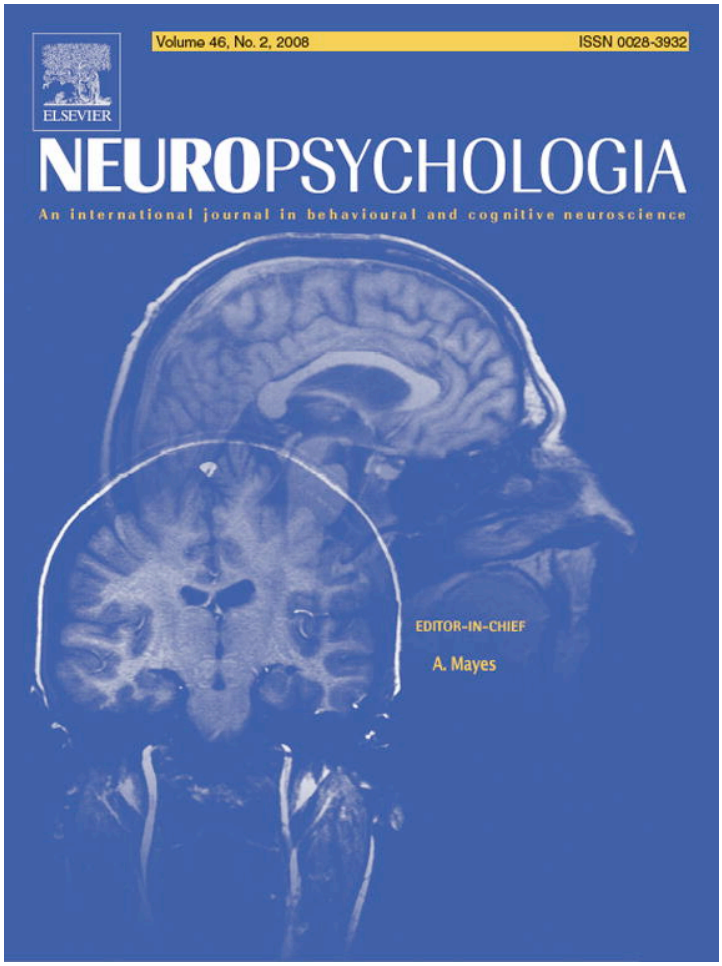

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The time course of social-emotional processing in early childhood: ERP responses to facial affect and personal familiarity in a Go-Nogo task☆

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Abstract

To date, little is known about the neural underpinnings of social-emotional processes in young children. The present study investigated the time course of children's ERP responses to facial expression and personal familiarity, and the effect of these variables on ERP measures of effortful attention in a Go-Nogo task. Dense-array EEG was collected from 48 4–6-year-old children who were presented with pictures of their mothers' and strangers' happy and angry faces. ERPs were scored following face presentation and following a subsequent cue signaling a Go or Nogo response. Responses to face presentation showed early perceptual components that were larger following strangers' faces, suggesting facilitated rapid processing of personally important faces. A mid-latency frontocentral negativity was greatest following angry mothers' faces, indicating increased attentional monitoring and/or recognition memory evoked by an angry parent. Finally a right-lateralized late positive component was largest following angry faces, suggesting extended processing of negatively valenced social stimuli in general. Following the Go-Nogo response cue, a right-lateralized mid-latency negativity thought to measure effortful attention was larger in Nogo than Go trials, and following angry than happy faces, possibly reflecting increased effortful control required in those conditions. The present study suggests that overlapping but differentiated networks for both rapid and elaborative processing of important socio-affective information are established by 4–6 years. Moreover, the extended spatial and temporal distribution of components suggests a pattern of response to social stimuli in which more rapid processes may index personal familiarity, whereas temporally extended processes are sensitive to affective valence on both familiar and unfamiliar faces.

Keywords: ERP; Development; Emotion regulation; Emotion processing; Social cognition; Face processing

1. Introduction

1.1. Overview

Social-emotional information processing, and the regulation of social-emotional responses, are currently of great interest in both developmental psychology and social cognitive neuroscience (Adolphs, 2002; Blair, Morris, Frith, Perret, & Dolan, 1999; Cole, Martin, & Dennis, 2004; Gross, 2002). The emergent field of developmental social cognitive neuroscience draws on behavioral and neuroscientific research to better understand the neural underpinnings of such processes as they emerge in childhood and adolescence. Yet studying the neural correlates of children's social-emotional functioning is fraught with methodological challenges (for review, see Paus, 2005). To overcome these difficulties, the use of simple, salient stimuli and simplified task parameters, as well as non-invasive methods, are required. The present study measured event-related potentials (ERPs), using personally salient emotional stimuli in an attentionally demanding task. In order to capture some of the dynamism and complexity of cognitive processes in children, we took a temporal distributional approach to ERP analysis (as recommended by Picton et al., 2000). Rather than looking at discrete components thought to mark a single perceptual or cognitive process, a temporal distributional approach entails looking at

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a range of ERP components at a number of time-points and scalp locations to investigate patterns of cortical activation over time.

Within the field of social cognitive neuroscience, considerable interest has focused on neural processing of facial expression and identity/familiarity, as both convey important social information. It has been proposed that, in adults, the processing of facial affect and identity is subserved by overlapping (Calder & Young, 2005) and mutually interacting (Vuilleumier & Pourtois, 2007) networks. These networks include posterior perceptual regions that are responsive to emotional expression and/or identity and personal familiarity (Ganel, Valyear, Goshen-Gottstein, & Goodale, 2005; Henson et al., 2003; Winston, Henson, Fine-Goulden, & Dolan, 2004), and frontal regions that mediate processing of socially relevant information (Adolphs, 2002; Gobbini & Haxby, 2007; LaBar, Crupain, Voyvodic, & McCarthy, 2003). Furthermore, a body of evidence suggests that, in adults, frontal responses to facial affect may be lateralized, with greater right-hemisphere responses to stimuli that elicit negative affect (see Davidson, 2004) and/or response tendencies associated with withdrawal or avoidance (Harmon-Jones, 2004). The localization of social-emotional processes may correspond to temporal patterns as well, with posterior regions that mediate stimulus evaluation recruited earliest, and frontal regions implicated in extended processing and control becoming activated somewhat later (Adolphs, 2002). In adults, this real-time sequence of face processing thus appears to span rapid, relatively automatic perceptual responses as well as slower, learned, context-dependent "person knowledge" and explicit monitoring of one's own affective and behavioral responses (e.g. Dolan, 2002; Gobbini & Haxby, 2007; Lewis, 2005). However, the developmental schedule at which such spatiotemporal patterns emerge remains unknown.

Our goal was to measure a spectrum of ERP components, tapping rapid and extended responses to social-emotional stimuli, in early childhood, when social-emotional response repertoires are still developing. In keeping with the Interactive Specialization (IS) model of brain development (e.g. Johnson, 2001; Johnson et al., 2005) we assumed that cognitive functions are emergent processes arising from interactions among brain regions as well as between brain and environment. At different stages of development, social-emotional processing networks may be tuned to different aspects of facial affect and familiarity (e.g. Carver et al., 2003). We were interested in cortical responses to familiar and unfamiliar social stimuli in the kindergarten and early school years, a time when new skills for self-regulation are consolidating and social experience is broadening (Jones, Rothbart, & Posner, 2003; Prencipe & Zelazo, 2005; Zelazo, Müller, Frye, & Marcovitch, 2003). In particular, we were interested in children's differing responses to emotional expression on personally important, "overlearned" faces of mothers compared with emotion on unknown faces. Using a single paradigm, we aimed to address two sets of questions and hypotheses. The first concerned evaluative and regulatory responses to facial expression on mothers' and strangers' faces in 4–6-year-old children. The second concerned the impact of these responses on deliberate attentional processes recruited for achieving a specified goal.

1.1.1. Facial expression and familiarity in development

A substantial body of research suggests that facial expression is central to socialization processes that scaffold children's emotional development (de Haan, Belsky, Reid, Volein, & Johnson, 2004; Malatesta-Magai et al., 1994). In particular, smiling faces signal encouragement and angry faces are thought to signal the need to stop or change a behavior (Blair et al., 1999; Hare, Tottenham, Davidson, Glover, & Casey, 2005). The identity of the expressive face is also important to a child's well-being, as it is caregivers who routinely respond to children's behavior with angry and happy expressions. Thus, emotional expressions on personally important faces may be particularly salient to young children.

1.1.2. Cortical regions mediating social-emotional processing

A number of brain regions, which are linked to the amygdala and associated with social-motivational processing, discriminate personal familiarity and emotional expression in adults. Haxby and colleagues (e.g. Gobbini & Haxby, 2007) have proposed a set of core and extended networks for face processing. Core regions include the fusiform and lingual gyri, which mediate rapid perceptual processing (Ganel et al., 2005; Pessoa, McKenna, Guttierez, & Ungerleider, 2002; Vuilleumier & Pourtois, 2007; Winston et al., 2004), and have been found to be responsive to the salience of facial stimuli (Ganel et al., 2005; Pessoa et al., 2002; Surguladze et al., 2003; Vuilleumier, Richardson, Armony, Driver, & Dolan 2004). Networks for extended social and emotional processing include prefrontal regions, such as anterior cingulate cortex (ACC) and ventral prefrontal cortex (V-PFC). A number of neuroimaging studies have shown regions of V-PFC and ACC to be implicated in emotional feeling, evaluation of social feedback, attachment, empathy, self-regulation, and "person-knowledge" evoked by images of personally important faces (Allman, Hakeem, Erwin, Nimchinsky, & Hof, 2001; Blair et al., 1999; Dolan, 2002; Gobbini & Haxby, 2007; Gobbini, Leibenluft, Santiago, & Haxby, 2004; Leibenluft, Gobbini, Harrison, & Haxby, 2004; Nitschke et al., 2004; Ochsner et al., 2004; Rolls, 2007). Convergent evidence suggests that, although specific perceptual and prefrontal cortical regions may play different roles in social-emotional processing, all of these regions participate in networks that are responsive to the motivational salience — related to emotional expression and/or familiarity — of a face.

Although there is a paucity of neuroimaging (fMRI and PET) studies localizing precise regions responsive to faces in young children, a substantial body of developmental research using event-related potentials (ERPs) has mapped specific ERP components that are responsive to either facial emotion or the personal familiarity of faces. Moreover, in both adults and children ERP studies have enabled development of fine-grained models of the time course of face processing. Below we review the ERP components responsive to facial emotion, facial identity in general, and facial salience/familiarity in particular, as well as social-emotional processes thought to be indexed by such components.

2. Cortical responses to facial expression and familiarity

2.1. Early, mid-latency, and extended ERP components

2.1.1. Early ERP components: The P1

The P1 is an early posterior positive peak, thought to reflect early visual processing of stimuli. Some ERP studies have found the P1 to be preferentially responsive to face stimuli in both adults & children (Batty & Taylor, 2003; Halit, de Haan, & Johnson, 2000; Linkenkaer-Hansen et al., 1998; Taylor, Edmonds, McCarthy, & Allison, 2001). Other studies have found this component to be sensitive to attentional modulation and priming but not to faces per se (e.g. Jemel, George, Olivares, Fiori, & Renault, 1999; Rossion et al., 1999). Studies of children have found that the P1 has a shorter latency in response to faces than objects (Taylor et al., 2001), a result that has been attributed to the salience of faces rather than the face-specificity of this component. It has been suggested that, rather than being face specific, P1 sensitivity to facial manipulations may be a result of top–down attentional influences on early face processing (de Haan, Johnson, & Halit, 2003; Taylor, 2002).

P1 response to facial emotion. There is also conflicting evidence regarding the P1's sensitivity to facial expression. A number of adult studies have reported effects of facial expression on the P1 (Batty & Taylor, 2003; Eger, Jedynak, Iwaki, & Skrandies, 2003; Pourtois, Grandjean, Sander, & Vuilleumier, 2004) and, at equivalent latencies, in the visual cortex (Halgren, Raij, Marinkovic, Jousmäki, & Hari, 2000; Pourtois et al., 2004; Streit et al., 1999). Based on these results, Vuilleumier and Pourtois (2007) have suggested that there is rapid extraction of information related to emotion or salience before more fine-grained perceptual processes are complete. The only study to date that, to our knowledge, reports P1 responses to facial emotion in preschoolers found a pattern of longer latencies following negative emotions than neutral/positive emotions in 4–6-year-olds—an effect that was not found in older children or adults (Batty & Taylor, 2006). The authors propose that this pattern of results reflects age-related differences in face processing, and that younger children rely more on rapid global, and possibly subcortical, processing of facial emotion (Batty & Taylor, 2006). Based on this study, one would predict that 4–6-year-old children would show longer-latency P1s following angry than happy faces.

2.1.2. Early ERP components: The N170

The N170 is an occipitotemporal negative peak that follows the P1 and has been consistently found to be sensitive to faces. In adults it is larger in amplitude and shorter in latency following faces than other types of stimuli (Bentin, Allison, Puce, & Perez, 1996; Carmel & Bentin, 2002; George, Evans, Fiori, & Davidoff, 1996; Rossion et al., 2000; Taylor, McCarthy, Saliba, & Degiovanni, 1999). It is larger and later when faces are inverted, and smaller or absent when nonfaces are inverted (Bentin et al., 1996; Eimer & McCarthy, 1999; Itier, Latinus, & Taylor, 2006; Rossion et al., 1999). Source analyses and implanted electrode studies suggest generators for this component in occipital and temporal cortices, including face-sensitive regions of the fusiform gyrus and superior temporal sulcus (Itier & Taylor, 2004a; Latinus & Taylor, 2006; Pizzagalli et al., 2002; Puce, Allison, & McCarthy, 1999). Thus, the N170 is thought by many (but not all—see Gauthier, Skudlarski, Gore, & Anderson, 2000; Rossion et al., 2000) to index face-specific processing.

N170 in development. Based on developmental data, researchers have suggested that the neural substrates of face processing are more spatially and temporally distributed earlier in development, and become increasingly specialized and focalized over infancy and early childhood (de Haan, Pascalis, & Johnson, 2002; Halit, de Haan, & Johnson, 2003). By 4 years, an N170 with an adult-like morphology has been found to reliably discriminate between faces and objects (Taylor et al., 1999, 2001). Behavioral studies also suggest that by the age of 4 children reliably discriminate upright from inverted faces as adults do (Mondloch, Le Grand, & Maurer, 2002; Pascalis, Demont, de Haan, & Campbell, 2001). Thus, a specialized capacity for face processing, and the basic neural networks subserving it, may be in place by 4 years. Such a capacity continues to be fine-tuned into adulthood, however, as recognition of upright and inverted faces continues to improve beyond 16 years (Itier & Taylor, 2004b; Kolb, Wilson, & Taylor, 1992), and the N170 increases in amplitude and decreases in latency through adolescence (Taylor et al., 2001).

N170 response to facial familiarity. One interpretation of the N170 is that it marks the categorization of the face as a face, prior to matching perceptual input with higher-order representations that discriminate identity (Bentin & Deouell, 2000; Eimer, 2000). In support of this view, a number of studies have found that the N170 does not discriminate between famous faces and unknown faces (Bentin & Deouell, 2000; Eimer, 2000; Puce et al., 1999; Zion-Golumbic & Bentin, 2007, but see Latinus, Bayle, Deltheil, Bohler, & Taylor, under review), and that discrimination of identity occurs at later stages of processing (Bentin & Deouell, 2000; Eimer, 2000; Zion-Golumbic & Bentin, 2007). The N170 *does* discriminate facial familiarity when face recognition is primed, however, and has been found to be smaller in response to familiar than unfamiliar faces (Campanella et al., 2000; Jemel et al., 1999). Moreover, the few studies looking at N170 responses to personally familiar faces suggest that discrimination between personally familiar and unknown faces is occurring by the latency of the N170. In adults, the N170 (or, in MEG studies, the M170) has been found to discriminate personally familiar (e.g. colleagues and acquaintances, Herzmann, Schweinberger, Sommer, & Jentzsch, 2004; Kloth et al., 2006) and personally important (e.g. one's own face or a parent's face, Caharel et al., 2002; Caharel, Courtay, Bernard, Lalonde, & Rebai, 2005) faces from unfamiliar faces. In young children, it has been found to be smaller in response to caregiver's faces than unknown faces (Parker, Nelson, & The Bucharest Early Intervention Project Core Group, 2005).

How might personally important faces elicit differences in cortical activation indexed by the N170? Tong and Nakayama (1999) have proposed a model for "robust representations" of

overlearned faces, which are processed more efficiently than unfamiliar or recently learned faces. These authors presented behavioral evidence that personally important faces were processed more rapidly than recently learned faces in a number of contexts, and suggested that important others' faces may elicit a more efficient visual code for categorizing a face. Such an efficient code should translate into more efficient cortical processing. With famous faces, which are not as "overlearned" as personally important faces, priming may be required to facilitate more efficient categorization, again indexed by smaller N170s. Thus, both ERP evidence of priming and ERP studies designed to tap robust representations of personally important faces — including a rare developmental study measuring N170 responses to personally familiar faces (Parker et al., 2005) — suggest that mothers' faces should elicit smaller N170s in children.

N170 responsiveness to facial expression. There is also conflicting evidence about whether the N170 is responsive to emotional expression. Whereas a number of studies have found that the N170 does not discriminate emotional expression (e.g. Eimer, Holmes, & McGlone, 2003; Herrmann et al., 2002; Münte et al., 1998), others have found that expression modulates N170 amplitude (Batty & Taylor, 2003; Caharel et al., 2005; Eger et al., 2003; Miyoshi, Katayama, & Morotomi, 2004). The only study, to our knowledge, to investigate N170 responses to facial affect in development found larger N170s following negative facial expressions in adolescents over 14 years. The N170 did not discriminate between positive and negative emotions in children under 14, however (Batty & Taylor, 2006). Thus, even if the N170 is sensitive to emotional expression, based on this study we would not expect N170 amplitude to be responsive to affective valence in 4–6-year-olds.

2.1.3. Mid-latency ERPs: The Nc

Nc response to facial familiarity. The Nc is a well-researched frontocentral negative deflection (~225–700 ms) that has been found to discriminate facial familiarity in infants and young children. In adults, an equivalent component may be the N400, a frontal negative deflection (250–500 ms) that has been found to be larger (more negative) following familiar than unfamiliar faces (e.g. Barrett, Rugg, & Perrett, 1988; Bentin & Deouell, 2000; Eimer, 2000). In development, the Nc is responsive to facial familiarity from early infancy. It has been found to discriminate between caregivers' and strangers' faces in infants (Carver et al., 2003; de Haan & Nelson, 1997; Parker et al., 2005) and in normal (but not autistic) preschoolers (Carver et al., 2003; Dawson et al., 2002). In the adult literature it has been proposed that the adult N400 marks processes related to face-specific semantic memory (Eimer, 2000). Similarly, in the developmental literature, it has been proposed that the Nc may index recognition memory (Courchesne, Ganz, & Norcia, 1981; Nelson, 1994). It has also been suggested that larger Ncs may reflect increased attention to salient stimuli (de Haan & Nelson, 1997; Nelson, 1994). Stimulus salience and recognition memory may be tightly coupled, however, as the most familiar face may also be the most salient—at least in some periods of development.

Although the Nc discriminates parent and stranger faces in infancy, the comparative magnitude of responses to specific faces may shift over childhood in conjunction with a changing social environment. Infants have been found to have larger Ncs to mothers' than strangers' neutral faces (Carver et al., 2003; de Haan & Nelson, 1997, but see Parker et al., 2005), but this pattern reverses by the preschool years. A cross-sectional study of three groups of children from 18 to 54 months suggested that, whereas the youngest children showed the typical infant pattern of larger Ncs for mothers' faces, children over the age of 45 months showed stronger responses to strangers' faces (Carver et al., 2003). Other studies have found larger Nc amplitudes in response to strangers' faces in preschoolers as well (Dawson et al., 2002; Parker et al., 2005). This age-related difference in response to familiarity can be interpreted as a systematic developmental trend, which has been attributed to the increased salience of strangers' faces as children enter a wider social world; however, whether the presence of emotional expression is capable of modifying the relative salience of parent versus stranger faces in young children is not yet known. A principal objective of the current research was to investigate this possibility.

Nc responses to facial emotion. ERP studies of children's responses to emotion faces have also demonstrated distinct differences in Nc responses to emotional expression (Lewis, Todd, & Honsberger, 2007; Nelson & Nugent, 1990; Pollak, Klorman, Thatcher, & Cicchetti, 2001). Studies of 4–6-year-old children have found the Nc to be greater in amplitude in response to disgust, fear and sad faces than to happy faces (Batty & Taylor, 2006), and larger and more rapid in response to angry than happy faces (Lewis et al., 2007; Nelson & Nugent, 1990). These results are consistent with adult studies finding frontal negativities, thought to index affective and regulatory processes, that are larger in response to negative stimuli (Luu, Tucker, Derryberry, Reed, & Poulsen, 2003; Tucker et al., 2003). Our own research has found evidence of individual differences in Nc responses as well, revealing that more anxious children have more rapid Ncs (Lewis et al., 2007). It has been proposed that the Nc response to facial emotion reflects increased attention to salient stimuli (de Haan & Nelson, 1997; Nelson, 1994; Nelson & Nugent, 1990), as well as regulation of anxiety elicited by an angry face (Lewis et al., 2007). Based on previous research, we would expect larger Ncs following angry than happy faces. Again, because no one to date has looked at both facial expression and familiarity in children of this age, whether and how response to emotional expression and familiarity may interact is not known.

2.1.4. Extended ERPs: The LPC

LPC response to affect. There is some evidence that longer-latency components may index extended responses to the affective valence of a face. A right-lateralized late positive component (LPC), thought to mark extended processing of salient stimuli, has been shown to be larger following negative than positive stimuli in adults (Cunningham, Espinet, DeYoung, & Zelazo, 2005). Later frontal or central positive peaks, also thought to index allocation of cortical resources for extended processing, have been found to be larger following angry than

happy faces in children (e.g. Lewis et al., 2007; Pollak et al., 2001). Moreover, Lewis, Lamm, Segalowitz, Zelazo, & Stieben (2006) found a late frontal component in 5–16-year olds that was largest following a negative emotion induction. Thus, we would expect larger LPC responses following angry faces in young children.

2.1.5. Progressive pattern of response across the waveform

Few studies have looked beyond specific components at a comprehensive pattern of ERP responses to both affect and identity, as they unfold over time. However, one study looking at a range of components in adults found a pattern in which early ERPs were sensitive to identity, whereas later ERPs were sensitive to emotional valence (Münte et al., 1998). There is also behavioral evidence that facial identity is processed faster than emotional expression (Campbell, Brooks, de Haan, & Roberts, 1996; Strauss & Moscovitch, 1981). It has been suggested that invariant aspects of faces, such as identity or familiarity, need to be identified rapidly but do not need to be tracked continuously. In contrast, facial expression, which is constantly changing, requires extended online monitoring (Calder & Young, 2005). Thus, in addition to our specific questions about individual components, we were interested in whether this type of pattern would be in place in children as young as 4–6 years.

3. ERPs indexing voluntary attentional monitoring and self-regulation

For children, adult displays of facial emotion often signal the need to modulate behavior (e.g. de Haan et al., 2004; Malatesta-Magai et al., 1994). For example an angry face — particularly an angry parent's face — may communicate the need to stop (Blair et al., 1999), or withdraw (Hare et al., 2005). Such behavior regulation becomes effortful and explicit when choice between conflicting responses, rule use, or response inhibition, is required. A wide body of behavioral research tells us that, by age 4 years, children have reached a host of important milestones in effortful self-regulation (Dunn & Hughes, 1998; Jones et al., 2003; Zelazo et al., 2003). In older children and adults, such processes are mediated by brain networks that include OFC and anterior cingulate cortex (ACC) as well as other frontal brain regions (Casey et al., 1997; Hariri, Bookheimer, & Mazziotta, 2000; Ochsner et al., 2004). These anterior networks are often more active when participants are instructed to explicitly minimize an emotional response, or to avoid distraction by an emotional stimulus to perform a cognitive task (e.g. Hariri et al., 2000; Ochsner et al., 2004). To date there has been little research on how networks mediating explicit attentional processes interact with emotional stimuli in young children.

3.1. The N2

One well-researched ERP component associated with effortful emotion regulation is the N2, a negative deflection around 200–400 ms (in adults) after the presentation of a stimulus (e.g. Bokura, Yamaguchi, & Kobayashi, 2001; van Veen & Carter, 2002). In Go/Nogo tasks the N2 is generally larger in Nogo trials that require participants to recruit effortful attention to withhold a response (e.g. Overtoom et al., 1998). Nonetheless, the N2 is thought to tap more than response inhibition (Nieuwenhuis, Yeung, Van den Wildenberg, & Ridderinkhof, 2003; van Veen & Carter, 2002), and is associated with effortful attentional processes that include action monitoring, evaluation of stimulus salience, conflict detection, and marking situations for further monitoring (Nieuwenhuis et al., 2003; Tucker et al., 2003; van Veen & Carter, 2002). In adults, cortical generators of the N2 have been modeled in the dorsal ACC (van Veen & Carter, 2002) and the V-PFC (Bokura et al., 2001; Plizska, Liotti, & Woldorff, 2000), regions associated with self-regulation processes (e.g. Kringelbach & Rolls, 2003; Ochsner et al., 2004; Paus, 2001; Rolls, 2000).

In children, the N2 has also been associated with measures of prefrontally mediated executive function (Lamm, Zelazo, & Lewis, 2006) and emotion regulation (Lewis, Lamm, et al., 2006), as well as behavioral indices of flexible emotion regulation skill (Lewis, Granic, & Lamm, 2006). In 4–6-year-olds, N2 amplitudes have been found to be larger following angry faces, particularly in Go trials, possibly reflecting greater effortful attention required when children must override a prepotent response to stop an action when presented with facial anger (Lewis et al., 2007). Behavioral evidence has shown that newfound abilities for executive function and self-regulation are stabilizing between 4 and 6 years (Jones et al., 2003; Prencipe & Zelazo, 2005; Zelazo et al., 2003). Thus, studying the relative amplitude of the N2 elicited when children must either perform or withhold a behavioral response, in conjunction with images of emotionally expressive faces, may give us insight into the neural correlates of regulatory behavior in this age range. Based on existing data from 4- to 6-year-olds, we would expect the N2 to be larger in Nogo than Go trials and larger following angry than happy faces, particularly in trials where a response is required. Based on fMRI and ERP data in older children and adults, we would also expect to model sources for the N2 in dorsal ACC and OFC/V-PFC regions.

4. Summary

Salient faces invoke a cascade of cortical processes, from early, relatively automatic responses to later processes that are deliberate and effortful. Over hundreds of milliseconds, frontal regions associated with emotion processing and regulation may be increasingly activated. Posterior and frontal cortical processes may be measured by early, mid-latency and late ERPs associated with facial familiarity and/or emotional expression. Previous studies have tended to focus on either earlier or later ERP components. In children, they have generally focused on either affect or personal familiarity alone. Furthermore, little is known about how effortful attention processes may interact with responses to facial emotion in 4–6-year-old children whose self-regulation skills are just coming online. A temporal distributional approach, investigating a range of components at different time-points and scalp locations, may aid in understanding the complexity of rapid and extended social processing in young children.

4.1. The present study

In order to determine the time course of responses to facial emotion and identity, as well as how affective valence modulates processes of effortful self-regulation in young children, we used emotionally expressive faces of children's mothers and strangers as stimuli in a modified Go/Nogo task. This design enabled us to look at both rapid and extended cortical responses to facial familiarity and expression that were independent of the demands of a cognitive task, as well as to examine how facial emotion may modulate the effortful attentional control (as measured by the N2) required to perform the task. We had two sets of hypotheses and conducted separate analyses on data following (1) face stimuli and (2) following subsequent response cues. Thus, a Results and Discussion section are presented separately for these two phases of the study.

4.1.1. Research questions and hypotheses concerning face presentation

(1) We hypothesized that 4–6-year-old children would show longer-latency P1s following angry than happy faces. (2) We expected the N170 to be responsive to facial familiarity but not expression in this age group, and be smaller following personally known faces. (3) We expected that the Nc would show larger amplitudes following angry faces, and that it would also be responsive to facial familiarity. (4) We predicted that a late positive component, possibly right-lateralized, would show larger amplitudes following angry faces.

4.2. Research questions and hypotheses concerning Go/Nogo cue presentation

(1) We predicted that children would show the typical pattern of larger N2s in Nogo than Go trials. (2) We predicted that N2s would be larger following angry than happy faces, and that this difference would be greater in Go than Nogo trials. (3) We expected modeled generators for the N2 in the dorsal cingulate and ventral prefrontal regions to be sensitive to the response demand of the task (Go versus Nogo) and the valence of the stimulus (happy versus angry).

5. Methods

5.1. Participants

Participants were 48 children, ages 4–6.10 years ($M = 5.6$ years), and their mothers. Participants were recruited through flyers, advertisements, and word of mouth, and were from a wide variety of cultural and socioeconomic backgrounds. All children were screened for uncorrected visual impairments and were free of psychiatric disorders or medications. Each family received $40 for their participation, and the children received a toy. Ethics approval of the project was obtained from the University of Toronto.

5.2. Materials and procedure

Mothers' smiling and frowning faces were photographed against a light background controlling for gaze direction (looking straight at the camera) and light conditions. Photographs were rated by 3 adult raters for emotion type and intensity level on a scale of 1–5, and mean ratings for each photo were calculated. For each subject five happy and five angry photographs of his/her mother, as well as five happy and five angry photographs of another mother, were processed to remove information unrelated to the faces. For each participant, all faces were matched for emotional intensity, age, and physical characteristics. Contrast and luminance levels among photographs were also controlled. Photograph size was 1.5 inches × 1.8 inches on screen. Picture size was designed to maintain a foveal angle of 4.3° by 5° at a distance of 57cm in order to prevent eye movement artifacts when the frame appeared around the periphery of the face.

Mothers either initially visited the laboratory alone, in order to be photographed, or emailed digital photos of themselves based on written instructions we sent them. The goal was to obtain faces expressing anger or disapproval that were typical of children's daily experience rather than extreme expressions of anger. Mothers were instructed to make faces that included the face that, "when they see it, the children *know* they're in trouble or had better stop what they are doing." They were instructed to include photos with naturalistic but universally recognizable as angry faces, including knit or frowning eyebrows. Instructions included a request to pose both angry and happy faces with mouth open and mouth closed, to control for confounds between expression and amount of tooth showing. Five photos with mean ratings for most intensely angry or displeased expressions, including photos with mouth open and mouth closed, were chosen first and then happy faces were chosen that matched the angry faces in intensity. Photos that were not identified by all raters as angry/displeased or happy were rejected. Finally, photos of another mother were chosen that were matched for age, appearance, and affective intensity. The same five happy and five angry photos that were used as mother's faces for a given child were used as stranger's faces for another child. Written consent was obtained from parents at the time of photographing or consent forms were emailed to parents and signed copies were obtained at the time of testing.

Parents then brought their children to the University of Toronto for ERP testing. Following a brief introduction, child assent was obtained and the electrode net (EGI 128-channel sensor net) was applied (10–15 min). Children were given instructions on the task, and were allowed to practice until confident. During the testing procedure, one researcher remained in the testing room. In a few cases (4), when the child was anxious, the mother remained in the testing room as well, standing behind the child with a hand on the child's shoulder. During the task, the researcher in the testing room coached the children on maintaining attention and remaining still. A chin rest was used as well to prevent excessive head movement. Children were also videotaped during the task and a researcher in the control room watched the video for signs that children's attention was wandering. If a child's attention wandered, he/she was gently reminded to attend to the task. Total testing time was approximately 15 min.

5.3. Task

Stimuli were presented using E-Prime version 1.1 (Psychological Software Tools, Pittsburgh, PA). Following instruction screens, read aloud by the experimenter, there was a practice block of 18 trials (repeated as necessary). The practice block also served to familiarize children with the stranger's face so that differential responses were not confounded by the perceptual novelty of the stranger face stimuli. In each trial, a 400 ms fixation cross was followed by the appearance of a face (see Fig. 1). Each trial consisted of two stimuli. First, a face appeared and remained onscreen for 1000–1500 ms (randomized duration within this range). Second, at the end of this window, a colored frame appeared around the face. The color of the frame (blue versus purple) cued the child to either press a button or withhold a button press. The color of the frame signaling Go or Nogo was counterbalanced across subjects. In correct Go trials both face and frame disappeared immediately after the button was pressed. In correct Nogo trials, the frame remained around the face for 1500 ms, and then both face and frame disappeared. A red X appeared and remained onscreen for 700 ms if the button was not pressed within 600–1000 ms of frame presentation (Go trials), or if the button was pressed incorrectly during a Nogo trial (Fig. 1).

Overall there were 160 trials, with a 1000 ms inter-trial interval. The task was divided into two blocks with a brief break in between blocks. There were four types of face stimulus: Mother Happy, Mother Angry, Stranger Happy, and Stranger Angry, with 40 trials of each type (Fig. 1). Face presentation was pseudorandom: equal numbers of each face type appeared over the course of the task but the order of presentation was unpredictable. The modification of the

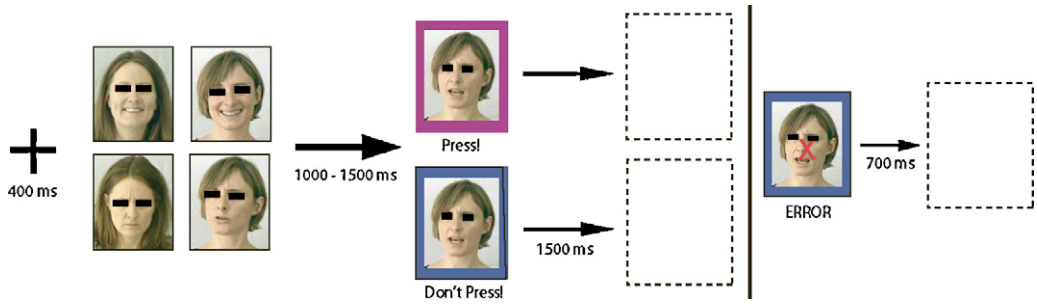

Fig. 1. Task design: The color of the frame cued the child to either press a button, or withhold a press. Four categories of face stimulus were used: Mother Happy, Mother Angry, Stranger Happy, and Stranger Angry. Correctly pressing the button caused both face and frame to immediately disappear from the screen. A red X appeared over the face on incorrect trials (incorrectly pressing, not pressing fast enough, or incorrectly withholding a press).

Go/Nogo task to have equal numbers of Go and Nogo trials was implemented so that the task would be easy enough for 4-year-olds to perform, and to maximize the number of correct Nogo trials for analysis. Because young children have trouble sitting still and maintaining attention to the task for extended periods of time, it was also necessary to limit the task duration to 15 min. Altogether there were 80 Go and 80 Nogo trials, and both Go and Nogo cues could follow any of the four types of face.

5.4. EEG data collection and analysis

EEG was recorded from scalp electrodes using the 128-channel Geodesic Sensor Net (Tucker, 1993) and EGI software (EGI, Eugene, OR). Electrode impedances were kept below 50 KΩ prior to recording. All recordings were referenced to Cz (channel 129), and an averaged reference was calculated offline (Bertrand, Perrin, & Pernier, 1985; Tucker, Liotti, Potts, Russell, & Posner, 1993). Signals were sampled at 250 Hz. EEG data were filtered using a 1–30 Hz bandpass and segmented into epochs from 200 ms before to 1000 ms after face stimuli and 800 ms after frame stimuli. We excluded trials with blink and eye movement artifacts and trials on which 20 or more channels exceeded a voltage threshold of 100 μV (absolute) or a transition threshold of 100 μV (sample to sample). Correct, artifact-free trials were averaged for each subject in each condition, and the data were baseline-corrected to 50 ms before face onset and 100 ms before frame onset.

Because we were interested both in (1) mapping children's undiluted responses to the different face types, and (2) mapping the effect of facial emotion on the Go/Nogo response, we analyzed data time-locked to two categories of stimuli (1) face stimuli, referred to henceforth as *Face*, and (2) frame stimuli cueing the response, referred to henceforth as *Frame*.

5.4.1. Analysis of face data

In order to measure the response to faces, prior to the appearance of the Frame, we analyzed the data for the 1000 ms following *Face* onset. In this analysis data was segmented into four conditions: Happy Mother, Happy Stranger, Angry Mother and Angry Stranger.

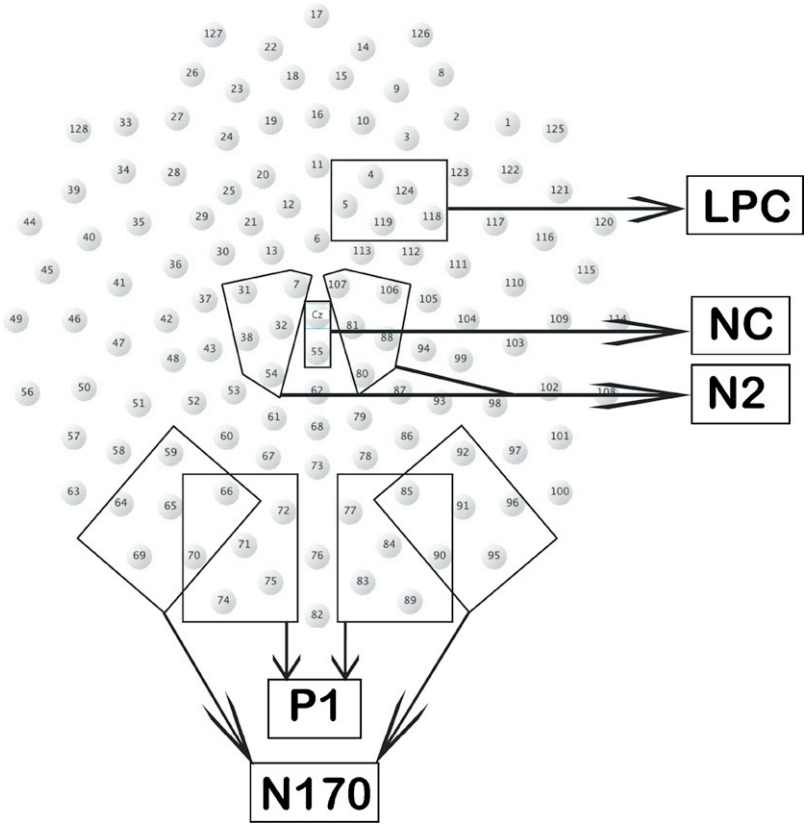

Fig. 2. Electrode sites used in scoring the P1, N170, Nc, LPC, and N2.

5.4.2. Analysis of frame data

In order to examine the effect of affective valence and familiarity on the amount of effortful attention required to make or withhold a response, the data from correct trials for the 800 ms following *Frame* onset were also analyzed. Waveforms time locked to the Frame stimuli were segmented into eight conditions: Happy Parent Go, Happy Stranger Go, Angry Parent Go, Angry Stranger Go, Happy Parent Nogo, Happy Stranger Nogo, Angry Parent Nogo, and Angry Stranger Nogo.

Trial count means were calculated for each condition for segments following both Face and Frame onset. After eliminating participants who did not complete the procedure (2) and those with excessive movement artifacts, data from 38 children following Face presentation were retained for analysis. For the Face data, mean trial count was 21.4 trials across all conditions. Because there were eight conditions following Frame onset, there was a reduced average of 13.7 trials for the N2 component following Frame onset. After we eliminated all participants with a trial count of less then 10 correct, artifact-free trials in any condition, data from 20 children were retained for the Frame (N2) analysis.

5.5. ERP component scoring

Montages of electrode sites for scoring each component were selected where activation was maximal in the grand-averaged data (Fig. 2) and informed by previous research (e.g. Carver et al., 2003; Nelson & Nugent, 1990; Taylor, Batty, & Itier, 2004). For all components except the LPC, peak amplitudes were measured at the latency of the largest peak for each child in each condition, and were measured separately for each hemisphere (Picton et al., 2000).

5.5.1. Face stimuli

P1 and N170. The P1 and N170 were scored at six right and six left posterior electrode sites (see Taylor et al., 2004). The P1 and N170 were scored separately on both the right and left, and laterality was included as a factor in the ANOVAs as previous studies have shown a right-lateralized pattern of activation in adults but not children (Taylor et al., 2001, 2004). The P1 was scored as the largest positive deflection following stimulus onset at posterior sites (mean latency 164 ms) and the N170 as the largest negative deflection at posterior sites following the P1 (mean latency 266 ms).

Nc. The Nc was scored as the first negative peak following the frontal P2, between 250 and 500 ms (mean latency 398 ms) at the two central midline sites where this very focal component was maximal (see Carver et al., 2003; Lewis et al., 2007; Nelson & Nugent, 1990).

LPC. In the grand averaged data the LPC appeared as a right-lateralized positivity and was measured only at a cluster of electrodes on the right. For the LPC, mean amplitudes were measured in eight 50-ms time windows between 600 and 1000 ms post-stimulis. Fig. 3 shows the topographical maps for each compo-

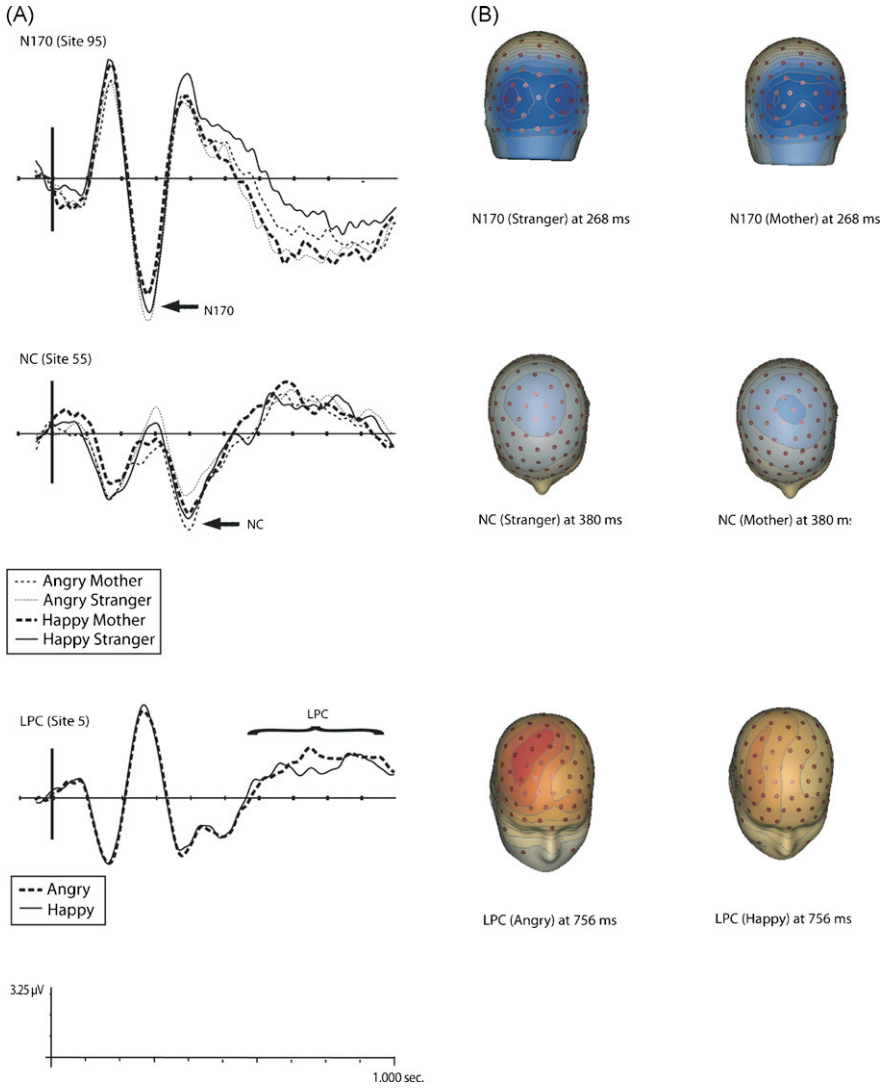

Fig. 3. (A) Stimulus-locked, grand-averaged waveforms (−50–1000 ms following Face presentation) for all four experimental conditions, at electrode sites that represent each component analyzed for the N170, Nc and LPC. (B) Topographical maps for the N170 and Nc are shown following parent and stranger faces and topographical maps for the LPC are shown following happy and angry faces to illustrate main effects found at these components.

nent and the grand-averaged waveforms for the N170, Nc, and LPC measured following face presentation.

5.5.2. Frame stimuli

N2. Following Frame presentation, the N2 was scored as the greatest negativity following the frontal P2 at central sites between 250 and 500 ms (mean latency 389 ms). Because grand averaged data suggested that there was a slightly right-lateralized pattern of activation in some conditions, data were analyzed at two clusters of five electrode sites to the right and the left of Cz, based on the pattern of activation revealed by grand averaged topographic plots. Laterality could then be included as a factor in the analyses. The N2 was scored within 250–500 ms following frame onset. Fig. 5 shows the grand-averaged waveform for the N2 following frame presentation.

5.6. Source analysis

In order to model neural generators underlying children's N2s, temporal-spatial source modeling was performed on grand-averaged data using Brain Electrical Source Analysis (BESA; Berg & Scherg, 1994). Regional source models were derived following Frame onset using a spherical head model with an isotropic realistic head approximation factor of 20. A master source model was created on data averaged over all conditions. Because the children were so young, and the paradigm novel, we used BESA's source analysis program to fit sources for each component in the regions that best accounted for the scalp variance, rather than seeding hypothesized sources. Regional sources were fitted component by component, starting with the largest component, and subsequent sources were fitted to account for remaining variance. A final solution was considered adequate if the residual variance was less than 5% in each condition (Berg & Scherg, 1994). The source model was then applied to the data of individual children in each condition, and source amplitudes were extracted (in nanoamps) from sources of interest for statistical comparison.

6. Results I: Face presentation

6.1. ERP results

To examine the response of early ERP components to facial affect and personal familiarity, as well as whether these components showed an effect of right lateralization found in adults, repeated-measures ANOVAs were performed on the amplitude and latency of the P1 and N170 using personal familiarity (2), affect (2), laterality (2), and site (6) as within-subject factors. All contrasts were Bonferroni corrected. There were no significant amplitude or latency effects for the P1. Analysis of N170 amplitude showed a main effect of personal familiarity, F (1, 37) = 14.06, p = .001, partial η^2 = .27, with larger amplitudes to strangers' faces than mothers' faces (−11.48 [mean] ± .79 μV [standard error] and −10.01 ± .92 μV, respectively). There was no effect of affect, F (1, 37) = .26, *ns*, nor of laterality, F (1, 37) = .30, *ns*. There were no latency effects for the N170.

To determine the responsiveness of the Nc to facial affect and personal familiarity, repeated-measures ANOVAs were also performed on Nc amplitude and latency at the two central midline sites where the effect was maximal, with factors of personal familiarity (2), affect (2), and site (2). For Nc amplitude there was a main effect of personal familiarity, with larger Ncs following mothers' faces than following strangers' faces, F (1, 37) = 4.87, p = .03, partial η^2 = .12 (−6.71 ± .66 and −5.53 ± .69 μV, respectively). This effect was qualified by an affect by personal familiarity interaction, F (1, 37) = 5.28, p = .03, partial η^2 = .12, that revealed largest amplitudes following angry mothers' faces (−6.93 ± .66 μV). The next largest amplitudes were found following happy mothers' (−6.48 ± .81 μV), then happy strangers' (−6.10 ± .84 μV), and finally angry strangers' faces (−4.96 ± .66 μV), respectively. There was no effect of affect for Nc amplitude, F (1, 37) = .42, *ns*. Analysis of Nc latency revealed no effect of affect, F (1, 37) = .06, *ns*, or personal familiarity, F (1, 37) = .01, *ns*, although there was an interaction between them, F (1, 37) = 6.54, p = .01, partial η^2 = .15 (Fig. 4). For mothers' faces, latencies were shorter following angry (392.89 ± 5.05 ms) than happy faces (402.68 ± 6.48 ms), whereas for strangers' faces latencies were shorter following happy faces (393.84 ± 5.42 ms) than angry faces (401.00 ± 5.62 ms). Thus, for the Nc, amplitudes were largest, and latencies shortest, following angry mothers' faces.

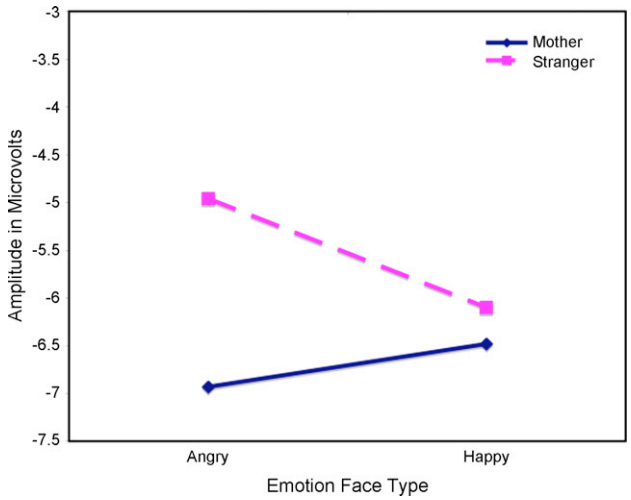

Fig. 4. Mean Nc amplitudes (μV) showing interaction between emotion type (angry vs. happy) and identity (mother vs. stranger). Amplitudes are overall larger following mothers' vs. strangers' faces, with largest amplitudes following angry mothers' faces and smallest amplitudes following angry strangers' faces.

Because the LPC was an extended positive deflection without a distinct peak, mean amplitude values were measured over eight 50-ms time windows from 600 to 1000 ms. Separate repeated-measures ANOVAs were performed for each time window using personal familiarity (2), affect (2), and site (5) as within-subject factors. In all time windows mean amplitudes were largest following angry faces (Table 1). They were significantly larger following angry than happy faces in two successive time windows, from 750–800 ms F (1, 37) = 10.82, p = .002, partial η^2 = .23, and from 800–850 ms, F (1, 37) = 6.25, p = .02, partial η^2 = .14. There were no effects of personal familiarity, nor any interactions between personal familiarity and affect, for any of the time windows.

7. Discussion 1: Face presentation

7.1. Early, mid-latency and Late ERP components

In order to examine children's early, mid-latency, and extended ERP responses to personal familiarity and emotional

Table 1
Mean amplitudes and standard errors for happy and angry faces from 600 to 1000 ms following face presentation

	600–650 *ms*		650–700 *ms*		700–750 *ms*		**750–800 ms**		**800–850 ms**		850–900 *ms*		900–950 *ms*		950–1000 *ms*	
	M	S.E.M.	*M*	S.E.M.	*M*	S.E.M.	***M***	**S.E.M.**	***M***	**S.E.M.**	*M*	S.E.M.	*M*	S.E.M.	*M*	S.E.M.
Happy	1.75	.35	2.44	.34	2.35	.40	**2.26**	**.40**	**2.48**	**.38**	2.68	.40	2.44	.35	2.01	.36
Angry	2.02	.44	2.61	.44	3.03	.40	**3.52**	**.42**	**3.43**	**.43**	3.31	.41	3.06	.45	2.80	.45

$p < .05$.

expression, we measured P1, N170, Nc and LPC components following Face presentation. Results revealed a main effect of personal familiarity for the N170, which was larger following strangers' faces than mothers' faces, an interaction between personal familiarity and affect for the Nc, which showed largest amplitudes and shortest latencies for angry mothers' faces, and a main effect of affect for the LPC, which revealed largest amplitudes in response to angry faces. The overall pattern of results showed that early ERP components were sensitive to familiarity, mid-latency components discriminated between emotional expressions on personally important faces, and extended components discriminated between negative and positive emotion.

7.2. N170

7.2.1. N170 response to personal familiarity

Consistent with our hypothesis, the N170 was responsive to personal familiarity but showed no main effect of affect, with larger amplitudes following strangers' than mothers' faces. Although a number of studies have found that, in adults, the N170 does not discriminate between famous and unknown faces (Bentin & Deouell, 2000; Eimer, 2000; Puce et al., 1999; Zion-Golumbic & Bentin, 2007, but see Latinus et al., under review), our results are consistent with studies suggesting that the N170 discriminates between personally familiar and unfamiliar faces (Caharel et al., 2002, 2005; Herzmann et al., 2004). To our knowledge, only one other developmental study has looked at effects of facial familiarity on this component in young children, and this study also found the N170 to be smaller in response to caregiver than stranger faces (Parker et al., 2005). Our results are also convergent with behavioral studies finding that adults show consistently faster and view-independent processing of highly familiar, or "overlearned" faces (Tong & Nakayama, 1999), faster processing of familiar faces wearing emotional expressions (Campbell et al., 1996), and with studies finding that familiar emotional expressions facilitate processing of familiar faces (Gallegos & Tranel, 2005; Kaufmann & Schweinberger, 2004). More generally, our findings are consistent with studies finding that adults show smaller N170s in response to famous faces than unfamiliar faces when identity is primed (Jemel et al., 1999). Thus, smaller amplitudes following mothers' faces

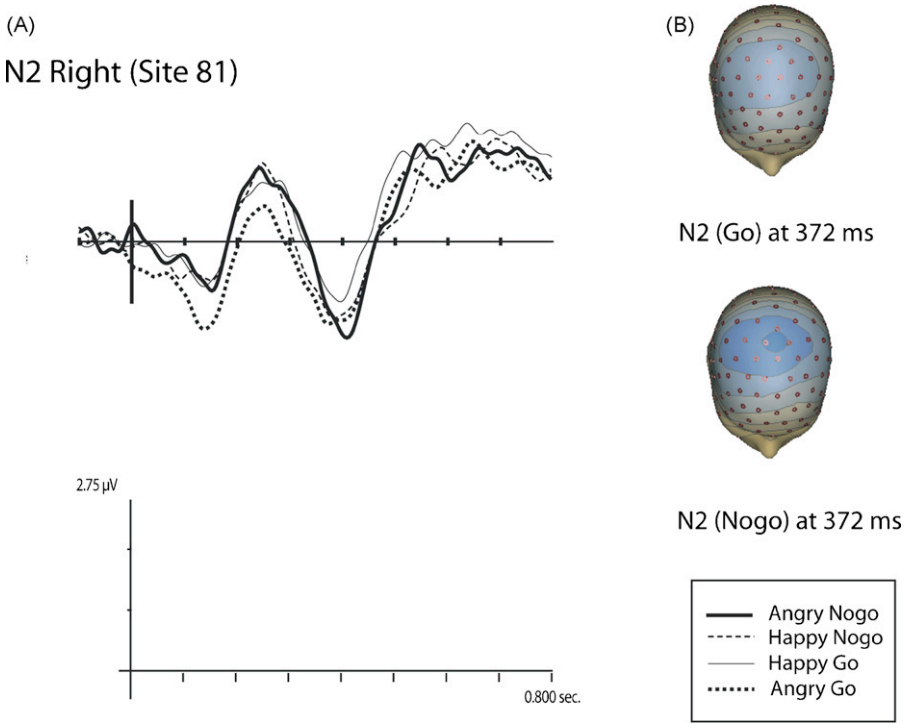

Fig. 5. (A) Stimulus-locked, grand-averaged waveforms at site 81 (to the right of Cz), collapsing across parent and stranger faces, for Angry Nogo, Angry Go, Happy Nogo, and Happy Go conditions (−100–800 ms following Frame presentation). (B) Topographical maps showing scalp activation following Go and Nogo trials.

may reflect facilitated processsing of personally important faces. Although face-processing in 4–6-year old children is still developing (e.g. Kolb et al., 1992; Mondloch et al., 2002; Mondloch, Dobson, Parsons, & Maurer, 2004), by this age range mothers' faces are highly overlearned. As a child's well-being still hinges on a parent's positive or negative expression, they are also highly salient.

These results support the notion that N170 amplitudes discriminate between faces that are unfamiliar and faces that are highly salient and overlearned – at least in young children. Thus, they support the view that categorization processes tapped by the N170 are not insulated from effects of salience or personal familiarity. There are several possible explanations for this effect: (1) Top–down, (2) bottom–up, and (3) developmental.

(1) Jemel et al. (1999) propose that processing indexed by the N170 is penetrable to top–down attentional influences, and Bentin and Golland (2002, p. B12) suggest that early visual categorization of a face may be "consistent with conceptual knowledge and perhaps affected by it." In our paradigm, where children knew from the start they would be seeing their mothers' faces, the smaller N170s in response to mothers' faces may reflect a general priming effect that faciliates the categorization of a face as such.
(2) Some researchers have suggested a "bottom–up" explanation of early perceptual responses to emotionally salient faces (Adolphs, 2002; Pizzagalli et al., 2002). These authors propose that rapidly activated basal forebrain regions modulate feedforward occipital and temporal processing. For example, occipital and temporal visual cortex regions receive numerous afferent projections from the amygdala (Amaral & Price, 1984), and may receive information from amygdala cells that respond to facial familiarity between 100 and 200 ms (Liu, Ioannides, & Streit, 1999; Nakamura, Mikami, & Kubota, 1992). Primary visual cortex activation is also rapidly tuned by early feedback from downstream regions of visual cortex that mediate global processing (Bullier, 2001), which suggests that coarse global processing of faces can occur at very early latencies (Taylor, 2002). Thus, rapid input from subcortical regions and other areas of visual cortex may allow for coarse categorization of faces as personally important before more detailed structural encoding is complete.
(3) Finally, developmental evidence indicates that young children may process facial information somewhat differently from adults. For example, Taylor et al. (2004) suggest that young children's N170s may reflect a greater reliance on coarse global processing than on fine-grained processing of facial information—an interpretation consistent with the bottom–up model. They also propose that in 4–6-year-old children the N170 may be generated by more distributed sources across occipital and temporal cortices than in adults. Thus, it is possible that a greater reliance on global processing — which may be characteristic of young children *and* may facilitate processing of personally important faces —contributed to the N170 effect we found.

7.2.2. *N170 response to affect*

The finding that there was no N170 response to affect is consistent with previous findings that the N170 does not discriminate facial emotion in 4–6-year-olds (Batty & Taylor, 2006), despite evidence from a number of studies suggesting it discriminates facial expression in adults (Batty & Taylor, 2003; Caharel et al., 2005; Eger et al., 2003; Miyoshi et al., 2004, but see Eimer and Holmes, 2002; Herrmann et al., 2002; Münte et al., 1998). Indeed, there is evidence that the N170 does not show a mature pattern of response to facial emotion until 14–15 years (Batty & Taylor, 2006). Overall, looking at the pattern of N170 responses to both facial emotion and personal familiarity, our results suggest that in children of this age the N170 shows an adult-like sensitivity to personally important faces in contrast to unfamiliar faces — at least when the personally important faces are of childrens' mothers — but may not show a mature pattern of response to facial emotion.

7.3. *Nc*

7.3.1. *Nc response to personal familiarity*

Analysis of Nc amplitude showed a main effect of personal familiarity, with larger Ncs following mothers' faces than strangers' faces. This is consistent with previous findings that the N400, a mid-latency frontal negativity measured in adults, is responsive to facial familiarity (Bentin & Deouell, 2000; Eimer, 2000), and that the Nc is responsive to facial familiarity in children (Carver et al., 2003; de Haan & Nelson, 1997). However, our results show an additional interaction between personal familiarity and affect for both Nc amplitude and latency. Thus, although responses were largest to mothers' faces overall, the Nc response to the valence of the expression depended on the familiarity of the face. Notably, amplitudes were largest and latencies shortest following angry mothers' faces. It has been suggested that the Nc reflects recognition memory and/or the tagging of emotionally salient stimuli for further processing (de Haan & Nelson, 1997; Nelson, 1994). In fact, recognition memory and stimulus appraisal may both be entrained in evaluation of reward and punishment based on past experience. Over the course of socialization, children repeatedly encounter both happy and angry/displeased expressions on their mothers' faces, and we specifically instructed mothers to pose faces that would be familiar to their children. Evaluation of the reward or punishment value of a face is linked to one's experience with it (Adolphs, 2002). Thus, either happy or angry expressions on mothers' faces would elicit more recognition memory than on a stranger's face. But familiar angry faces may be associated with negative consequences, and thus mothers' angry faces may tend to be more salient than happy faces. The high salience of emotion on mothers' faces may also account for the fact that we found the opposite pattern of response to studies finding larger Nc responses in 4-year-olds to neutral stranger faces than neutral parent faces (Carver et al., 2003; Dawson et al., 2002). Although mothers' faces may be less salient to children of this age than strangers' faces when emotion is not present, a familiar angry expression may render the mothers' faces relatively *more* salient. Thus, our results suggest that, to 4–6-year-olds, mothers' emo-

tional expressions are more salient than strangers' expressions, and may elicit higher levels of attention and recognition memory.

The finding that angry stranger faces elicited the smallest amplitudes and longest latencies, and that happy faces elicited greater and faster activation than angry faces in response to strangers, is harder to explain. Angry expressions on stranger faces may have been less salient to children because they were harder to interpret than smiling faces. In this paradigm, for the sake of ecological validity, we asked the mothers to pose typical reprimanding faces that were less intensely angry than faces standard emotion face sets. For this reason, the angry faces may have been more ambiguous to children who were not their own. This result may also reflect inexperience with angry strangers in children of this age. Indeed our interpretation of all of our Nc results should be qualified by the small effect sizes for the Nc, which may be driven by high levels of individual variability. Such individual differences in Nc response patterns may be the subject of future research.

7.4. LPC

7.4.1. LPC response to affect

As predicted, the LPC was sensitive to affective valence. A larger response to angry faces was observed in a right-lateralized late positive deflection over right prefrontal cortex between 750 and 850 ms. This result is consistent with findings of larger-amplitude late positive ERPs in response to negative emotional expression in children (Lewis et al., 2007; Pollak et al., 2001), and following an emotion induction in 5–16-year-olds (Lewis, Lamm, et al., 2006). It is also consistent with findings that late right-lateralized frontal positive deflections are responsive to negatively valenced stimuli in general (e.g. Cunningham et al., 2005). Finally, our findings are consistent with neuroimaging studies in adults finding right prefrontal activation in response to angry faces (e.g. Blair et al., 1999), and in tasks requiring extended emotional processing (e.g. Nakamura et al., 1999). Thus, the LPC may be tapping sustained responses of wider networks to negative facial affect. Our findings offer evidence that such an extended frontal response to affective valence can be observed in 4–6-year-old children. Moreover, such a response appears to be unaffected by the familiarity of the face.

7.5. P1

7.5.1. P1 response to affect

Finally, we failed to find significantly longer P1 latencies following negative facial expressions for the P1, as found by Batty and Taylor (2006). This may be because we were using moderately angry or reprimanding faces, rather than intensely angry or fearful faces, and our faces were not sufficiently disturbing to elicit an effect of valence for this component. Future studies using more intense emotional expressions may elucidate these effects.

7.6. Distributed pattern of response to face stimuli

Taken together, results for Face stimuli suggest that the N170 responses primarily reflect personal familiarity, including facilitated processing of a salient and "overlearned" face. In contrast, the mid-latency Nc was more sensitive to the familiar and upsetting image of an angry mother. Thus, one can speculate that the Nc may have tapped implicit emotional memories, or "person knowledge" (Gobbini & Haxby, 2007), as well as greater attention to faces that are both salient and familiar. At longer latencies, the right-lateralized LPC showed a reliable response to emotional valence, and was largest following angry faces.

The pattern of results suggests a time course for the processing of complex social-emotional information in young children, in which early ERPs are most responsive to the personal familiarity of emotional faces, mid-latency ERPs are sensitive to the interaction of affect and familiarity — to particular expressions on particular faces — and later, right-lateralized frontal ERPs suggest greater extended processing of affective valence. Thus, the temporal pattern of response moves from early tagging of personally important identity, to mid-latency responses that invoke the salience and autobiographical meaning of a familiar expression on a particular face, to more extended emotional processing of what the expression on the face means to his/her well-being. This pattern is consistent with data suggesting that adults show earlier ERP and behavioral responses to facial identity and later responses to facial affect (Münte et al., 1998; Strauss & Moscovitch, 1981). It is also convergent with implanted electrode studies in monkeys showing an early and transient response in face-sensitive neurons to facial familiarity, and a more sustained response to facial expression (Sugase, Yamane, Ueno, & Kawano, 1999). One intepretation of this pattern is that, once one has registered an invariant cue such identity or familiarity, there is no need for further processing. In contrast, such changeable cues as emotional expression require ongoing attentional monitoring (Calder & Young, 2005). Although it is possible that our paradigm failed to capture early cortical response to affect suggested by a number of studies (Batty & Taylor, 2006; Halgren et al., 2000; Pizzagalli et al., 2002; Pourtois et al., 2004), our data suggest that a differentiated temporal pattern for processing facial familiarity and expression is in place by 4–6 years. Many aspects of face processing continue to be refined into adolescence; however, such a basic motivational pattern of response to specific aspects of the social environment, appears to be in place by the preschool years.

8. Results II: Frame presentation

8.1. Behavioral data

Response times were collected from correct Go trials. Repeated-measures ANOVAs using affect (2) and personal familiarity (2) as within-subject measures failed to reveal any significant differences, presumably due to the degree of variability in young children's reaction times [579.49 (mean) ± 18.39 (standard error) ms following happy faces versus 588.77 ± 20.54 ms following angry faces, and 574.76 ± 16.81 following mothers' faces versus 592.89 ± 22.90 ms following strangers' faces]. Accuracy rates

were high, as the task was quite easy, and the average number of incorrect Nogo trials was low (3.38 ± .76).

8.2. ERP results

The Nogo N2 in response to frame onset was analyzed to look at the effect of emotional valence, personal familiarity and response type on N2 amplitudes. A repeated-measures ANOVA was performed using response (2), affect (2), identity (2) laterality (2), and site (5) as within-subject factors. There was a main effect of response, $F(1, 19) = 4.29$, $p = .05$, partial $\eta^2 = .18$, revealing greater N2 amplitudes for Nogo than for Go trials [−5.02 (mean) ± .53 (standard error) μV, and −3.97 ± .68 μV, respectively], and of affect, F (1, 19) = 14.44, $p = .001$, partial $\eta^2 = .43$, due to larger N2 amplitudes for Angry than for Happy trials (−5.07 ± .61 μV, and −3.92 ± .54 μV, respectively). There was also a main effect of laterality, $F(1, 19) = 4.62$, $p = .04$, partial $\eta^2 = .20$ with larger amplitudes on the right than on the left side (−4.80 ± .59 μV, and −4.19 ± .56 μV, respectively). There was no interaction between affect and response, $F = 1.97$, ns; however, planned comparisons revealed amplitudes to be significantly larger following angry than following happy faces in Go trials, t (1, 19) = 4.14, $p = .001$, but not in Nogo trials, t (1, 19) = .67, ns. There was no main effect of personal familiarity, F (1, 19) = .05, ns, nor were there any significant interactions between personal familiarity and any other factors (Fig. 6).

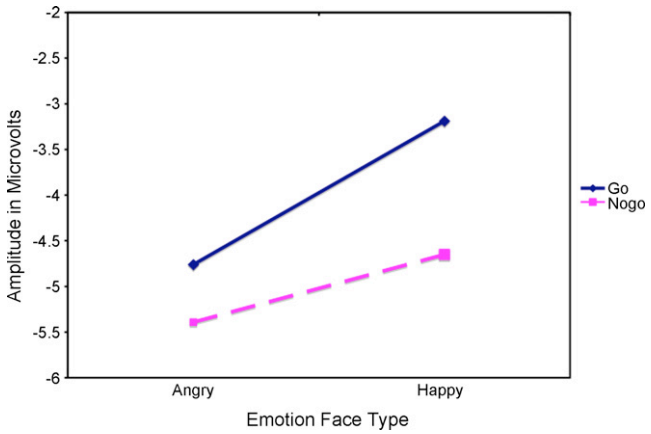

Fig. 6. Mean N2 amplitudes (μV) showing interaction between emotion type (angry vs. happy) and response type (Go vs. Nogo). In the Go condition, amplitudes are significantly greater following angry than happy faces.

8.3. Source analysis

Following frame onset, at the latency of the N2 (250–500 ms), BESA analysis of the wave form modeled two symmetric gener-

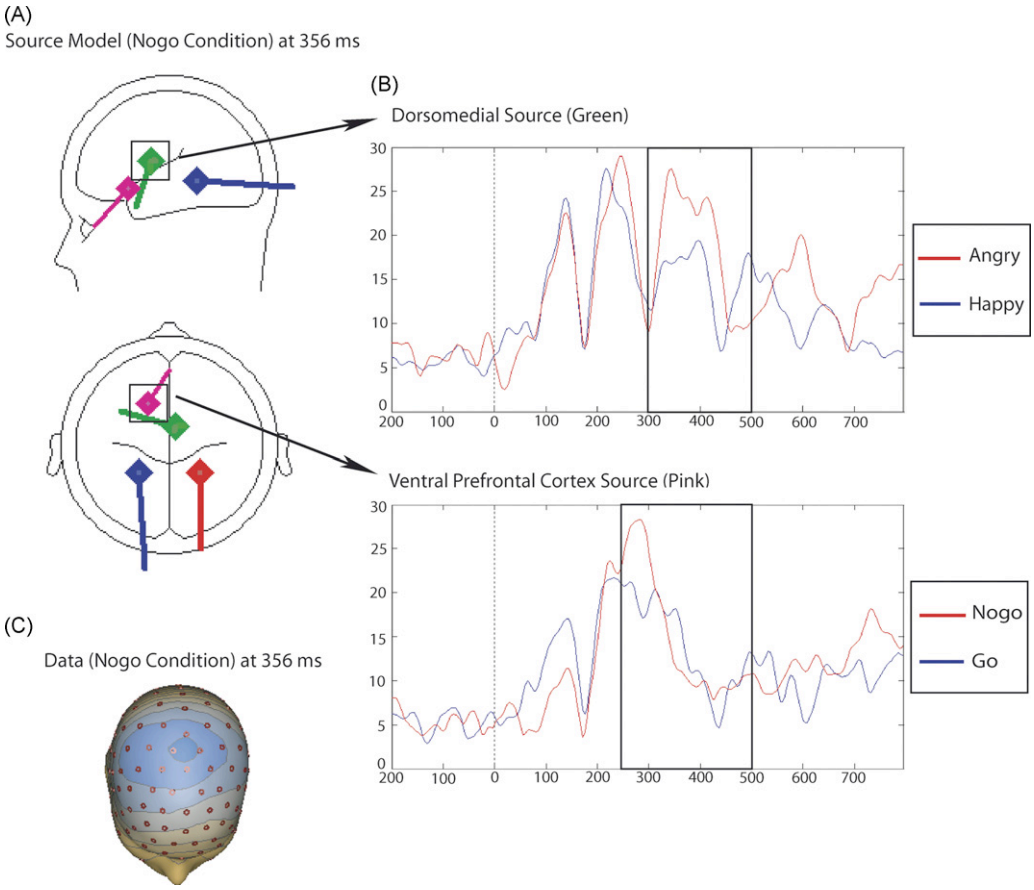

Fig. 7. (A) BESA regional source model, based on stimulus-locked, grand-averaged waveforms, shown at 356 ms following frame presentation for peak N2 activation. (B) Source waveforms for dorsomedial source (green source) with frame around time period at which statistics were extracted (300–500 ms), and for ventral prefrontal source (pink) extracted between 250–500 ms. (C) Topographical map showing scalp distribution of data in the Nogo condition.

ators in the region of the medial posterior cortex, a generator in the region of the left ventral prefrontal cortex, and a dorsomedial source in the region of the anterior cingulate cortex. The model accounted for over 98% of the scalp variance in all conditions (Fig. 7). We specifically wished to investigate differences in activation, related to response demand and stimulus valence, for generators in ventral prefrontal and cingulate regions. Because there were no main effects of personal familiarity nor any interactions between personal familiarity and any other factor in the scalp N2 data, we collapsed across parent and stranger faces to analyze source data in four conditions: Happy Go, Happy Nogo, Angry Go and Angry Nogo. Data from 33 children had sufficient artifact-free trials and were retained for analysis. We next applied the source model to individual participants in each separate condition to obtain estimations of current activation (in nanoamps) in these regions. Peak source wave activations were then extracted from the two generators in ventral prefrontal (250–500 ms) and anterior cingulate regions (300–500 ms) during the time window of the N2 (the ventral prefrontal source wave peaked slightly earlier than the dorsomedial source wave). ANOVAs were then performed for the ventromedial prefrontal and dorsomedial sources with response (2) and affect (2) as within-subject factors. For the ventral prefrontal source there was a main effect of response, $F\ (1, 32) = 5.39$, $p = .03$, partial $\eta^2 = .17$ with larger amplitudes for Nogo than Go trials (56.37 ± 2.77 and 52.77 ± 2.43 nAmp, respectively). There was no effect of affect, $F\ (1, 32) = .51$, *ns*. In contrast, for the dorsomedial source there was a main effect of affect, $F\ (1, 32) = 6.59$, $p = .01$, partial $\eta^2 = .14$, revealing larger amplitudes following angry than happy faces (70.95 ± 4.12 and 66.24 ± 3.81 nAmp, respectively). For this source there was no main effect of response, $F\ (1, 32) = .15$, *ns*. Thus, the ventral prefrontal source was sensitive to response type, and showed greater activation in Nogo trials, whereas the dorsomedial source was sensitive to affective valence, and showed greater activation following angry faces.

9. Discussion II: Frame presentation

In order to investigate effects of facial expression and familiarity on attentional processes associated with self-regulation, we measured the N2 component following the appearance of a Frame that cued Go and Nogo trials. Results showed amplitudes were larger following angry faces and in Nogo trials. Source models suggested a dorsomedial prefrontal region was larger in trials with angry faces and a region of ventral prefrontal cortex was larger in Nogo trials.

9.1. N2

9.1.1. N2 response to affect

As predicted, children had larger N2 responses following angry faces, suggesting that more effortful attention is required to perform the task when children are confronted with negative affect. These larger amplitudes following angry faces are consistent with previous studies finding the N2 to be larger following negative emotion induction (Lewis, Lamm, et al., 2006) and following angry faces (Lewis et al., 2007). Such results suggest that more effortful control or further processing may have been required to perform the task when confronted with an angry face. The relatively large effect size suggests that the pattern of processing emotional valence of a stimulus for extended periods of time, and when one is faced with an effortful cognitive task, is a robust one. The right-lateralized pattern of N2 activation may also reflect ongoing effects of the motivational significance of the face stimuli.

9.1.2. N2 response to task

As predicted, N2s were larger in Nogo than Go trials, although the effect size was modest. Results for the Nogo N2 have been mixed in children. A number of studies have found larger N2s for Nogo trials in children (Johnstone, Pleffer, Barry, Clarke, & Smith, 2005; Overtoom et al., 1998), particularly in paradigms using an emotion induction (Lewis, Lamm, et al., 2006) and following emotional stimuli (Lewis et al., 2007). Other developmental studies have found no difference between Go and Nogo trials (e.g. Davis, Bruce, Snyder, & Nelson, 2003). Differences in findings may be associated with differences in the ages of the children and the difficulty of the task. It has been argued that, beyond marking inhibitory control, the N2 reflects increased levels of effortful attention or conflict/salience monitoring required to effortfully regulate a response (Nieuwenhuis et al., 2003; Tucker et al., 2003; van Veen & Carter, 2002). The N2 has also been associated with executive function and emotion regulation processes in children as well as adults (Lewis, Lamm, et al., 2006). In our task, the behavioral data showed that children performed well, and were successful at withholding responses on Nogo trials. The children reported that they took considerable satisfaction in pressing the button and making the face go away, which moved the game forward. Thus, more effortful attention may have been required to override a compelling impulse to press the button, despite the fact that the task was not speeded.

The main effects of response and affect were not qualified by an interaction between the valence of the stimulus and the response demands of the task. However, planned *t*-tests, based on our previous findings of larger amplitudes following angry faces in a Go trials (Lewis et al., 2007), found significant differences between angry and happy faces in the Go but not in the Nogo condition. This finding suggests that the main effect of affect was influenced more by the Go trials. Thus, we and others suggest that more effortful attention or response monitoring is required to press a button in response to negative facial expression and override a prepotent action tendency to stop or withdraw (Blair et al., 1999; Hare et al., 2005). In contrast, pressing a button while looking at a face signaling encouragement and approval may generate the least amount of response conflict. Furthermore, the absence of any effect of personal familiarity on the N2 suggests that the regulatory N2 response is unaffected by the familiarity or personal importance of a face.

Because there were eight conditions in the N2 analysis, both the N and the trial count were relatively low, and these results should be treated with caution. However, they suggest that fron-

tomedial responses associated with self-regulation are in place in 4–6-year-old children, and that young children may draw on similar cortical mechanisms to those employed by adults to mediate effortful control of behavior and/or emotion. These mechanisms continue to be refined over development, however. For example, recent research has found a linear reduction in N2 amplitude between the ages of 5 and 16 years, suggesting greater efficiency of regulatory processes with age (Lewis, Lamm, et al., 2006). This pattern is in keeping with models proposing that overall brain activity decreases with development as regions become more specialized (e.g. Johnson et al., 2005). Longitudinal research will be important for investigating such developmental changes within a younger age group.

9.2. Source analysis following frame presentation

Source models must be treated with caution, especially when applied to young children's data, and should not be used to make claims about the precise location of neural generators. However, they can provide statistics on relative activation in brain regions between conditions, and can be useful for generating hypotheses for future research. For our Frame data, source localization modeled ventral prefrontal and dorsal midline sources similar to those reported in previous studies (Lewis, Lamm, et al., 2006). Comparison of source wave activation between conditions revealed greater activation in Nogo trials for the ventromedial source, and greater activation following angry faces for the source in the dorsal ACC region. Each of these sources shows a pattern of results that reflects one of the main effects found for the N2 measured at the scalp. The larger ventral prefrontal activation in Nogo trials indicates that this source may be contributing to the pattern of larger amplitude N2s in Nogo trials, a finding convergent with evidence that the ventral prefrontal cortex is implicated in executive tasks requiring the use of simple rule-sets (Zelazo & Cunningham, 2007), including response inhibition and social reversal learning (e.g. Kringelbach & Rolls, 2003). In contrast, the dorsal medial region discriminated between positive and negative stimuli, a finding that is consistent with studies finding increased dorsal ACC activation in response to angry faces (Blair et al., 1999; Harmer, Thilo, Rothwell, & Goodwin, 2001) and in situations that require the regulation of emotional responses (e.g. Ochsner et al., 2004; Critchley et al., 2003). Thus, dorsal and ventral prefrontal sources may be contributing to different aspects of the executive processes indexed by the N2. When self-regulation in the face of an emotional stimulus is required, the ventral prefrontal regions may discriminate more between the demands of the task. In contrast, activity in dorsal ACC regions may reflect effortful attentional control, as well as the coordination of distributed brain regions, required when one must either ignore distraction from an angry face or override a prepotent response to facial anger. Although this source source model needs to be confirmed by future fMRI research, it suggests that, by 4–6 years, both ventral PFC regions and dorsal ACC networks are active in self-regulation processes.

10. General discussion

The present findings suggest that overlapping but differentiated networks, subserving rapid and extended responses to affect and identity, are active by the age of 4–6 years. Our temporal distributional approach, looking at a range of components emerging over time, revealed a pattern in which different components, at different timepoints, respond to the salience of particular aspects of the environment. Specifically, the rapid, early components are sensitive to the personal familiarity of a face, which is registered quickly and, once registered, does not require ongoing online monitoring. In contrast, temporally extended components are sensitive to facial expression: There was no significant response to personal familiarity beyond 500 ms following face presentation, whereas ERP components continued to be responsive to the valence of the face until as long as 1500 ms after the face first appeared (when the N2 was measured). This extended response to facial emotion can be interpreted as reflecting the need for ongoing monitoring of changeable aspects of other people's social behavior that are important to one's well-being. In fact, information about people's emotional states may be considered the most important social information one can process and interpret, in both childhood and adulthood, with the greatest pertinence for adjusting one's own behavioral orientation and mood.

Daily social interactions involve perceiving and interpreting emotional signals as well as acting according to response rules learned through socialization. A goal of the present study was to create a simplified version of such interactions, within a laboratory setting, to study social-emotional responses in young children at an age where new cognitive and regulatory abilities are just coming online. Our findings are congruent with models of social-emotional processing that propose that such daily social exchanges elicit interactive, hierarchical sets of neural processes (Zelazo & Cunningham, 2007). Such processes include relatively automatic levels of categorization, as measured by the N170. They also extend to more elaborated, temporally enduring processes, as indexed by the LPC. Longer-latency components may index cortical processes signaling recruitment of more distributed networks for more extended social-emotional processing, allowing for more powerful, context-specific regulation of affective and behavioral responses (Bunge & Zelazo, 2006; Zelazo & Cunningham, 2007).

The time window between the age of 3 and 7 years is characterized by numerous cognitive changes. Among these are major milestones in the capacity for effortful self-regulation, as presumably measured by the N2. Such capacity for regulation provides children with attentional tools to modulate more automatic, implicit responses (see Eisenberg, Hofer, & Vaughan, 2007). To date, few studies have examined neurophysiological correlates of this capacity in children in this age range. The present finding that 4–6 year olds entrain similar frontal networks to those employed by adults suggests that basic neurophysiological patterns associated with effortful control are in place as new behavioral skills are consolidating.

10.1. Limitations and future directions

This study was the first to examine ERP responses to both personal familiarity and facial expression in young children, measuring ERP components across an extended time course and indexing a range of cognitive processes. Some limitations qualify the interpretations of our results, however. First, we did not collect data from an adult control group, which could help to parse task-specific effects from processing of facial familiarity and expression. We made this choice because we designed our paradigm specifically to be relevant to young children who see their mothers' approving and disapproving faces on a daily basis. For adults who no longer live with their parents, an encounter with one's mother's facial emotion may be more or less immediately salient, and may elicit a very different set of responses. Second, young children can remain still only for short periods of time. For this reason the maximum length of a task and the number of possible trials in each condition are limited, and the number of trials lost to movement artifacts can be high. As a result, the trial count and N for the Frame N2 analysis, although comparable with other developmental studies, were comparatively low. Finally, effect sizes were small for Nc and N2 results, and they, in particular, require replication. Despite these limitations, this study demonstrates a comprehensive approach to studying the time course of social-emotional processing in early development, as well as presenting unique findings that point to specific avenues of future research. Future fMRI studies can elaborate the role of specific networks of prefrontal regions in emotion processing and regulation in young children compared to adults. Longitudinal studies can further track developmental changes in the mediation of different levels of social-emotional processing and attentional control.

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