: Evidence from evoked potential fields during brief presentation of face stimuli. *Neuropsychologia, 41*, 808–817.

Eimer, M., & Holmes, A. (2002). An ERP study on the time course of emotional face processing. *Neuroreport, 13*, 427–431.

Eimer, M., & Holmes, A. (2007). Event-related brain potential correlates of emotional face processing. *Neuropsychologia, 45*, 15–31.

Eriksen, B. A., & Eriksen, C. W. (1974). Effects of noise letters upon the identification of a target letter in a nonsearch task. *Perception & Psychophysics, 16*, 143–149.

Fan, J., McCandliss, B. D., Sommer, T., Raz, A., & Posner, M. I. (2002). Testing the efficiency and independence of attentional networks. *Journal of Cognitive Neuroscience, 14*, 340–347.

Fossella, J., Sommer, T., Fan, J., Wu, Y., Swanson, J. M., Pfaff, D. W., et al. (2002). Assessing the molecular genetics of attention networks. *BMC Neuroscience, 3*, Electronic version from: http://www.biomedcentral.com/content/pdf/1471-2202-1473-1414.pdf.

Fox, E., Russo, R., & Dutton, K. (2002). Attentional bias for threat: Evidence for delayed disengagement from emotional faces. *Cognition & Emotion, 16*, 355–379.

Garner, M., Mogg, K., & Bradley, B. P. (2006). Orienting and maintenance of gaze to facial expressions in social anxiety. *Journal of Abnormal Psychology, 115*, 760–770.

Gehring, W. J., & Willoughby, A. R. (2002). The medial frontal cortex and the rapid processing of monetary gains and losses. *Science, 295*, 2279–2282.

Gray, J. R. (2004). Integration of emotion and cognitive control. *Current Directions in Psychological Science, 13*, 46–48.

Gray, J. R., & Burgess, G. C. (2004). Personality differences in cognitive control? BAS, processing efficiency, and the prefrontal cortex. *Journal of Research in Personality, 38*, 35–36.

Gray, J. R., Burgess, G. C., Schaefer, A., Yarkoni, T., Larsen, R. J., & Braver, T. S. (2005). Affective personality differences in neural processing efficiency confirmed using fMRI. *Cognitive, Affective & Behavioral Neuroscience, 5*, 182–190.

Hajcak, G., Moser, J. S., & Simons, R. F. (2006). Attending to affect: Appraisal strategies modulate the electrocortical response to arousing pictures. *Emotion, 6*, 517–522.

Haneda, K., Nomura, M., Iidaka, T., & Ohira, H. (2003). Interaction of prime and target in the subliminal affective priming effect. *Perceptual and Motor Skills, 96*, 695–702.

Hare, T. A., Tottenham, N., Davidson, M. C., Glover, G. H., & Casey, B. J. (2005). Contributions of amygdala and striatal activity in emotion regulation. *Biological Psychiatry, 57*, 624–632.

Hare, T. A., Tottenham, N., Galvan, A., Voss, H. U., Glover, G. H., & Casey, B. J. (2008). Biological substrates of emotional reactivity and regulation in adolescence during an emotional go-nogo task. *Biological Psychiatry, 63*, 927–934.

Herrmann, M. J., Aranda, D., Ellgring, H., Mueller, T. J., Strik, W. K., Heidrich, A., et al. (2002). Face-specific event-related potential in humans is independent from facial expression. *International Journal of Psychophysiology, 45*, 241–244.

Hillyard, S. A., Vogel, E. K., Luck, S. J. (1998). Sensory gain control (amplification) as a mechanism of selective attention: Electrophysiological and neuroimaging evidence. Philosophical Transactions of the Royal Society: *Biological Sciences, 393,* 1257–1270.

Itier, R. J., & Taylor, M. J. (2004). Face recognition memory and configural processing: A developmental ERP study using upright, inverted, and contrast-reversed faces. *Journal of Cognitive Neuroscience, 16*, 487–502.

Kieras, D. E., Meyer, D. E., Ballas, J. A., Lauber, E. J., Braver, T. S., Cohen, J. D., et al. (2000). VII: Computational modeling of control. In S. Monsell & J. Driver (Eds.), *Control of cognitive processes: Attention and performance XVIII* (pp. 679–751). Cambridge, MA: The MIT Press.

Kleinhans, N. M., Johnson, L. C., Mahurin, R., Richards, T., Stegbauer, K. C., Greenson, J., et al. (2007). Increased amygdala activation to neutral faces is associated with better face memory performance. *Neuroreport, 18*, 987–991.

Koster, E. H. W., Crombez, G., Verschuere, B., & De Houwer, J. (2004). Selective attention to threat in the dot probe paradigm: Differentiating vigilance and difficulty to disengage. *Behaviour Research and Therapy, 42*, 1183–1192.

Lang, P. J., Bradley, M. M., & Cuthbert, B. N. (1998). *International Affective Picture System (IAPS): Instruction manual and affective ratings*. (Tech. Rep. No. A-4). Gainesville: University of Florida, The Center for Research in Psychophysiology.

Lewis, M. D., Granic, I., & Lamm, C. (2006a). Behavioral differences in aggressive children linked with neural mechanisms of emotion regulation. *Annals of the New York Academy of Sciences, 1094*, 164–177.

Lewis, M. D., Lamm, C., Segalowitz, S. J., Stieben, J., & Zelazo, P. D. (2006b). Neurophysiological correlates of emotion regulation in children and adolescents. *Journal of Cognitive Neuroscience, 18*, 430–443.

Lewis, M. D., Todd, R. M., & Honsberger, M. J. M. (2007). Event-related potential measures of emotion regulation in early childhood. *Neuroreport: For Rapid Communication of Neuroscience Research, 18*, 61–65.

Liddell, B. J., Williams, L. M., Rathjen, J., Shevrin, H., & Gordon, E. (2004). A temporal dissociation of subliminal versus supraliminal fear perception: An event-related potential study. *Journal of Cognitive Neuroscience, 16*, 479–486.

Luck, S. J. (2006). The operation of attention—millisecond by millisecond—over the first half second. In H. Ogmen & B. G. Breitmeyer (Eds.), *The first half second: The microgenesis and temporal dynamics of unconscious and conscious visual processes* (pp. 187–206). Cambridge, MA: MIT Press.

Luck, S. J., & Hillyard, S. A. (1995). The role of attention in feature detection and conjunction discrimination: An electrophysiological analysis. *International Journal of Neuroscience, 80*, 281–297.

Luu, P., Flaisch, T., & Tucker, D. M. (2000). Medial frontal cortex in action monitoring. *Journal of Neuroscience, 20*, 464–469.

Luu, P., & Tucker, D. M. (2004). Self-regulation by the medial frontal cortex: Limbic representation of motive set-points. In M. Beauregard (Ed.), *Consciousness, emotional self-regulation and the brain* (pp. 123–161). Amsterdam, Netherlands: John Benjamins Publishing Company.

Luu, P., Tucker, D. M., & Makeig, S. (2004). Frontal midline theta and the error-related negativity: Neurophysiological mechanisms of action regulation. *Clinical Neurophysiology, 115*, 1821–1835.

Mangun, G. R., & Hillyard, S. A. (1995). Mechanisms and models of selective attention. In M. D. Rugg & M. G. H. Coles (Eds.), *Electrophysiology of mind: Event-related brain potentials and cognition* (pp. 40–85). New York: Oxford University Press.

Näätänen, R., & Picton, T. W. (1987). The N1 wave of the human electric and magnetic response to sound: A review and an analysis of the component structure. *Psychophysiology, 24*, 375–425.

Nelson, C. A., & Nugent, K. M. (1990). Recognition memory and resource allocation as revealed by children's event-related potential responses to happy and angry faces. *Developmental Psychology, 26*, 171–179.

Nieuwenhuis, S., Yeung, N., Van Den Wildenberg, W., & Ridderinkhof, K. R. (2003). Electrophysiological correlates of anterior cingulate function in a go/no-go task: Effects of response conflict and trial type frequency. *Cognitive, Affective & Behavioral Neuroscience, 3*, 17–26.

Palermo, R., & Rhodes, G. (2007). Are you always on my mind? A review of how face perception and attention interact. *Neuropsychologia, 45*, 75–92.

Parasuraman, R. (1998). *The attentive brain*. Cambridge, MA: The MIT Press.

Pizzagalli, D., Regard, M., & Lehmann, D. (1999). Rapid emotional face processing in the human right and left brain hemispheres: An ERP study. *Neuroreport: For Rapid Communication of Neuroscience Research, 10*, 2691–2698.

Pizzagalli, D. A., Lehmann, D., Hendrick, A. M., Regard, M., Pascual-Marqui, R. D., & Davidson, R. J. (2002). Affective judgments of faces modulate early activity (approximately 160 ms) within the fusiform gyri. *Neuroimage, 16*, 663–677.

Posner, M. I., & Rothbart, M. K. (2000). Developing mechanisms of self-regulation. *Development & Psychopathology, 12*, 427–441.

Potts, G. F., Martin, L. E., Burton, P., & Montague, P. R. (2006). When things are better or worse than expected: The medial frontal cortex and the allocation of processing resources. *Journal of Cognitive Neuroscience, 18*, 1112–1119.

Pourtois, G., Grandjean, D., Sander, D., & Vuilleumier, P. (2004). Electrophysiological correlates of rapid spatial orienting towards fearful faces. *Cerebral Cortex, 14*, 619–633.

Putman, P., Hermans, E., & van Honk, J. (2006). Anxiety meets fear in perception of dynamic expressive gaze. *Emotion, 6*, 94–102.

Putnam, S. P., Spritz, B. L., & Stifter, C. A. (2002). Mother-child coregulation during delay of gratification at 30 months. *Infancy, 3*, 209–225.

Righart, R., & de Gelder, B. (2006). Context influences early perceptual analysis of faces—An electrophysiological study. *Cerebral Cortex 16*, 1249–1257.

Rueda, M. R., Fan, J., McCandliss, B. D., Halparin, J. D., Gruber, D. B., Lercari, L. P., et al. (2004). Development of attentional networks in childhood. *Neuropsychologia, 42*, 1029–1040.

Sato, W., Kochiyama, T., Yoshikawa, S., & Matsumura, M. (2001). Emotional expression boosts early visual processing of the face: ERP recording and its decomposition by independent component analysis. *Neuroreport, 12*, 709–714.

Schulkin, J., & Rosen, J. B. (1999). Neuroendocrine regulation of fear and anxiety. In L. A. Schmidt & J. Schulkin (Eds.), *Extreme fear, shyness, and social phobia: Origins, biological mechanisms, and clinical outcomes* (pp. 140–172). New York: Oxford University Press.

Segalowitz, S. J., & Davies, P. L. (2004). Charting the maturation of the frontal lobe: An electrophysiological strategy. *Brain and Cognition, 55*, 116–133.

Shields, A. M., & Cicchetti, D. (1995). *The development of an emotion regulation assessment battery: Reliability and validity among at-risk grade-school children*. Paper presented at the Society for Research in Child Development. Indianapolis, IN.

Shields, A. M., & Cicchetti, D. (1998). Reactive aggression among maltreated children: The contributions of attention and emotion dysregulation. *Journal of Clinical Child Psychology, 27*, 381–395.

Shoda, Y., Mischel, W., & Peake, P. K. (1990). Predicting adolescent cognitive and self-regulatory competencies from preschool delay of gratification: Identifying diagnostic conditions. *Developmental Psychology, 26*, 978–986.

Simpson, J. R., Ongür, D., Akbudak, E., Conturo, T. E., Ollinger, J. M., Snyder, A. Z., et al. (2000). The emotional modulation of cognitive processing: An fMRI study. *Journal of Cognitive Neuroscience, 12*, 157–170.

Taylor, M. J., Batty, M., & Itier, R. J. (2004). The faces of development: A review of early face processing over childhood. *Journal of Cognitive Neuroscience, 16*, 1426–1442.

Taylor, M. J., McCarthy, G., Saliba, E., & Degiovanni, E. (1999). ERP evidence of developmental changes in processing of faces. *Clinical Neurophysiology, 110*, 910–915.

Tendolkar, I., Ruhrmann, S., Brockhaus-Dumke, A., Pauli, M., Mueller, R., Pukrop, R., et al. (2005). Neural correlates of visuo-spatial attention during an antisaccade task in schizophrenia: An ERP study. *The International Journal of Neuroscience, 115*, 681–698.

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

Todd, R. M., Lewis, M. D., Meusel, L.-A., & Zelazo, P. D. (2008). The time course of social-emotional processing in early childhood: ERP responses to facial affect and personal familiarity in a go-nogo task. *Neuropsychologia, 46*, 595–613.

Tottenham, N., Borscheid, A., Ellertsen, K., Marcus, D. J., & Nelson, C. A. (2002, April). *Categorization of facial expressions in children and adults: Establishing a larger stimulous set.* Paper presented at the Cognitive Neuroscience Society, San Francisco.

van Veen, V., & Carter, C. S. (2002). The anterior cingulate as a conflict monitor: fMRI and ERP studies. *Physiology & Behavior, 77*, 477–482.

Vuilleumier, P., & Pourtois, G. (2007). Distributed and interactive brain mechanisms during emotion face perception: Evidence from functional neuroimaging. *Neuropsychologia, 45*, 174–194.

Yeung, N., Holroyd, C. B., & Cohen, J. D. (2005). ERP correlates of feedback and reward processing in the presence and absence of response choice. *Cerebral Cortex, 15*, 535–544.