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An ERP study of conflict monitoring in 4–8-year old children: Associations with temperament

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ABSTRACT

Although there is great interest in identifying the neural correlates of cognitive processes that create risk for psychopathology, there is a paucity of research in young children. One event-related potential (ERP), the N2, is thought to index conflict monitoring and has been linked cognitive and affective risk factors for anxiety. Most of this research, however, has been conducted with adults, adolescents, and older children, but not with younger children. To address this gap, the current study examined 26 4–8-year-olds, who completed a cued flanker task while EEG was continuously recorded. We assessed whether the N2 was detectable in this group of young children and examined associations between the N2 and factors reflecting affective risk (e.g., reduced executive attention, temperamental effortful control, and temperamental surgency). We documented an N2 effect (greater N2 amplitude to incongruent versus congruent flankers), but only in children older than 6 years of age. Increases in the N2 effect were associated with less efficient executive attention and lower temperamental effortful control. We discuss the implications of these findings and consider how they may inform future studies on biomarkers for cognitive and affective risk factors for anxiety.

1. Introduction

There has been a surge of research in recent years on understanding the development of cognitive control processes (e.g., inhibitory and attentional control) based in part on theoretical and empirical studies linking these processes to the development of emotion regulation, self-regulation and adaptive behavioral outcomes (e.g., Rothbart et al., 1995; Posner and Rothbart, 2007; Lewis and Stieben, 2004). Although there have been numerous studies linking these types of cognitive control processes with neurophysiological markers via scalp recorded event-related potentials (ERPs), most of this work has been with older children, adolescents and adults. For example, the N2 is a early frontal negativity that is elicited during conflict and inhibition tasks (Nieuwenhuis et al., 2003) and is believed to be a marker for cognitive control processes, most notably conflict monitoring and detection (Van Veen and Carter, 2002a,b). However, we do not know much about the presence or function of the N2 and the association between the N2 and behavioral indicators of risk and resilience in very young children. Thus, the primary goal of current study was to test whether the N2 (1) is present and (2) varies predictably with degree of stimulus conflict in a sample of typically developing children as young as 4 years of age.

Attentional processes, such as executive control, are believed to be important links between early temperament (e.g., fearful behavior) and either adaptive or maladaptive outcomes (Olvet and Hajcak, 2008; Lewis et al., 2008). For instance, vigilant attention to threat and effortful con-

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trol have been examined as mechanisms in the etiology of anxiety (Mathews and MacLeod, 2005; Lonigan et al., 2004; Lonigan and Vasey, 2009). Numerous studies have documented physiological differences associated with the development of temperamental variation in behavior such as fearful/inhibited behavior (see Fox et al., 2005 for review) and attentional and effortful control (Posner and Rothbart, 2007). Specifically, it has been proposed that the temperamental inhibition includes a biological diathesis which gives rise to a pattern of fearful and anxious behavior (Kagan et al., 1992). The N2 has been linked to affective, attentional, and cognitive factors that appear to play a role in the emergence of a range of mood and anxiety problems (Dennis and Chen, 2009; Ladouceur et al., 2010; Perez-Edgar and Fox, 2005). Thus, the N2 has the potential to serve as a neurophysiological marker for a biological diathesis associated with affective risk (Dennis and Chen, 2009; Dennis et al., 2009; Luu and Tucker, 2004). Thus, a secondary goal of the current study is to examine whether the N2 is associated with temperamental differences that have been linked to affective risk: reduced executive attention, low effortful control, high negative affectivity, and low surgency.

1.1. N2 and conflict monitoring

The N2 is a negative-going waveform that is maximal in frontocentral electrodes appearing sometime between 200 and 400 ms after the onset of a stimulus. N2 amplitudes are thought to reflect the degree to which cognitive control resources are recruited to resolve conflict and inhibit incorrect responses (Braver et al., 2001; Jones et al., 2002; Folstein and Van Petten, 2008). Thus, the N2 is largest in those conditions that involve the most conflict typically reflected in increased error rates and/or reaction times (Van Veen and Carter, 2002a,b). Methodologically, the N2 is generated during tasks in which two or more incompatible response tendencies are activated at the same time such as tasks that require the inhibition of a pre-potent response (e.g., Go-No Go task) or that include incongruent stimuli (e.g., incongruent visual flankers) (Folstein and Van Petten, 2008; Kopp et al., 1996; Nieuwenhuis et al., 2003; Van Veen and Carter, 2002a,b). For instance, in a flanker task the N2 is expected to be larger to the incongruent (conflict trials) compared to the congruent trials (i.e., N2 effect).

The N2, along with other medial frontal negativities (e.g., error-related negativity), has been linked to activity of the anterior cingulate cortex (ACC; Banich et al., 2001; Carter et al., 1998; Van Veen and Carter, 2002a,b), which is a key region of the medial frontal cortex involved in the processing of both cognitive and affective conflict (e.g., Bishop et al., 2004; Vuilleumier et al., 2001). Again, however, the bulk of this work has been conducted in adults so there is very little research clarifying the functional significance of the N2 in children.

1.2. Development of the N2

As early as age 4, the N2 is evident in contexts in which there is cognitive emotional challenge (Nelson and Nugent, 1990; Todd et al., 2007). The amplitude of the N2 tends to be larger in children compared to adults and generally decreases with age (Henderson, 2010; Johnstone et al., 2005; Jonkman, 2006; Lewis et al., 2006b; Lewis and Stieben, 2004), although some exceptions have been documented (Ladouceur et al., 2004). This decline in N2 amplitude is often accompanied by improved performance on cognitive tasks (Lamm et al., 2006) and smaller N2 amplitudes are observed during tasks of attention and cognitive control (Bachevalier and Mishkin, 1984; Casey et al., 1997; Goldman et al., 1971). Thus age-related reductions in the N2 are thought to reflect the maturation of physical structures, including cortical thickening (O'Donnell et al., 2005) and reductions in grey matter volume (Giedd et al., 1999).

In both children and adults, the N2 is linked to neural generators in medial frontal areas of the cingulate cortex; however, children show considerably more posterior activation than is seen in adults (Jonkman, 2006; Lewis et al., 2006a,b; Stieben et al., 2007). This pattern of greater N2 activation in posterior cortical regions suggests the involvement of more automatic attentional processing in addition to more deliberative top-down cognitive control (Lewis et al., 2006a,b; Stieben et al., 2007).

In addition to these general developmental changes in the N2, individual variation in N2 amplitudes and links between the N2 and emotional traits are somewhat variable across development. In general, the amplitude of the N2 in children compared to adults is expected to be larger under conditions that require cognitive or emotional regulation, suggesting that system may still be under development (Johnstone et al., 2005; Lewis et al., 2006b; Todd et al., 2007). However, there are also some inconsistent developmental findings. For instance, both young children (ages 4–6; Nelson and Nugent, 1990) and adolescents (ages 13–16; Lewis et al., 2006b) show a larger N2 in response to emotional information relative to school-aged children (ages 7–12 across studies). These differences suggest a changing attunement to emotional information or nonlinear changes in emotion-related sensitivity of the N2 across childhood. Thus, the development of the N2 is not fully understood and more research documenting developmental effects are needed.

1.3. N2 relations with affective and cognitive control behaviors

As reviewed above, findings concerning the development of the N2 in terms of amplitude are somewhat mixed. As we will review next, the literature examining individual differences in the association between the N2 and behavior is also mixed. Research findings demonstrate that the N2 and similar medial frontal negativities thought to tap cognitive control are larger and have a shorter latency during the experience of negative emotion and in children with anxiety (Lewis et al., 2008). On the other hand, greater emotional flexibility, thought to be indicative of better regulation and control of negative emotions, is also associated with larger N2 amplitudes in children between 8 and 12 years of age (Lewis et al., 2006a), although the same was not true in younger children (5–7-year olds). Thus, it appears for older children and adolescents that both increased negative affect and more effective regulation of negative emotions is linked to greater neural "effort" as reflected in larger N2 amplitudes. Given the ongoing development of prefrontal cortical regions in young children, greater N2 amplitudes might indicate the effective recruitment of cognitive resources to support task performance and be associated with better performance. On the other hand, greater N2 amplitudes could also reflect a "neural inefficiency" pattern (i.e., increased N2 associated with less efficient behavioral performance) found in some studies with adults (e.g., Dennis and Chen, 2009) and studies of older children (Lamm and Lewis, 2010).

There have been a handful of studies examining the association between temperamental variation and N2 activity. In children as young as age 7, characteristics such as high soothability or attention control have been associated with larger N2 amplitudes during different types of cognitive control tasks (Perez-Edgar and Fox, 2005, 2007). In contrast, in a sample of children ages 9–12, Henderson (2010) demonstrated increased social anxiety outcomes for high-shy children with larger N2 amplitudes to incongruent flanker trials. However, in the Henderson study there was not a direct association between N2 amplitudes and shyness suggesting that perhaps temperamental shyness, reflecting reactivity, may be distinct from regulatory measures such as those indexed by the N2. Thus, examination of these neural markers in young children may be critical for understanding the relation between reactive and control aspects of temperament.

Given the importance of attentional factors in the emergence of mood and anxiety problems (Fox et al., 2002; Perez-Edgar and Fox, 2005; Vasey et al., 1995), in the present study we wished to examine associations between the N2 and executive attention efficiency. Although research with adults suggests that greater N2 amplitudes to incongruent compared to congruent trials (the N2 effect) reflects adaptive conflict monitoring (Kopp et al., 1996; Nieuwenhuis et al., 2003; Van Veen and Carter, 2002a,b), other research suggests that larger N2 effects are associated with *less* efficient executive attention performance (i.e., slower reaction times to incongruent compared to congruent trials; Dennis and Chen, 2009). Therefore, a larger N2 effect may reflect less efficient control capacity which results in poor task performance (i.e., less efficient executive attention). It is unclear whether this is also the case in children.

In the present study, we will examine associations between the N2 and attention performance using the Attention Network Test (ANT; Fan et al., 2002). The ANT is a cued flanker task that yields measures of attention performance in three anatomically and functionally discrete domains: alerting, orienting, and executive attention (Posner and Petersen, 1990; Fan et al., 2002). This will allow us to examine the specificity of associations between the N2 and executive attention, or whether the N2 is linked to a range of attentional processes.

Taken together, these studies with adults and children are inconclusive in terms of whether larger N2 amplitudes are associated with greater cognitive control and reduced negative affect, or vice versa. Notably, research with adults highlights the importance of focusing on the N2 effect (i.e., incongruent–congruent) because it reflects conflict monitoring (incongruent) relative to a non-conflict baseline (congruent); in contrast, most of the research reported above with children only examines correlations between N2 amplitudes to conflict-only contexts and behavioral individual differences. In the present study, we will examine both to better tease apart how the N2 relates to temperamental predispositions and to better compare with previous studies. That is, if the N2 effect reflects activity of neural resources to resolve the conflict there should be a distinction between congruent and incongruent trials, but there might be a cost to performance if that distinction – the N2 effect – is too large (reflecting inefficiency or too much effort possibly reflecting that task is too difficult). In the present study, we will examine whether greater N2 effects are related to disrupted attention performance, reduced effortful control, and increased negative affect. This will extend the existing research with children that typically only examine the N2 within trial-type (and typically during the conflict trials).

1.4. The current study

Childhood is a period of extensive cognitive change. The N2, which is highly sensitive to changes in cognitive and affective processing, may be particularly useful for measuring the ongoing development of emotional and cognitive control. Moreover, the use of ERPs in research with children has many advantages, including relative ease of administration compared to other neuroimaging techniques, and an excellent temporal resolution that allows measurement of extremely rapid covert cognitive processes. Unfortunately the N2 literature as it pertains to child populations and developmental processes is quite sparse. To address this gap, in this study, we examined age-related differences in the N2 in a sample of 4–8-year-old, typically developing children, associations with attention performance during the ANT, and whether the N2 varied with individual differences in temperament.

We tested three hypotheses. First, we hypothesized that there will be age-related changes in the pattern of N2 amplitudes such that older children would show a clear N2 effect—larger N2 amplitudes to incongruent versus congruent trials during the flanker task, reflecting a more adult-like pattern.

Because results on the association between the N2 effect and behavior are mixed, the next set of hypotheses was exploratory. Even though it is developmentally normative to show a larger N2 effect compared to adult, the degree to which this distinction is made may be associated with problems. Thus, given the most recent research, we hypothesized that a larger N2 effect would be associated with less efficient executive attention performance. Next, we explored the relation between the N2 effect and maternal report of temperament. Specifically, we focus on three broad dimensions of temperament: surgency, negative affect, and effortful control (Rothbart et al., 2001). Given the paucity of research linking temperament to neural markers, these analyses were largely exploratory. However, we did hypothesize that the N2 effect would be negatively correlated with the temperament dimension of effortful control which most closely measures the executive functioning, as well as increased negative affect and reduced surgency.

2. Methods

2.1. Participants

Thirty-five children participated in the current study. Participants were recruited through fliers and announcements in a community newsletter. To be eligible for participation, children had to be between 4 and 8 years of age, right-handed, free of any known neurological impairments, and not taking any stimulant medications. Of the full sample, four children refused to wear the electrode cap and one child removed the cap during data collection. One visit could not be completed due to equipment malfunction. Thus, 29 children (10 females) completed the visit and 26 children provided complete EEG and behavioral data. The average age of participants was 68.58 months (*SD* = 15.49). The sample was largely middle-class, with mean Hollingshead index of 48.62 (12.62) ranging from 21 to 66; 80% of the sample was Caucasian with 20% racial/ethnic minorities.

2.2. Procedure

2.2.1. Laboratory visit

Upon determining that their child was eligible for participation in the study, parents were mailed a packet including a consent form and a child temperament questionnaire to be completed and brought to the laboratory visit. Upon arrival to the laboratory, children were fitted with a neural net used for EEG data collection. Following baseline recording, the children participated in laboratory episodes including a conversation with a stranger[1] and attention task followed by a post baseline collection. Families received $20 for their participation and children received a small gift.

2.2.2. Attention network test

Children individually completed a child version of the Attention Network Test (Dennis et al., 2009; Fan et al., 2002; Rueda et al., 2004) on a Dell PC using E-Prime 1.1 (Psychology Software Tools, Inc.: Pittsburgh, PA). The experimenter was present throughout testing, but did not provide feedback to participants outside of encouragement to complete the task. Children were seated approximately 10 in. from the computer screen and given a response box to either hold in their lap or place on a table in front of them, whichever was more comfortable.

The experimenter explained the task to each participant using a set of index cards depicting an array of five fish. Participants were instructed to pay attention only to the fish in the middle of the array (i.e., the target) and "feed that fish" using the response box. Prior to beginning the practice trials, the experimenter asked participants to indicate which button on the response box corresponded to the correct response for the target arrays depicted on the index cards. When it was clear that participants were ready to begin we started with a set of practice trials.

A session of the ANT consisted of a total of 16 practice trials and three experimental blocks of 32 trials. Each trial began with the presentation of a fixation cross for 400 ms. For purposes of behavioral scoring, on some trials a warning cue replaced the fixation cross and was presented for 150 ms and represented one of four warning cue conditions: a center cue, a double cue, a spatial cue, or no cue. In the center cue condition, an asterisk was presented at the same location of the fixation cross. In the double cue condition, an asterisk appeared at locations of the target both above and below the fixation cross. In the spatial cue condition, a single asterisk appeared in the position of the upcoming target. A fixation period of 450 ms followed the disappearance of the cue. Following this, the target array appeared and remained on the screen until a response was detected or a maximum of 1700 ms elapsed, followed by a ITI of 1000 ms. Participants were told that a fish (target) would appear on the screen and that they should "feed the fish in the middle" by pressing the button on the response box that matched the direction that the fish was facing. During congruent trials, the target fish was surrounded by fish facing in the same direction; during incongruent trials, the target fish was surrounded by fish pointing in the opposite direction. Accuracy and reaction time were recorded for each trial. A schematic representation of the task is shown in Fig. 1.

2.2.3. Electroencephalograph recordings

EEG data were recorded during the ANT using a 128-channel dense array Geodesic Sensor Net (Tucker, 1993) and analyzed using Net Station software from Electrical Geodesics, Inc. (EGI, Eugene, OR) at a sampling rate of 500 Hz. All impedances were reduced to less than 70 kΩ (Ferree et al., 2001) during data acquisition. EEG was recorded using a 0.1–100 Hz bandpass filter with a 16-bit analog-to-digital converter and referenced to Cz for acquisition and re-referenced offline to the average reference (Bertrand et al., 1985; Tucker et al., 1993) and corrected for polar average reference effects (PARE; Junghöfer et al., 1999) prior to data analysis. Artifacts were screened using automatic detection methods (Net Station, EGI, Inc.) and visually inspected. Eye blink and eye movement artifacts (70 μV threshold) and signals exceeding 200 μV were removed during averaging. Data were highpass filtered at .10 Hz and a lowpass filtered at 35 Hz. Channels with excessive noise throughout the experiment were marked as "bad" and excluded from analyses.

[1] As a part of the laboratory visit, children took part in a conversation with a stranger episode designed to elicit fear and wariness. While the child was seated in front of the computer, a stranger (2nd research assistant) entered the physiology chamber, stood next to the child's chair, and engaged the child in casual conversation for approximately 2 min. The stranger asked questions (e.g., "What kinds of games do you like to play?" "What other things do you like to do?") and waited for child to respond. Following this, the stranger spoke, from a script, to the child about the purpose and functions of the EEG net (approximately 1 min), stated that it was time for them to leave, and exited the experimental room. After completion of this task, children completed the ANT task.

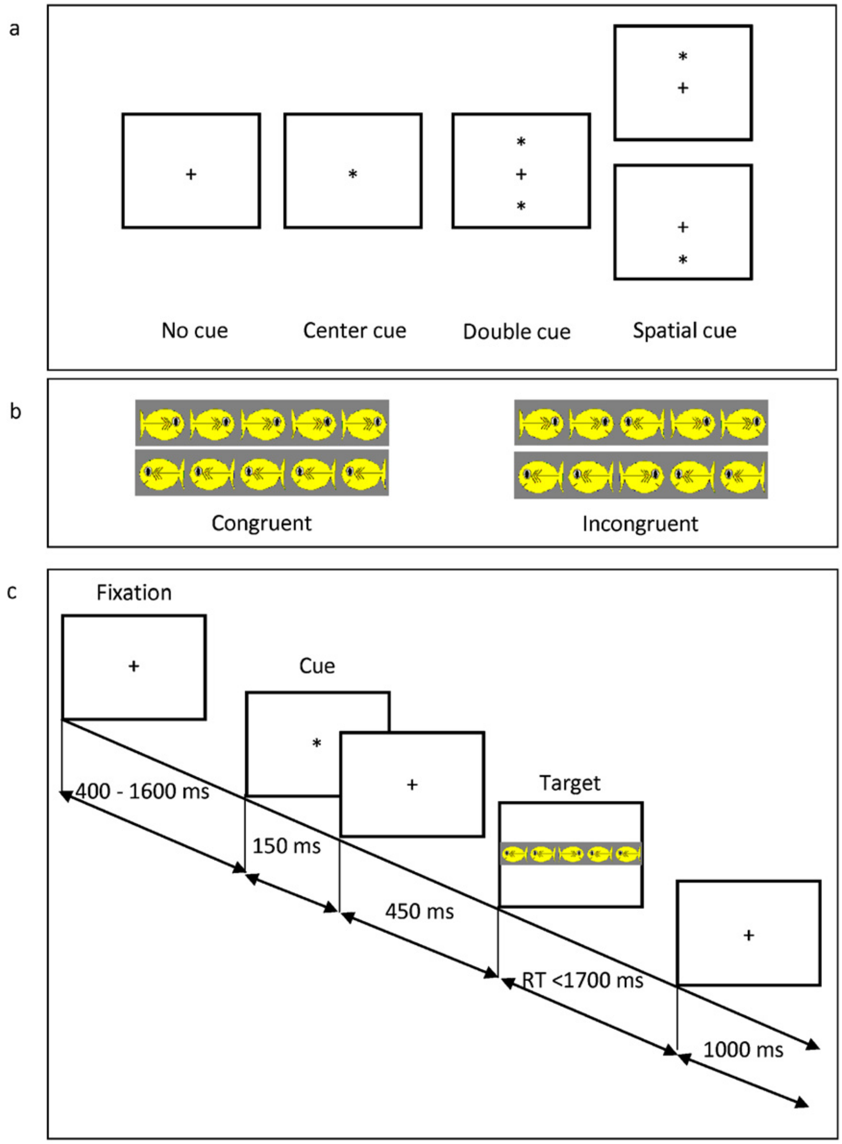

Fig. 1. Modification of attention network task.
Note: Experimental procedure. (a) The four cue conditions; (b) the four stimuli; and (c) an overview of the procedure.

2.3. Coding and data reduction

2.3.1. Event-related potentials

The EEG was time-locked to the stimulus, segmented 50 ms prior to and 500 ms following the stimulus, and divided according to type of trial (congruent versus incongruent). Epochs were baseline corrected for 50 ms preceding stimulus onset. Segments containing eye blinks, eye movements, or response times of less than 200 ms were excluded. Bad channels were replaced using spherical spline interpolation of values of neighboring channels (Perrin et al., 1987). The average number of bad channels interpolated in the final data set was 7.56. EEG data from one participant was not used because the EEG data file was corrupted. Two children were excluded from analyses because reaction time performance data indicated they may not have been cooperating or understand the instructions. Upon examination of videotapes this was confirmed. Thus, we analyzed the data from the remaining 26 children.

The time window for the N2 was identified using a principle components analyses with the grand averaged data. Three components were identified accounting for 93% of the variance and included a fast positive to negative peak between 92 and 176 ms; a second positive deflection at approximately 250 ms; and second negative deflection (identified as the N2) at 350 ms. For each individual, the N2 was defined as the greatest negative deflection occurring between 320 and 380 ms (±30 ms) post-response subtracted from the preceding positive peak. This deflection was maximal at Cz. This method was selected in order to capture the full degree of the negative deflection and account for possible individual differences in EEG amplitudes prior to the N2 (see Nieuwenhuis et al., 2004). N2 was calculated at three midline sites (Fz, Cz, and Pz) separately for the congruent and incongruent trials. We truncated extreme values above 1.5 *SD* (across participants) to the next lowest value.

2.3.2. Attention performance reaction times

From performance on the ANT, measures of efficiency of alerting, orienting, and executive attention were calculated from the reaction time (RT) data from the correct trials. RT to the flanker targets under different cue and type conditions measures the effects of these three attention networks. Alerting efficiency was calculated by subtracting the RT for trials in which the double cue was presented from trials with no cue presentation (RT no cue-RT double cue). Higher scores indicate greater alerting efficiency. Orienting efficiency was calculated by subtracting the RT for trials in which spatial cues were presented from trials in which a central cue was presented (RT center cue-RT spatial cue). Higher scores indicate greater efficiency in orienting because the spatial cue provides more information than the altering effects of the cue alone. Conflict score (i.e., executive attention efficiency) was calculated by subtracting the reaction time for congruent trials from reaction time for incongruent trials (RT incongruent–RT congruent). Higher scores indicate greater conflict which is interpreted as less efficient executive attention. Scores were examined for normality. Extreme values over 1.5 *SD* (across participants) above and below the mean were truncated to the next value.

2.3.3. Maternal-reported child temperamental shyness

Temperamental shyness was assessed using the Child Behavior Questionnaire Short Form (CBQ; Putnam and Rothbart, 2006a,b). The CBQ short form contains 94 items that assess three broad domains of temperament: surgency/approach, negative affect, and effortful control. Parents respond to statements on a 6-point Likert scale (1 = extremely untrue of my child, 2 = quite untrue of my child, 3 = slightly untrue of my child, 4 = neither true nor false of my child, 5 = slightly true of my child, 6 = extremely true of my child). All scales have been shown to have good internal consistency, with Cronbach's alphas ranging from .65 to .85.

3. Results

The descriptive statistics for N2 amplitudes at each electrode site (Fz, Cz, Pz) by trial type (incongruent or congruent flanker) and attention performance behavioral data are presented in Table 1. Children performed quite well on the task, completing correctly an average of 41 the congruent trials (range = 27–48) and 39 (range = 30–48) of the incongruent trials.

Table 1
Means and standard deviations for N2 amplitudes and performance.

	Congruent	Incongruent
Fz	−10.71 (5.71)	−11.74 (6.79)
Cz	−10.03 (5.72)	−10.86 (5.82)
Pz	−6.70 (5.26)	−8.31 (4.05)
Reaction time	911.69 (148.35)	977.50 (166.82)
% correct	83.26 (16.74)	76.08 (14.98)
Alerting	51.87 (54.03)	
Orienting	17.43 (77.37)	
Conflict	65.81 (68.38)	

3.1. N2 amplitude differences across electrode sites and trial type

In order to examine whether N2 amplitudes varied across sites, trial types, and age we conducted a repeated measures ANOVA. This 3 (Site: Fz, Cz, Pz) × 2 (Trial Type: congruent, incongruent) analysis revealed a significant main effect of Site, $F(2, 50) = 7.37$, $p < .01$, $\eta_p^2 = .23$, such that amplitudes at Fz and Cz were significantly larger than those at Pz (p's < .05) (Fig. 2). There was no effect of Trial Type, $F(1, 50) = 2.30$, indicating no significant N2 effect for the sample as a whole.

Next, given the large age range of children, we examined age as an additional factor in an additional ANOVA. We split the sample at the median age (72 months; 6 years). There were 14 children younger than 72 months and 12 children older than 72 months. Given the pattern of results in the original ANOVA showing that the N2 was maximal at Fz and Cz, the Pz site was dropped from these analyses. We conducted a 2 (Site: Fz, Cz) by 2 (Trial Type: congruent, incongruent) by 2 (age: younger, older) ANOVA analysis. There was a significant trial by age interaction, $F(1, 24) = 5.53$, $p < .05$, $\eta_p^2 = .19$. A set of posthoc comparisons were used to examined this interaction. We found a significant Trial Type × age interaction at Cz, $F(1, 24) = 7.77$, $p < .01$, $\eta_p^2 = .24$, but not at Fz. Testing this further revealed that the expected N2 effect (N2 incongruent > N2 congruent) was only significant for the older children, $F(1, 11) = 9.05$, $p < .01$, $\eta_p^2 = .45$. This effect is depicted in Fig. 3 with the difference waves (incongruent–congruent) plotted for older and younger children at Fz and Cz. In sum, we demonstrated that the expected difference between the N2 amplitudes by trial type to the flanker target was significant for the older children only and at electrode site Cz.

3.2. Associations between the N2 and performance and temperament

We were interested in examining whether the N2 effect at Cz was associated with attention performance and parent-reported temperament. To be consistent with other studies in children, we also examined the N2 to the congruent and incongruent trials. Given that we only found the N2 effect for older children, and age was correlated with the N2 effect ($r = -.42$, $p < .05$), we conducted partial correlations controlling for age. These correlations are summarized in Table 2. We found that greater N2 effect was associated with higher conflict scores, reflecting less efficient executive attention. The incongruent N2 was also associated

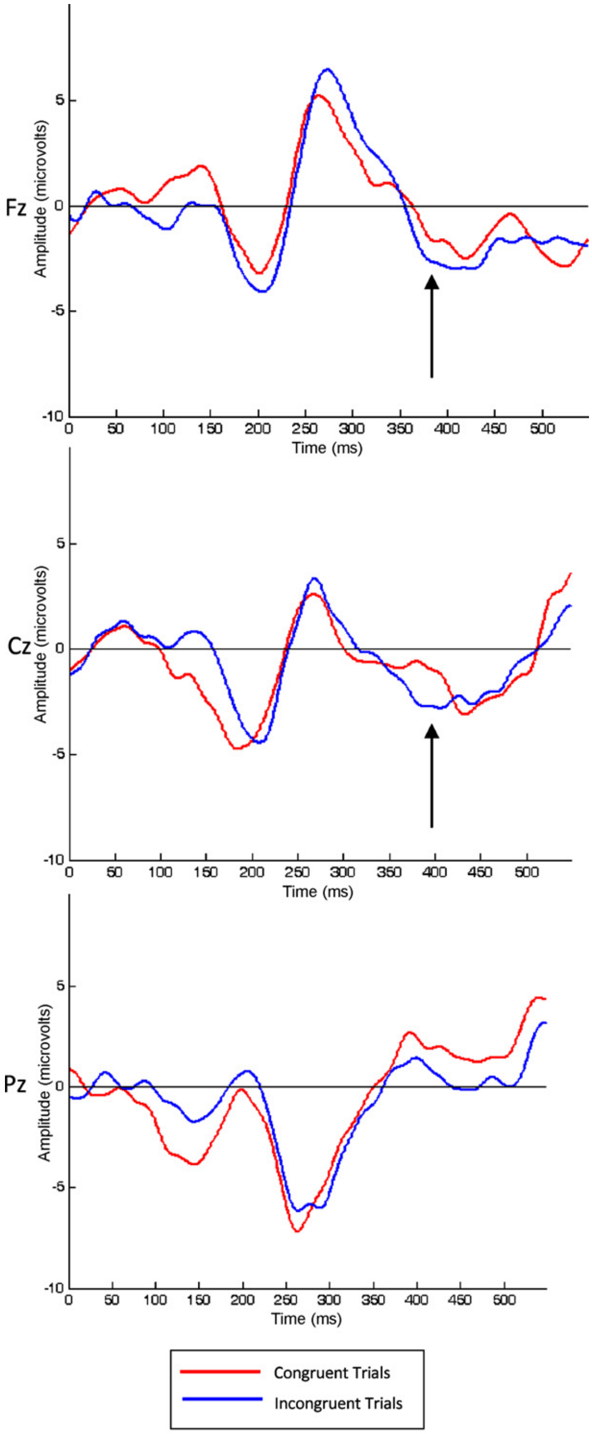

Fig. 2. N2 waveforms for congruent and incongruent trials.

with less efficient alerting but the N2 difference was not associated with alerting, or orienting. Turning to maternal-reported temperament, we focused on the three factor scores: Surgency, Effortful Control, and Negative Affect. Although larger incongruent N2 was associated with more surgency, N2 effect was not. Greater N2 effect and larger

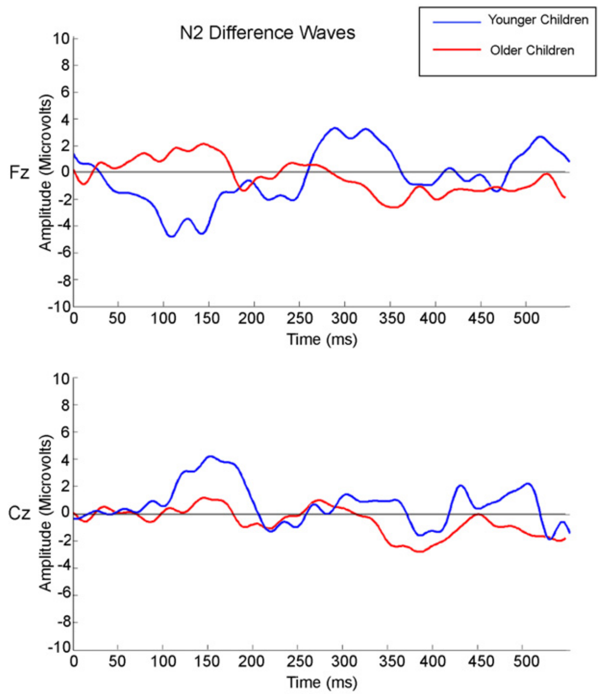

Fig. 3. N2 difference waveforms by age group.

N2 to incongruent trials were both associated with less Effortful Control. No associations were found with Negative Affect and congruent N2.

4. Discussion

The current study extends the literature on the N2 as a measure of conflict monitoring by demonstrating age-related differences in early childhood and associations between N2 and executive attention and temperament. The main goal of the project was to determine whether the N2 was associated with conflict monitoring in very young children. A secondary goal was to explore whether the magnitude of the N2 was associated with individual differences in attention and behavior. We will now turn to a discussion of each of these findings and implications for future developmental ERP research, including discussion of biomarkers for temperamental variation and affective risk.

4.1. Evidence for development of the N2 response and conflict monitoring effects

Consistent with predictions, we found age-related effects in the modulation of the N2. First, we found that N2 amplitudes on all trials were maximal at Fz and Cz for all children, suggesting frontalization of the N2 response even in preschoolers. As we reviewed in the introduction, N2 amplitudes across a variety of studies including but not limited to conflict N2, were more likely to be more widely distributed and larger at more parietal sites in children compared to adults. Although we did not have an adult comparison, the data from the current study suggest a frontocentral distribution of the conflict N2 even

Table 2
Partial correlations, controlling for age, between N2 at Cz and attention performance and temperament.

	Cz congruent N2	Cz incongruent N2	Cz incongruent-congruent N2
Conflict score	−.03	−.29	−.42[a]
Alerting score	.18	.41[a]	.21
Orienting score	.04	−.11	−.13
CBQ surgency	.21	−.36[b]	−.03
CBQ effortful control	−.25	.43[a]	.41[a]
CBQ negative affect	−.10	−.16	.08

[a] $p < .05$.
[b] $p < .10$.

in the youngest children. It is possible that we found the frontalization of the N2 in our sample because we used a validated, developmentally appropriate task as other researchers have suggested would enhance detection of effects (e.g., Hogan et al., 2005; Torpey et al., 2009).

Second, the expected modulation of the N2 (larger amplitudes to incongruent compared to congruent trials) was only evident for the older children. Thus, we have evidence that this N2 effect may be a good biomarker for conflict monitoring efficiency in children in early childhood (>6 in our sample) but not in preschool-aged children. These age differences are consistent with the literature demonstrating age-related changes across several ERP components thought to reflect the ongoing development of the ACC and prefrontal cortex in preschool and school-aged children (e.g., Henderson, 2010; Johnstone et al., 2005; Lewis et al., 2006b; Lewis and Stieben, 2004).

Third, we found that after controlling for age, the N2 effect was associated with less efficient executive attention. Although the N2 to incongruent trials alone was associated with alerting, the N2 effect (incongruent versus congruent) was not associated with orienting or alerting suggesting specificity of links with executive attention. So while the incongruency effect on the N2 is normative and present in older children, greater N2 effect may also reflect resource depletion which is one mechanism in executive attention interference. This finding is consistent with the findings of Dennis and Chen (2009) showing that the greater the N2 effect was associated with less efficient executive attention. To our knowledge, the current study is the first to demonstrate modulation of the N2 and its association with executive attention in children this young.

4.2. *N2 as a biomarker for temperamental variation in children*

Turning to the second, more exploratory goal of the current study, we found that larger N2 amplitudes to incongruent trials and the N2 effect were associated with less effortful control. Note that this effortful control finding, which reflects behavioral control and regulation (Rothbart et al., 2001) was consistent with the conflict score finding summarized above demonstrating consistency across different types of measures of executive functioning. The current findings extend the literature, especially developmental studies demonstrating an association between N2 amplitude and other, related aspects of control and regulatory processes (e.g., soothability and attentional control) (Perez-Edgar and Fox, 2005, 2007) both of which are components of the effortful control construct used in the current study. However, in these two other studies low levels of control and soothability were associated with smaller N2 amplitudes to incongruent trials; and the difference between trial types (i.e., N2 effect) was not explored. This could account for the differences in findings, or it could be that the differences in the types of tasks used to examine the N2 accounted for the discrepancy. In addition, it could be that the younger children (compared to age of children in other studies) in our sample who have low effortful control and self-regulation need to recruit more neural resources when resolving conflict specifically. As these skills and the PFC develop, fewer neural resources are needed to complete these tasks. To our knowledge, our study is the first to examine the N2 effect in relation to control processes and a given the relatively small number of studies on the N2 and behavioral control processes in children more empirical work is needed.

Although not hypothesized, larger N2 amplitudes to incongruent trials were associated with higher surgency scores while the N2 effect was not associated with surgency. Surgency is largely characterized by high intensity positive affect and approach behavior (Rothbart et al., 2001) and is often associated with risk-taking behaviors and risk for externalizing behavior problems (e.g., Putnam and Stifter, 2005; Rubin et al., 1995; Stifter et al., 2008). Although not necessarily thought of as the opposite end of the continuum of behavioral inhibition or fear, low surgency as reported by parents may be indicative of avoidant behavior consistent with behavioral inhibition and shyness. In fact low shyness loads on the surgency factor of the CBQ, thus we can think of this surgency measure as reflecting, in part, low shyness and low avoidance. Although speculative, this finding may suggest that the N2 is sensitive to temperamental shyness in young children much like it is for trait anxiety in adults (e.g., Dennis and Chen, 2009).

We do know that other ERP components, such as other medial frontal negativities like the ERN, are associated with temperamental shyness (McDermott et al., 2009) and anxiety (Hajcak et al., 2003). However it is important to note that McDermott and colleagues' study included adolescents who had been previously classified as inhibited which is a direct measure of shyness. Although, recall that Henderson (2010) failed to find a direct association between temperamental shyness and N2 in a sample of 9–13-year-olds. To date the literature across childhood and adulthood is somewhat mixed in finding an association between temperamental shyness and N2. Henderson

(2010) suggested that from a temperament perspective we should not expect an association between shyness which is considered to be a reactive component of temperament, and N2, which likely reflects a regulatory aspect of temperament related to cognitive control (see Rothbart et al., 2001). It is important to note, however, that several studies have found associations with other components of frontal negativities, such as N2 latencies and shy/fearful behavior in a clinical sample (e.g., Lewis et al., 2008). So across several studies varying in age and methods assessing temperamental aspects of behavior there appears to be mixed but promising findings that the N2 may be a marker for individual differences in temperament. In sum, it appears that modulation of the N2 is a good candidate as a biomarker for regulatory aspects of temperament, such as effortful processes, and for approach/withdrawal individual differences.

4.3. Limitations

The large age range of participants resulted in fairly small sample sizes when age effects were considered. This precluded our ability to examine associations separately by age and likely reduced power to detect effects. Moreover, given that this sample included typically developing, unselected children there was likely a restricted range of temperamental variation especially with respect to shyness. Parents with shy or fearful children may have been unlikely to volunteer for the study thus limiting our ability to detect these differences as others have found. Finally, the association between N2 and conflict monitoring may have been due to method overlap—that is, both the N2 and the RT scores are based on the incongruent–congruent contrast. This suggests the possibility that the association reflects neural correlates of specific behavioral performance rather than our proposed theoretical association between the N2 effect and executive functioning. Thus, in order to provide compelling evidence for this theoretical link, future work is needed in future studies examine whether the N2 is associated with other measures of executive attention that are measured outside of the ANT context.

5. Conclusions

Findings from the current study were consistent with evidence that the N2 reflects conflict monitoring as is does in adults, yet extends these findings by demonstrating a developmental effect (i.e., the expected modulation of the N2 only for children older than 6). This suggests that age-related changes may reflect relatively immature prefrontal cortex development in the preschool-aged children. As hypothesized in exploratory predictions, the N2 effect was associated with less efficient attention performance and reduced effortful control. Moreover, greater surgency was associated with larger N2 effects and larger incongruent N2 amplitudes. Taken together, results add to the developmental literature on the morphology and function of the N2, and suggest that the N2 holds promise as a neural biomarker for a range of attentional and temperamental factors that are linked to affective risk and resilience.

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