



Negative affectivity and EEG asymmetry interact to predict emotional interference on attention in early school-aged children



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ABSTRACT

Negative affectivity (NA) is a broad construct that has been associated with the development of psychopathologies, such as anxiety, and with exaggerated attention to threatening stimuli. EEG asymmetry reflects biological individual differences in emotional reactivity that may underlie the association between NA and attention to threat. The present study included a sample of 31 five-seven year olds (M age in months = 74.39, SD = 6.57) to test the hypothesis that greater NA, combined with greater right anterior and posterior asymmetries, predicts increased attention interference following threat stimuli. Children completed an executive attention task which presented task-irrelevant threat (angry) and non-threat (neutral) faces prior to each trial. EEG asymmetry was measured at baseline for anterior, anterior-temporal and posterior scalp regions and child NA was measured via maternal report. As predicted, children showing greater NA and greater right anterior-temporal asymmetry showed more attention interference following angry faces. Additionally, two trend-level effects emerged: children showing greater NA and greater left anterior-temporal asymmetry showed less attention interference following angry faces, and children showing greater NA and greater left posterior asymmetry showed less attention interference, but only following neutral faces. Discussion focuses on the utility of using EEG asymmetry in the study of temperament, attentional biases, and the biological processes by which temperament confers risk for psychopathology.

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1. Introduction

Emotional reactivity is among the core aspects of temperament that influence children's adaptive behavior, including the ability to regulate behavior and attention in the presence of emotional demands (Cicchetti & Cohen, 2006; Cole, Dennis, Martin, & Hall, 2008; Gottman, Katz, & Hooven, 1997). Temperament theory has focused on two over-arching dimensions of temperamental reactivity in early childhood: surgency and negative affectivity (Rothbart, Ahadi, Hershey, & Fisher, 2001). Negative affectivity (NA) is a reactive dimension of temperament reflecting the degree to which a child displays discomfort, fear, anger/frustration, sadness, and reduced soothability (Rothbart & Bates, 2006; Thomas & Chess, 1977).

NA has been associated with a broad array of emotional pathologies, in particular those that are related to disruptions in how emotional information is attended to and processed, such as anxiety and depression (Compas, Connor-Smith, & Jaser, 2004; Dougherty, Klein, Durbin, Hayden, & Olino, 2010; Klein, Durbin, Shankman, & Santiago, 2002; Laurent, Joiner, & Catanzaro, 2011; Mikolajewski, Allan, Hart, Lonigan, & Taylor, 2012; Morgan, Shaw, & Olino, 2012). For example, anxiety is characterized by an attention threat bias, or disrupted attention towards threat-relevant stimuli (e.g., angry faces). This is evidenced at multiple stages of attention, depending on when and how attention is measured (Amir, Foa, & Coles, 1998), including exaggerated vigilance for threat, greater difficulty disengaging attention from threat, and attentional avoidance of threat (Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007; Mogg & Bradley, 1998; Williams, Mathews, & MacLeod, 1996).

Nakagawa and Sukigara (2012) examined the relation between temperamental NA in 12-month-old infants and individual differences in attentional disengagement from threatening stimuli (e.g., fearful faces). They found that infants displaying greater NA

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had difficulty disengaging their attention from fearful faces compared to happy or neutral faces, and showed overall increased negative affect across the 12–36 month period. This suggests a developmental trajectory whereby children displaying greater NA, who also show greater attentional capture and interference by threat-relevant stimuli, may be at elevated risk for developing affective psychopathologies (Derryberry & Rothbart, 1997; Pérez-Edgar et al., 2011). Thus, a critical research goal is to increase the understanding of how NA influences disrupted attention towards emotional stimuli.

1.1. Negative affectivity and EEG asymmetry

One method that can be useful in investigating how temperamental characteristics, like NA, confer risk for later affective disruptions is EEG asymmetry. EEG asymmetry (relative difference in activity between left and right hemispheres) has traditionally been thought to reflect trait-like differences in emotional reactivity. Individual differences in temperament correlate with distinct patterns of asymmetric EEG activity in anterior (frontal and anterior-temporal) and posterior hemispheres of the brain (Davidson, Ekman, Saron, Senulis, & Friesen, 1990; Heller, Etienne, & Miller, 1995; Heller & Nitschke, 1998). Activity in the left anterior regions of the brain reflects trait-like tendencies to experience and express approach-related emotions such as happiness and anger, whereas activity in the right anterior regions of the brain reflects withdrawal-related emotions such as fear (Davidson, 1992; Davidson and Fox, 1982, 1989; Davidson et al., 1990; Fox & Davidson, 1987; Gable & Harmon-Jones, 2008; Miskovic & Schmidt, 2010).

Anterior EEG asymmetry has been successfully used to predict the developmental trajectory of children with temperamental characteristics such as behavioral inhibition (Fox, Schmidt, Calkins, Rubin, & Coplan, 1996; Henderson, Fox, & Rubin, 2001). For example, in a study by Fox, Henderson, Rubin, Calkins, and Schmidt (2001), children identified as behaviorally inhibited in infancy and who remained inhibited and wary towards novel situations as toddlers displayed greater right anterior asymmetry, while those exhibiting less inhibition and wariness exhibited a shift in asymmetry from greater right to greater left anterior asymmetry.

Although anterior EEG asymmetry has been linked to parental report measures of temperament in infancy (e.g., LoBue, Coan, Thrasher, & DeLoache, 2011), and to the continuity of temperamental characteristics (e.g., Fox et al., 2001), few studies have examined whether EEG asymmetry helps explain the association between NA and cognitive biases that might put children at risk for affective psychopathology. Given that NA is associated with withdrawal type-behaviors and traits, and anterior EEG asymmetries (characterized as greater right-than-left activity) are also associated with withdrawal-type behaviors and traits, it is of interest to examine whether anterior EEG asymmetry will moderate or mediate responses between NA and executive attention (Coan & Allen, 2004). In the present study, we pursued this goal by testing the hypothesis, through both mediation and moderation analyses, that greater right anterior asymmetry will either partially or fully explain which children showing high NA will also show greater attentional capture by threat (i.e., measured as more interference on an attention task in the context of threat-relevant angry faces versus neutral or happy faces).

Less is understood about temperament and posterior EEG asymmetry. Greater right posterior asymmetry is thought to reflect more general emotional arousal (Bruder et al., 1997; Heller, 1993; Heller & Nitschke, 1998; Levin, Heller, Mohanty, Herrington, & Miller, 2007; Sobotka, Davidson, & Senulis, 1992). For example, Heller, Nitschke, and Miller (1998) found that posterior regions of the brain are not only specialized for cognitive processes as was previously assumed, but for affective behaviors as well. Heller

and colleagues posit that arousal, independent of high or low valence, is dependent on functions of the right posterior brain regions. Given that arousal is a key feature of anxiety, a posterior asymmetry (greater right activity than left) has been theorized to be related to the arousal facet of anxiety disorders (Bruder et al., 1997; Nitschke, Heller, Palmieri, & Miller, 1999). Greater activation in the right posterior brain regions has also been linked to performance on attention tasks. Specifically, greater activity in the right hemisphere has been associated with faster reaction times on attention tasks as well as the maintenance of attention in monitoring the occurrence of sensory stimuli (Heller, 1993). However, EEG studies on left posterior asymmetries have failed to show consistent associations with emotion regulation, emotion processing, or attention. Furthermore, studies examining adults evidencing depression and/or anxiety have documented individual differences in patterns of posterior EEG asymmetry. Non-anxious/depressed patients showed greater left posterior asymmetry (due to decreased right posterior activation) whereas anxious-depressed patients showed greater right posterior asymmetry (due to increased right posterior activation; Bruder et al., 1997). These findings are consistent with the model that, in adults, greater right posterior asymmetry is indicative of anxious arousal (Heller et al., 1995).

Thus, one of the aims of the present study was to investigate the extent to which posterior EEG asymmetries relate to NA and emotional interference on attention. Given rapid neural development occurring during the early school years (Casey, Giedd, & Thomas, 2000; Casey, Tottenham, Liston, & Durston, 2005), it remains unclear whether individual differences in posterior and anterior asymmetries will be associated with similar or distinct patterns of attention to emotion. Such developmental shifts have been documented in a previous fMRI study, in which researchers examined developmental differences in attentional control among 8-to-12 year old children and adults on a combined flanker task and go/no-go paradigm (Bunge, Dudukovic, Thomason, Vaidya, & Gabrieli, 2002). Children who had greater attention interference showed greater activation in posterior regions of the right hemisphere while adults who had greater attention interference had greater activation in anterior regions of the right hemisphere. Thus, we tested the exploratory hypothesis that, like children with greater right anterior asymmetries, children with greater right posterior EEG asymmetries, if indicative of individual differences in anxious arousal, will be more likely to show attention interference in the presence of threat stimuli. We predicted that this pattern would be enhanced among those children showing high temperamental NA.

Given that the processes through which NA relates to attention to threat are not fully understood, there is a need for studies that combine the examination of EEG asymmetry and NA with that of attention performance in an emotional context. Accordingly, the overall goal of the present study was to merge these literatures and investigate whether NA is related to disrupted attention towards threat, measured as emotional interference on attention during an executive attention task. In addition, we examined whether individual differences in EEG asymmetry influences these associations. School-aged children were recruited in order to examine these processes during a period of rapid neural development – preschool and early elementary school.

We tested the hypothesis that children showing greater NA, combined with greater right anterior or posterior asymmetry, will be more likely to have disrupted patterns of attention towards threat, measured as greater interference on an executive attention task in the context of angry versus neutral or happy faces. As EEG asymmetry might also represent a specific biological mechanism through which NA creates risk for attention disruptions, we tested whether individual differences in asymmetry fully mediate the associations between NA and attention interference.

2. Methods

2.1. Participants

Participants were 31 children between the ages of five and seven (17 girls, *M* age in years = 5.74, *SD* = .58). The age distributions for the girls were eight five-year olds and nine six-year olds. The boys included in the study were two five-year olds, ten six-year olds and two seven-year olds. Participants were an ethnically diverse group of children (thirteen Caucasians, eight African-Americans, four Hispanics, one Asian, and five identified by their mother as “Other” ethnicity). Maternal report on their children’s handedness indicated that all participants were right-handed. Mothers reported no diagnosed developmental disorders or attention problems were present, and completed questionnaires assessing child temperament and emotional behavior. Participants spent approximately 3 h in the laboratory and, at the end of the study, families were compensated with \$100.00 for their time.

2.2. Procedures and measures

Children were accompanied by their mothers to the laboratory where mothers gave informed consent and children gave verbal assent. Mothers filled out questionnaires assessing their child’s temperament and behavior. During the laboratory visit, children completed a computerized task measuring EEG baseline followed by a computerized attention task while continuous EEG data was recorded. Specifically, EEG was measured at baseline while children sat quietly for eight 1-min periods, counterbalanced in order for eyes closed (C, O, O, C, O, C, C) or eyes open conditions (O, C, C, O, C, O, C, C). Other computer-based tasks (e.g., directed emotion regulation) and behavioral assessments (e.g., observed emotional behavior, observed parent–child interactions) followed but are not included in the present report.

2.3. EEG acquisition

Using the BioSemi system (BioSemi; Amsterdam, NL), EEG activity was recorded continuously via 64 Ag/AgCl scalp electrodes embedded in an elasticized nylon cap based on the international 10/20 system. Eye movements were monitored by electro-oculogram (EOG) signals from electrodes placed 1 cm above and below the left eye (to measure vertical eye movements) and 1 cm on the outer edge of each eye (to measure horizontal eye movements). The EEG signal was preamplified at the electrode to improve the signal-to-noise ratio. EEG was recorded at a sampling rate of 512 Hz. The voltage from each active electrode was referenced online with respect to a common mode sense active electrode producing a monopolar (nondifferential) channel. All data were re-referenced offline to an average reference and filtered with a high pass frequency of .1 Hz and a low pass frequency of 30 Hz.

2.4. EEG data reduction

The raw EEG data was scanned through a computerized artifact scan batch for ocular and movement artifacts using Brain Electrical Source Analysis version 5.1 (BESA; MEGIS Software GmbH, Munich, Germany). Trials with EEG or EOG activity above ± 100 mV were excluded from further analysis. All artifact-free EEG data measured at baseline were transformed to raw power scores with a Fast Fourier Transformation (FFT) filtered using a Hanning window of 1-s width and 50% overlap to retain as much data as possible. Power (μ^2) was computed in the alpha frequency band (8–12 Hz) for anterior (FC5, FC6), anterior-temporal (T8, T7) and posterior (P8, P7) sites. These sites were selected based on the greatest power values

displayed for each region, respectively. As power values are expressed in units of voltage squared, the distributions tend to be skewed and the data were log transformed to normalize the distributions. Alpha activity is associated with lower levels of awareness or increased levels of relaxation, therefore decreased alpha activity is considered to be an indication of increased mental activity. In addition, because asymmetrical activity was of interest to this study, a difference score subtracting left power scores from right power scores was calculated for anterior (FC6–FC5), anterior-temporal (T8–T7) and posterior (P8–P7) sites. The difference score provides a unidimensional scale representing relative activity of the right and left hemispheres. Higher or positive scores indicate relatively greater left activity and lower or negative scores indicate relatively greater right activity.

2.5. Attention task

Children completed a child version of the Attention Network Test (ANT; Dennis, Malone, & Chen, 2009; Rueda et al., 2004) in the experimental booth. This task is a combination of a cued reaction time (Posner, 1980) and a flanker task (Eriksen & Eriksen, 1974) designed to assess three attention networks: alerting, orienting, and executive attention. Cues are presented prior to the target flanker task, in which participants indicate the direction of a central stimulus that is accompanied by either congruent or incongruent flanking stimuli. Since the executive attention system is primarily implicated when a task involves conflicting response options such as the flanker task (Eriksen & Eriksen, 1974), we focused our analyses on the executive attention system only, measured as the degree of conflict interference during the ANT (detailed further below).

Participants were seated approximately at a distance of 65 cm from a personal IBM computer with a 14-in. monitor (Windows XP) in a dimly lit room. The ANT was presented using E-Prime software (Psychological Software Tools, Pittsburgh, PA). Based on previous studies (Birk, Dennis, Shin, & Urry, 2011; Dennis & Chen, 2009; Dennis et al., 2009), the task was modified by briefly presenting faces (angry, happy, or neutral faces) for 200 ms prior to each trial of the task in order to create an emotional context and thus measure the degree to which distinct types of emotional faces influenced executive attention performance. Participants were presented with three experimental blocks, with each block presenting either angry, happy, or neutral faces prior to each trial of the task. Order of blocks was counterbalanced across participants. Each block consisted of 64 trials.

The original ANT designed for adults used arrows to represent the central stimuli and flankers (Fan, McCandliss, Sommer, Raz, & Posner, 2002). To make the task more relevant and interesting to young children, the central stimuli and flankers were changed to fish (Rueda et al., 2004).

Each trial of the ANT consisted of a series of events (see Fig. 1). First the emotional face stimuli (angry, happy, or neutral) were presented for 200 ms followed by a fixation cross, which was variably presented on the screen from 400 to 1600 ms. Subsequently, one of the four cueing conditions (no cue, center cue, double cue, or spatial cue) was presented for 150 ms. This was again followed by the fixation cross that was presented for 450 ms. After the fixation period, the central target along with the flankers was displayed up to 1700 ms. The final event consisted of a fixation period which was variably presented for 1000 ms. Each trial lasted for approximately 5100 ms.

The target measure, executive conflict interference, was calculated as the mean reaction time (RT) of congruent flankers subtracted from the mean RT of incongruent flankers (summed for all cueing conditions). RTs ± 2 standard deviations from the mean were replaced with sample means to account for high variability

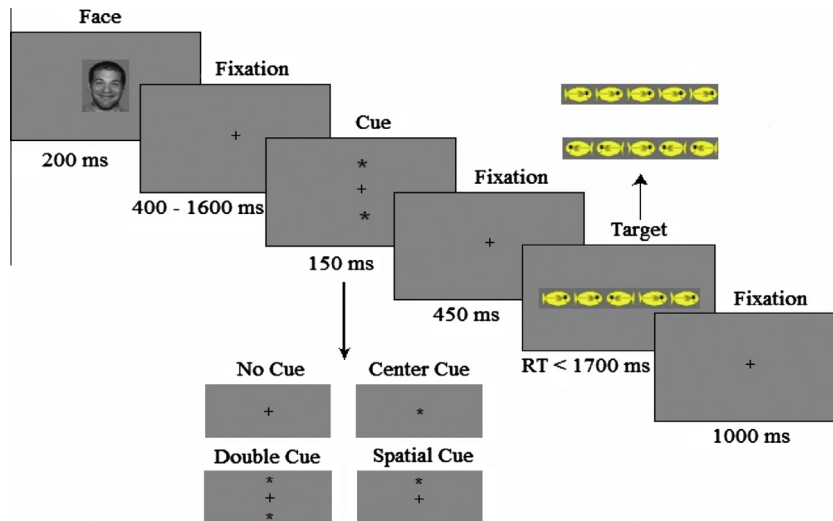


Fig. 1. Experimental procedure for the modified ANT (see also Dennis et al., 2009).

in RTs on the ANT. Higher scores indicate greater conflict interference – thereby signifying decreased or worse executive attention performance.

2.6. Emotional face stimuli

The emotional face stimuli presented at the beginning of each ANT trial were taken from a battery of faces developed by the Research Network on Early Experience and Brain Development (Tottenham et al., 2009). This battery consisted of 646 facial expressions (anger, fear, sad, neutral, disgust, and happy) modeled by male and female actors of various ethnicities. This study included 48 black-and-white photographs of angry, happy, and neutral adult faces, equally divided between the three emotion types. Actors were equally divided between males and females, and males and females were equally divided among Caucasian, African American, Latino, and Asian ethnicities. Faces were presented randomly, for a total of four times each, for each block of trials (64 per block).

2.7. Temperament questionnaire

Mothers completed the Children's Behavior Questionnaire (CBQ; Rothbart et al., 2001) to assess child characteristics on various dimensions of temperament, rating each dimension on a 1–7 Likert scale. The CBQ is a 195-item questionnaire designed to measure 15 dimensions of temperament in children aged three to seven years. The CBQ scale included in this study was NA ($\alpha = .83$). NA measures negative affective arousal and includes 5 subscales: anger, fear, falling reactivity/soothability, distress, and sadness. Sample items for NA include “has temper tantrums when he/she doesn't get what s/he wants” and “gets quite frustrated when prevented from something s/he wants to do”.

3. Results

3.1. Descriptive statistics

Descriptive statistics for all study variables are shown in Table 1. Simple Pearson zero-order correlations between EEG asymmetry, negative affectivity and executive attention scores are shown in Table 2. Asymmetry scores for anterior, anterior temporal and posterior regions were all positively associated, whereas conflict

Table 1

Descriptive statistics for asymmetry scores, NA, and executive attention (conflict interference).

	M	SD	Range
Anterior asymmetry (FC6–FC5)	.12	.42	–.76–1.12
Anterior-temporal asymmetry (T8–T7)	.14	.43	–.61–1.46
Posterior asymmetry (P8–P7)	.39	.53	–.44–1.63
Negative affectivity	6.72	3.34	3.53–18.49
Conflict interference angry	33.48	75.86	–11.97–183.91
Conflict interference happy	17.94	129.74	–226.75–385.57
Conflict interference neutral	24.82	112.25	–184.16–248.84

Note: M = mean. SD = standard deviation.

interference scores across the three emotion conditions were not significantly associated with each other. Furthermore, negative affectivity was not correlated with EEG asymmetry and conflict interference scores.

Before conducting the primary analyses, age, and gender were examined in relation to the primary measures of interests: EEG asymmetry and NA. Overall, no age differences were found for EEG asymmetry in anterior ($r = .11$, $p = .58$) and posterior ($r = .11$, $p = .58$) regions. Age was related to anterior-temporal asymmetry ($r = .35$, $p = .05$) with younger children showing greater right asymmetry. Additionally, there were associations with age and NA ($r = -.37$, $p = .05$) with younger children displaying greater levels of NA, $t(28) = 2.36$, $p = .03$. Furthermore, gender differences emerged in relation to EEG asymmetry with boys ($M = -0.04$, $SD = 0.45$) showing greater right anterior asymmetry than girls ($M = 0.25$, $SD = 0.36$), $t(29) = -2.04$, $p = .05$. No other differences emerged for anterior-temporal [$t(29) = .02$, $p = .98$] and posterior [$t(29) = .12$, $p = .90$] regions. Similarly, no gender differences were found for NA, $t(28) = -.88$, $p = .39$.

3.2. Moderation analyses

The primary hypothesis was that children showing greater NA combined with greater right asymmetry in either anterior, anterior-temporal, or posterior regions would show reduced attention performance following threat-relevant angry faces. Nine hierarchical linear regressions were conducted to evaluate the association between patterns of EEG asymmetry and attention performance. The moderator variables were EEG asymmetry for anterior (FC6–FC5), anterior-temporal (T8–T7), and posterior regions (P8–P7).

Table 2
Correlations between asymmetry scores, NA, and executive attention (conflict interference).

	1	2	3	4	5	6	7
1. Anterior asymmetry (FC6–FC5)	–						
2. Anterior-temporal asymmetry (T8–T7)	.57**	–					
3. Posterior asymmetry (P8–P7)	.43 [†]	.40 [†]	–				
4. Negative affectivity	–.10	–.01	–.06	–			
5. Conflict interference angry	.11	–.04	–.01	.02	–		
6. Conflict interference neutral	.10	–.25	.19	–.27	.21	–	
7. Conflict interference happy	–.22	.11	–.33 [†]	.02	.23	–.13	–

* $p < .05$.

** $p < .01$.

[†] $p < .10$.

Table 3
Hierarchical regression analysis for variables predicting conflict interference following angry faces ($N = 30$).

Variable	<i>B</i>	<i>SE B</i>	β
Negative affectivity (NA)	2.42	3.97	.04
Anterior-temporal asymmetry	–11.29	36.63	–.05
Anterior-temporal asymmetry \times NA	–36.48	12.27	–.50**
R^2	.26		
<i>F</i> for change in R^2	8.84**		

** $p < .01$.

The dependent variables were executive attention following angry, happy, and neutral faces. NA scores were entered in the first step followed by EEG asymmetry in the second step of each regression.¹ The final step of each regression was the interaction between NA and EEG asymmetry scores (see Tables 3 and 4).

Given recommendations concerning probing interaction effects (Aiken & West, 1991; Finney, Mitchell, Cronkite, & Moos, 1984), if interaction terms' contributions to R^2 approached significance ($p = .10$), the interactions were followed up with the PROCESS macro for SPSS (Hayes, 2013) by using simple regression equations. The dependent variable on the *y*-axis (attention performance) was plotted against three levels of the predictor (NA): two standard deviation below the mean (low), 0 (mean value), and two standard deviation above the mean (high). Plotted regression lines represent primarily right (two standard deviations below the mean for moderator variable) or left (two standard deviations above the mean for moderator variable) asymmetry and a simple slopes analysis was conducted to determine whether the slope of each regression lines was significantly different from zero. For all steps of the analyses, predictor variables were centered to reduce problems of lack of invariance of regression coefficients and multicollinearity.

3.2.1. Anterior asymmetry

No significant effects emerged.

3.2.2. Anterior-temporal asymmetry

Predictors explained significant variance in conflict interference following angry faces for the regression with EEG asymmetry in anterior-temporal regions [$F(3,26) = 2.99$, $p = .049$, $R^2 = .26$]. As predicted, there was a significant interaction between EEG asymmetry for anterior-temporal electrodes and NA following angry faces [interaction step change statistics: $F(1,26) = 8.84$, $p = .006$, $R^2 = .25$; interaction coefficient: $t = -2.97$, $p = .006$]. As seen in Fig. 2, as NA increased, conflict interference following angry faces also increased, but only for those children showing greater right anterior-temporal asymmetry ($t = 2.41$, $p = .02$). Conversely, as NA

Table 4
Hierarchical regression analysis for variables predicting conflict interference following neutral faces ($N = 30$).

Variable	<i>B</i>	<i>SE B</i>	β
Negative affectivity (NA)	–7.59	5.56	–.23
Anterior-temporal asymmetry	–17.61	46.70	–.09
Anterior-temporal asymmetry \times NA	–40.62	21.32	–.43 [†]
R^2	.22		
<i>F</i> for change in R^2	3.63 [†]		

* $p < .05$.

[†] $p < .10$.

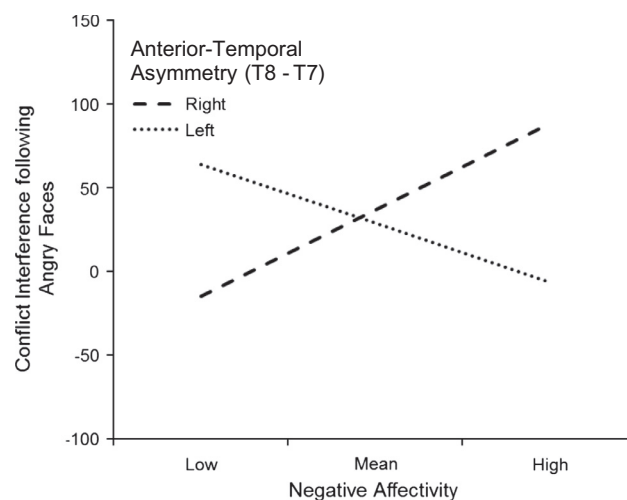


Fig. 2. Negative affectivity \times anterior-temporal asymmetry predicting conflict interference following angry faces.

increased, conflict interference following angry faces decreased, but only for those children showing greater left anterior-temporal asymmetry ($t = -1.97$, $p = .06$).

No significant effects emerged for attention performance following happy and neutral faces.

3.2.3. Posterior asymmetry

Predictors explained significant variance in conflict interference following neutral faces for the regression with EEG asymmetry in posterior regions at the level of a trend [$F(3,26) = 2.42$, $p = .09$, $R^2 = .22$]. There was a marginally significant interaction between EEG asymmetry for posterior electrodes and NA following neutrals faces [interaction step change statistics: $F(1,26) = 3.63$, $p = .07$, $R^2 = .11$; interaction coefficient: $t = -1.91$, $p = .07$]. As seen in Fig. 3, as NA increased, conflict interference following neutral faces decreased, but only for those children showing greater left posterior asymmetry ($t = -2.40$, $p = .02$). The slope for right posterior asymmetry was not significant ($t = 1.07$, $p = .30$).

¹ Regressions with age and gender entered in the first step did not differ from the reported results, thus were not included in the analyses.

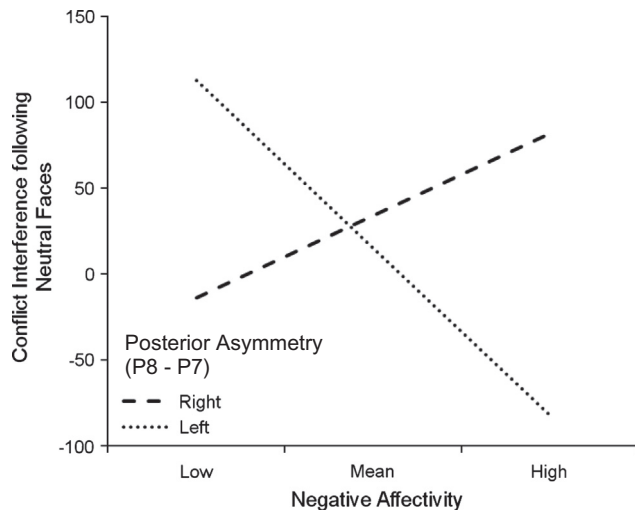


Fig. 3. Negative affectivity \times posterior asymmetry predicting conflict interference following neutral faces.

No significant effects emerged for attention performance following angry and happy faces.

3.3. Mediation analyses

To explore the hypothesis that children's asymmetry mediates the relationship between NA and conflict interference following threat-relevant angry faces we conducted a series of nine hierarchical multiple regressions using the PROCESS macro for SPSS (Hayes, 2013). This procedure tests the product of the coefficient for (α) the effect of the independent variable (NA) to the mediator (asymmetry) with (β) the effect of the mediator to the dependent variable (conflict interference) when the independent variable is taken into account. The 95% confidence interval for the direct path ($\alpha\beta$) was calculated; an overlap with zero indicates no significant mediation effects (MacKinnon, Fairchild, & Fritz, 2007; MacKinnon, Lockwood, Hoffman, West, & Sheets, 2002).

No significant effects emerged.

4. Discussion

The present study examined NA and EEG asymmetry in relation to executive attention performance following emotional stimuli. As predicted, we found that greater NA along with greater right anterior-temporal EEG asymmetry was associated with more attention interference following angry faces. Conversely, as might be expected, greater NA along with greater left anterior-temporal EEG asymmetry was associated with less attention interference following angry faces. A novel finding also emerged in which greater NA along with greater left posterior EEG asymmetry was associated with less attention interference, but only following neutral faces. Findings have the potential to extend the existing literature on the links between NA and disruptions in attention to emotion, and the neurophysiological substrates for these associations. Moreover, findings may shed light on the neural processes through which temperamental NA confers risk for later affective psychopathology.

Before testing study hypotheses, we examined associations among all study variables as well as age and gender effects. Asymmetry scores for anterior, anterior-temporal and posterior regions were all positively associated. This finding counters studies that have found inverse associations between anterior and posterior regions (Davidson, Schaffer, & Saron, 1985). However, these findings have typically been based on measuring EEG asymmetries

during a cognitive performance task (Davidson & Hugdahl, 1996; Davidson et al., 1985). Other studies, in contrast, have found that EEG asymmetries observed during a resting baseline may reflect relatively independent cortical processes (Hoptman & Davidson, 1998), which may account for concomitant increases in the activity of anterior, anterior-temporal and posterior regions, rather than expected inverse associations. In a pediatric sample, in particular, as specialization of discrete cortical regions mature through both segregation and integration of cognitive control networks (Fair et al., 2007), the inverse link between anterior and posterior functions may become less variable and more robust.

Correlational analyses also revealed that associations between EEG asymmetry and NA scores did not reach significance. This finding is in line with studies that have not found a relation between EEG asymmetry and dispositional negative and positive affect (Harmon-Jones & Allen, 1998), suggesting that these broad constructs may not directly map onto specific patterns of EEG asymmetry. Indeed, as suggested by our moderation analyses, dispositional affective tendencies like NA and EEG asymmetry may represent orthogonal and interacting individual differences that are rapidly maturing and changing during this developmental period. This is interesting to consider in light of age-related differences found in NA – specifically, that younger children displayed more NA than older children. This age shift is likely linked to the ongoing development of cognitive and emotional skills that support affect regulation (Forbes, Fox, Cohn, Galles, & Kovacs, 2006).

In addition to age differences, gender differences emerged with boys showing relatively greater right anterior asymmetry and girls showing relatively greater left anterior asymmetry. Such patterns of asymmetry may reflect the tendency for males to use more visuospatial processing, which relies heavily on the right hemisphere, and females to use more verbal processing which relies heavily on the left hemisphere (Bryden, McManus, & Bulman-Fleming, 1994; Shankman et al., 2005). However, age and gender did not influence primary study hypotheses, and thus cannot be used to interpret key findings. Counter to study hypotheses, no significant effects emerged for children showing high NA and greater anterior asymmetry. Though studies with adults have typically found an association with NA and anterior asymmetry, it is likely that ongoing development of the frontal cortex during early childhood could lead to variability in how basic cognitive processes such as attention are represented in the brain. Indeed, given the relative immaturity of the prefrontal cortex, young children may utilize more posteriorly-mediated control processes compared to adults (Casey et al., 2000; Segalowitz & Davies, 2004). This variability and posterior-shift of cognitive control in early development is consistent with our finding that children showing high NA and greater right anterior-temporal asymmetry showed more attention interference (worse executive attention) following the presentation of threat-relevant angry faces. Conversely, children showing high NA and greater left anterior-temporal asymmetry showed less attention interference (better executive attention) following the presentation of threat-relevant angry faces, although this finding was at the level of a trend ($p = .06$). Indeed previous asymmetry research has linked patterns of greater right anterior asymmetry with affective and anxiety disorders in adults (Davidson, Marshall, Tomarken, & Henriques, 2000) and school-aged children (Baving, Laucht, & Schmidt, 2003). In that same vein, research on negative emotionality has documented associations with attention biases – a propensity to be hypersensitive to threatening stimuli – and a risk for the development of anxiety disorders (Caspi, Henry, McGee, Moffitt, & Silva, 1995; Derryberry & Reed, 2002). Taken together, the present findings could reflect the links between attentional biases to threat and NA in children (Dennis & Chen, 2007, 2009; Derryberry & Reed, 1997, 2000), which could ultimately influence developmental trajectories towards affective

psychopathology. In the present study, the predicted interference effect by angry faces may indicate that those children with high NA and right anterior-temporal asymmetry had exaggerated attention and reactivity to the threat-relevant angry faces. This in turn would detract from the ability to allocate their attentional resources to the subsequent target attention task (Derryberry & Reed, 1998).

Children with high NA and left anterior-temporal asymmetry performed better following the presentation of threat-relevant angry faces. These findings appear to be consistent with previous research that has linked greater left anterior asymmetry to the processing of social threat and approach-related emotions such as anger (d'Alfonso, van Honk, Hermans, Postma, & de Haan, 2000; Fox & Davidson, 1988; van Honk et al., 2002). Anger is an emotion that has been associated with heightened approach tendencies, which in turn can motivate an individual to respond to threat in a constructive and vigilant manner (Berkowitz, 1993; Harmon-Jones & Allen, 1998) thereby increasing children's performance on the task. This interpretation is bolstered by the timing of the task: emotional stimuli (angry faces) were briefly presented for 200 ms prior to each trial of the attention task, suggesting enduring capture of attention by threat. We also examined whether posterior asymmetry moderated the impact of NA on attention. First, the non-significant main effect of posterior asymmetry showed that greater posterior asymmetry was not associated with attention interference following neutral faces. However, the trend-level interaction between posterior asymmetry and NA further specified that for children showing high NA, greater left posterior asymmetry was associated with *decreased* attention interference (better executive attention) following neutral faces. This suggests that in the context of high temperamental NA, greater left posterior activation (or decreased right posterior activation) represents a biological individual difference that may reduce emotional interference on attention. It is interesting that this effect of posterior asymmetry emerged only for neutral faces, but is consistent with the suggestion that neutral faces are inherently ambiguous (Thomas et al., 2001) and may be interpreted as either novel or threatening by those with exaggerated NA.

Results should be interpreted in the context of some study limitations. First, the sample used in this study consisted of typically developing children, thus limiting the generalizability of results. A second limitation was the inclusion of emotional stimuli that are not strongly arousing. Future research should also examine more salient and arousing affective stimuli, such as complex emotional pictures. The use of more arousing emotional pictures, or the inclusion of mood inductions in the design, may elicit stronger associations between EEG asymmetry in anterior and posterior regions and emotional interference effects. For example, one study found that using negative emotional film clips prior to recording EEG resulted in greater right posterior activity – indicating increased emotional arousal (Aftanas & Pavlov, 2005) and that EEG asymmetry moderated the impact of mood induction on attention interference effects (Dennis & Solomon, 2010).

Findings from this study highlight the potential utility of using EEG asymmetry in the study of emotion and attention, and extend the existing literature on EEG asymmetry and NA and its relation to biased attention and attention interference effects in children. Attention was targeted in the present study because impaired attention has been considered one of the cardinal features in the DSM-IV for depression and anxiety. Individuals who allocate excessive neural resources to “threatening stimuli” – in the case of individuals with anxiety related disorders – may have difficulty allocating further resources to other tasks that have attentional demands (Ferneyhough, Kim, Phelps, & Carrasco, 2012). Similarly, individuals who allocate excessive neural resources to disengage from emotional stimuli during attention demanding tasks may be

at an increased risk for developing affective psychopathologies (e.g., anxiety and depression; Mathews & MacLeod, 2002). Future studies could investigate these individual differences in affective style and its effect on attention using EEG as a measure that is sensitive to the interaction between cognitive, affective, and attentional processes. In addition, results may have implications for understanding how temperament confers risk for adaptive and maladaptive emotional attention in children.

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