THE MODERATION OF EEG ASYMMETRY ON ATTENTION BIAS PATTERNS BY ATTENTIONAL CONTROL CAPABILITIES IN EARLY CHILDHOOD

by

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Dedication

This is dedicated to my amazing wife, Elizabeth and our wonderful son, Harrison. They have taught me more about growth, change, and positive outcomes than I could ever have learned on my own.

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I would like to thank my family and friends for their tireless support through this process. I would especially like to thank my dissertation committee for their invaluable help and advice: Dr. Perez-Edgar, Dr. Curby, and Dr. Thompson.

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Abstract

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Frontal electroencephalogram (EEG) asymmetry, attention biases to threat, and individual differences in attentional focusing have all been linked to socio-emotional behavior and the development of social information processing in children (Rothbart & Posner, 2006). Children with right frontal EEG asymmetry are generally found to be more socially withdrawn than children with left frontal EEG asymmetry, who tend to be more approach-oriented (Fox et al., 2008). A separate literature finds that children who preferentially direct their visual attention to threatening or negative stimuli in the environment are more withdrawn and anxious (Bar-Haim et al., 2007). Regulatory mechanisms, such as the ability to focus attention, may moderate reactive traits, such as EEG asymmetry and attention biases to threat (Rueda, Posner, & Rothbart, 2005). This study investigated the relation between psychophysiological (EEG asymmetry) and cognitive (attention bias) mechanisms of socio-emotional development as a function of individual differences in attentional focusing in a sample of 31 children (15 female).

Introduction

Temperament can be defined as biologically-based individual differences in emotional reactivity to social and affective cues in the environment. These individual differences in reactivity are coupled with temperament-based differences in the ability to regulate these initial responses (Rothbart, Ellis, & Posner, 2004). The balance between reactivity and regulation co-develops through early childhood and forms the foundation of personality (Rothbart & Posner, 2006). Recent work suggests that the ability to focus attention may play a central role in the regulation of affective responses (Rothbart, Sheese, & Posner, 2007; Rueda, Posner, & Rothbart, 2005). Regulatory mechanisms may be able to alleviate the deleterious effects of negative reactivity on socio-emotional functioning (Reinholdt-Dunne, Mogg, & Bradley, 2009). The current paper aims to study the interaction of cognition and emotion in an early childhood sample using cognitive, parent-report, and psychophysiological measures of reactivity and regulation.

Temperament

One of the most commonly accepted models of temperament focuses on biologically-rooted variations in reactivity and self-regulation (Rothbart & Derryberry, 1981; Posner & Rothbart, 2007). Temperament develops over time through the maturation and interaction of these two factors and is influenced by genetic, environmental, and experiential variables (Posner & Rothbart, 2007).

Reactivity. There is a high degree of variance in the intensity with which infants outwardly express their emotions in response to sensory stimulation (Cole, Martin, & Dennis, 2004). High levels of negative emotional reactivity are associated with poor socio-emotional functioning and increased risk for anxiety and depression (Belsky, Fearon, & Bell, 2007; Perez-Edgar & Fox, 2005; Puliafico & Kendall, 2006).

Individual differences in the experience of emotion are, in turn, linked to variations in the underlying neural systems, particularly the limbic system (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001; Perez-Edgar et al., 2007; Schwartz, Wright, Shin, Kagan & Rauch, 2003). The amygdala, among other limbic structures, is thought to be the gateway to the brain's activation of inhibition and approach behaviors and the trigger for the fight or flight response rooted in the sympathetic nervous system (Fox et al., 2001; Fox, Henderson, Perez-Edgar, & White, 2008). In particular, individuals with a history of temperamental hyper-reactivity show elevated amygdala response to social stimuli, particularly faces (Perez-Edgar et al., 2007; Schwartz et al., 2003). This neural hyper-responsivity is coupled with a unique pattern of central nervous system reactivity to negative emotional stimuli (Dannlowski et al., 2009) seen in differences in heart rate, heart rate variability, vagal tone, skin conductance, salivary cortisol levels, and motor behaviors (Fox et al., 2008). The noted link between early negative reactivity and the subsequent emergence of anxiety is supported, in part, by this stable and unique pattern of neural and psychophysiological functioning (Kagan, Snidman, & Arcus, 1993).

Regulation. Self-regulation involves the processes of modulating initial reactivity, including differences in the tendency to approach or avoid evocative people and events, inhibition in the face of stress, and cognitive self-control (Rueda, Posner, & Rothbart, 2005). This broad construct is often characterized as effortful control, or the ability to inhibit a prepotent response and perform a subdominant one (Rothbart, Sheese, & Posner, 2007). Individuals who generate more powerful internal, reactive responses will require more potent regulation strategies in order to counter initial reactivity and function adaptively.

During infancy, a child's behavioral reaction is often directly related to the underlying physiological response (Goldsmith et al., 2004). Thus, when infants are overwhelmed by emotions, they are forced to seek external support for comfort and soothing. With development, he or she must learn to regulate his or her own thoughts and behaviors. In this way, regulation can be seen as a developmental process that begins externally and moves internally to facilitate social interaction (Thompson & Goodvin, 2007).

Underlying this behavioral shift is an associated, evolving, neural network. Based on the large number of connections between the amygdala and the prefrontal cortex (PFC), researchers have suggested that the PFC is in part responsible for regulating the activity of the amygdala (Davidson, 2004; Kim & Hamaan, 2007; Quirk et al., 2003). The regulation of affect has been linked with several areas of the PFC, including the anterior cingulate cortex (ACC), ventrolateral, orbitofrontal, and dorsomedial PFC (Feng, Shaw, Kovacs, Lane, O'Rourke, & Alarcon, 2008; Fox et al., 2008).

Attentional Control

As children are learning to regulate their internal physiological responses, the cognitive resources utilized to scan the environment and resolve conflicts are also developing (Bell & Wolfe, 2007). While external support provides the foundation of regulation, Posner and Rothbart (2007) assert that it is the development of neurobiological systems of attention that truly drives advanced effortful control abilities. Specifically, the maturation of the executive control network is thought to be necessary for the transition from external to internal sources of regulation (Rueda, Posner, & Rothbart, 2005). Executive control involves activating and inhibiting other attention networks when presented with competing stimuli or responses to focus attention, plan reactions, and inhibit impulses in order to achieve goals (Fan et al., 2002; Rueda, Sheese, & Posner, 2007). This top-down conflict-resolution network is activated during tasks similar to the classic Stroop task (Stroop, 1935) and includes the lateral PFC, basal ganglia, and the ACC (Posner & Rothbart, 2007; Wang & Fan, 2007).

Infants are initially unable to inhibit impulses in reaction to salient stimuli, but begin to first use attention shifting as a method for self-soothing and escaping overstimulation (Rueda et al., 2004). The ability to disengage attention from upsetting thoughts and stimuli is a key component to affect regulation. Early in life, caregivers work to distract infants from negative emotions and shift their attention to pleasant experiences to help them maintain adaptive levels of arousal (Fox et al., 2008; Rueda, Posner, & Rothbart, 2005). This capacity to control physiological arousal emerges in the first year as the executive control attention system and the PFC develop and becomes the foundation for attentional control and focusing abilities.

Children improve in their ability to perform conflict-based tasks throughout early childhood, especially as they enter formalized schooling (Wolfe & Bell, 2007). From age 4 to 7, the rapid development of attention and regulation abilities facilitate academic success and social interaction (Calkins, 2007; Fox et al., 2008; Posner & Rothbart, 2007; Rueda, Posner, & Rothbart, 2005; Simonds, et al., 2007). By age 7, reaction times and conflict scores in laboratory attention tasks suggest a high similarity in the efficiency of the executive control network compared to adults (Posner & Rothbart, 2007; Rueda, Posner, & Rothbart, 2005). At the same time, the neocortex continues to mature, helping the individual inhibit behavior when necessary and maintain emotional control (Bjorklund & Harnishfeger, 1995; Kochanska, Coy, & Murray, 2001).

The development of the PFC and attention focusing thus become the foundation for the internalization of effortful control during the entrance into formal schooling. The foundation of this integration of cognition and emotion lies in the neural structures employed by these two processes in the PFC (Rothbart, Sheese, & Posner, 2007). Measures of electroencephalogram activity (EEG) taken from the surface of the head are theorized to reflect neural activity in these underlying cortical and subcortical structures. The literature suggests that asymmetrical patterns of frontal EEG activity represent an underlying disposition to approach (left-asymmetry) or withdraw (right-asymmetry) from challenging or novel situations (Harmon-Jones, Gable & Peterson, 2010), reflecting the PFC-amygdala relation noted above. These patterns of frontal activation are influenced by both cortical (PFC) and subcortical (ACC and limbic system) structures. Thus, they include both reactivity and regulation components and reflect emotional and cognitive processes occurring simultaneously (Wolfe & Bell, 2007).

EEG Asymmetry

Patterns of frontal EEG asymmetry across the right and left frontal lobes are captured by calculating a difference score from the respective levels of activation from the left and right side of the prefrontal cortical area (Harmon-Jones et al., 2010; Silva, Pizzagalli, Larson, Jackson, & Davidson, 2002). Individuals with greater activation of the right as compared to the left frontal cortical areas are considered to display right frontal asymmetry, while those displaying greater activation of the left as compared to the right frontal cortical areas are considered to display left frontal EEG asymmetry (Silva, et al., 2002). Individual differences in emotion and behavior are related to the interaction of the "accelerator" aspects of the right hemisphere and "braking" aspects of the left hemisphere through infancy and toddlerhood (Rothbart & Posner, 2006). It is posited, therefore, that greater left activation of the prefrontal cortex can indicate greater amygdala inhibition while greater right activation of the PFC can indicate less inhibition of the amygdala (Davidson, 2004).

In support of this conceptualization, studies have found that frontal EEG asymmetry may be reduced or exacerbated through experimental manipulation of affect

(Field et al., 1998; Schmidt, Fox, Schulkin, & Gold, 1999), often with the presentation of negative stimuli (e.g., sad movies) (Davidson & Fox, 1982; Harmon-Jones & Sigelman, 2001). EEG asymmetry patterns are also dependent on individual differences in socioemotional characteristics from infancy through young adulthood (Fox & Reeb, 2008). As such, behaviorally inhibited, anxious or depressed children and adults have all been shown to exhibit right frontal EEG asymmetry (Baving, Laucht, Schmidt, 2002; Buss et al., 2003; Davidson & Fox, 1989; Diego, Field, & Hernandez-Reif, 2001; Fox et al., 1995; Henriques & Davidson, 1991; Thibodeaua, Jorgensena & Kima, 2006). These patterns of EEG asymmetry become increasingly stable as children move from preschool and begin formal education (Vuga, et al., 2008).

Attention Bias to Threat

Along with these individual differences in EEG activity, the literature indicates that children exhibiting strong initial reactions to environmental stimuli also display preferences in their allocation of attention to salient stimuli (Carlson & Rienke, 2008; Mogg, Bradley, & Williams, 1995; Perez-Edgar & Fox, 2005). As social, communicative creatures, we are naturally attracted to faces and our attention is preferentially directed toward emotional faces more than neutral faces (Mogg et al., 1995). There also appears to be an attentional advantage for negative stimuli (e.g. fear and anger) versus positively-charged faces/cues as negative stimuli often convey information about danger in the environment, while most positive stimuli do not carry messages that directly influence survival (Brosch et al., 2008; LoBue & DeLoache, 2008). The literature suggests that highly reactive clinical and non-clinical populations of adults and children display an attention bias toward threatening stimuli (e.g., angry faces) as opposed to neutral stimuli (Bradley, Mogg, White, Groom, & de Bono, 1999; Mogg et al., 1995). Strong attention biases to threat have been linked to elevated levels of emotional reactivity and suppressed regulation capabilities (Mogg & Bradley, 1998; Rothbart & Posner, 2006).

If an individual consistently directs their attention to the most threatening aspects of the environment and reacts intensely to them, that person may be more prone to subsequently encode and rehearse negative emotions and behaviors. In this way, stable biases to threat, even if subtle, may produce individual differences in broad patterns of socio-emotional functioning via cascading and self-reinforcing biases in social cognition and behavior (Rapee, 2002). Indeed, there is growing agreement that attention biases to threatening or negative emotional stimuli early in life may be the mechanism through which the development of poor socio-emotional functioning emerges (Carlson & Reinke, 2008; Lonigan et al., 2004; Mogg & Bradley, 1998; Mogg, Philippot et al., 2004; Rothbart & Posner, 2006; Waters et al., 2010).

Supporting the relations between attention bias patterns and patterns of socioemotional functioning, recent work in adults (Schutter et al., 2001; Miskovic & Schmidt, 2010) has found that EEG activity is linked to attention bias. For example, Miskovic and Schmidt (2010) found that individuals with right frontal EEG asymmetry were more likely to display an attention bias to threat. To date, no published studies have examined these relations in children. As such, it is uncertain if frontal EEG asymmertry can predict attention bias scores in the first years of life. Such a relation would support models linking patterns of reactivity and attention to subsequent socioemotional functioning.

In addition, there are inconsistencies in the literature regarding the presence and direction of the affect-attention bias link (Bar-Haim et al., 2007; Bar-Haim et al., 2010; Bradley, Mogg, Falla, & Hamilton, 1998; Wald et al., in press). Lonigan and Vasey (2009) suggest that the documented heterogeneity in this relation may be due to uncaptured moderators, particularly individual differences in effortful control. As previously mentioned, the foundation for effortful control in early childhood lies in the development of attention focusing capabilities (Rueda, Posner, & Rothbart, 2005; Zhou et al., 2007).

Current Study

The literature suggests that the links between temperament, attention bias, and social functioning are early appearing and may be fairly stable over time. Given that individual differences in reactivity (reflected in EEG asymmetry and attention bias patterns) are implicated in socio-emotional development, it is useful to study this relationship beginning at an early age. As noted above, right frontal EEG asymmetry has been linked to increased attention bias to threat in adults (Miskovic & Schmidt, 2010). To date, no study has examined the equivalent pattern in young children. Regulatory aspects of temperament have been found moderate the relation between reactivity and the allocation of attention in adults (Lonigan et al., 2004; Lonigan & Vasey, 2009; Reinholdt-Dunne, Mogg, & Bradley, 2009). Attention focusing may play this role for school-age children, acting as a moderator of the influence of EEG asymmetry on attention bias to threat. As such, our goal was to examine how psychophysiological measures of reactivity/regulation (EEG asymmetry) relate to cognitive measures of social information processing (attention bias scores) and how this relationship may be maximized under certain attention focusing conditions. We tested 3 hypotheses: (1) Children with right frontal baseline EEG asymmetry patterns should exhibit greater attention bias toward threatening stimuli relative to children with left frontal EEG asymmetry. (2) Individual differences attention focusing skills will moderate the influence of EEG asymmetry on attention bias to threat, in that higher levels of attention focusing will mitigate attention bias scores in children with right frontal EEG asymmetry. (3) Significant findings should be specific for threatening faces and should not transfer to happy bias scores.

Method

Participants

Participants were 57 children (25 female) aged 4 to 7 years (M=5.58, SD=0.625). This sample was selected from a larger participant pool characterized by Colorado Child Temperament Inventory (CCTI) and the Behavioral Inhibition Questionnaire (BIQ) in order to ensure a range of temperamental traits. Of this sample, 31 children (15 female) aged 4 to 6 years (*M*=5.58, *SD*=0.62) had complete data for all of the central measures. From the initial sample of 57: 17 participants were missing EEG data due either to refusal to wear the cap or poor data collection; 2 subjects did not complete the dot probe task; and 6 subjects who completed the dot probe task had an accuracy of less than 60%. One final participant was removed because their asymmetry score was more than 3 standard deviations from the mean.

The average accuracy on the dot probe was 82.74 (SD=12.22) for the analysis sample (N=31) and 82.37 (SD=11.3) for the full sample (N=51, excluding those with less than 60% accuracy). The final sample did not differ from the excluded children on age, gender, or the central measures of interest (p's > .10). The sample was comprised of 78% White, Non-Hispanic participants. Table 1 notes the mean and standard deviation values for age and the central constructs: EEG Asymmetry, Threat Bias, and Attentional Focusing.

Electroencephalogram (EEG) Recording

Electroencephalogram measures were recorded from 64 EEG and EOG channels, using the Lycra NeuroScan Quick-cap system (NeuroScan, Texas, USA). EEG channels were referenced to an electrode 2 cm posterior to Cz. Vertical eye movements (VEOG) were collected through electrodes placed above and below the left eye, while horizontal eye movements (HEOG) were collected through electrodes placed on the external canthi of each eye. Researchers attempted to keep all electrode impedances below 10 K ohms. The data from each channel were digitized at a 500 Hz sampling rate (High pass 0.10 Hz; Low pass 40 Hz). The digitized EEG data were manually inspected and channels with unreliable EEG signals were removed. The data were then re-referenced to produce an average reference configuration. Portions of the EEG data contaminated with eye movement or motor artifact were automatically removed from all channels using predetermined parameters (e.g., signal ±100 μV). The re-referenced, artifact-free EEG data were submitted to a discrete Fourier transform using a 1-s Hanning window with 50% overlap between consecutive windows.

EEG Asymmetry Calculation

Baseline EEG measures were collected at rest across the entire scalp, while subjects sat at rest with eyes open for two minutes. Data analysis focused on the F3 and F4 frontal electrodes (Silva et al., 2002). For each electrode site, alpha power was computed as the natural logarithm of power in the 8-13 Hz frequency band; asymmetry scores were then calculated by subtracting the natural log of alpha power from the left electrode (F3) from the corresponding electrode over the right hemisphere (F4).

As alpha asymmetry is thought to be inversely related to brain activity, a positive score reflects greater relative right-sided power (or increased left-sided activity), whereas a negative score reflects greater relative left-sided power (or increased right-sided activity) (Davidson, 2004). Participants were divided into Right (N=15) and Left (N=17) EEG asymmetry groups for the categorical analyses (see below).

Dot Probe Task

Participants completed a computer-based dot-probe task consisting of 96 trials, separated into two blocks of 48 trials each. Trials began with a fixation cross presented in the center of the screen for 500 milliseconds (ms). Next, a pair of photographs of the same face appeared flanking the fixation point for 500 milliseconds. After the face pair disappeared, a white target asterisk was visible on either the left or right side of the screen in a location previously occupied by one of the face pictures. Subjects were instructed to respond to the target (or probe) as quickly as possible.

Facial stimuli utilized in the experiment were part of the NimStim collection (Tottenham et al., 2009) and displayed either a happy, angry, or neutral emotional expression. Face pairs fell into three types: an angry face coupled with a neutral face, a happy face with a neutral face, or two neutral faces. On congruent trials, the target asterisk appeared in the same location as the happy or angry face. On incongruent trials, the cueing face and asterisk were on opposite sides of the screen. Neutral-neutral face pairs were used as control trials in the dot-probe task. Trial congruency was also counterbalanced throughout the task.

Individual attention bias scores were computed for each child by subtracting mean reaction times on congruent trials from mean reaction times on incongruent trials for angry-neutral and happy-neutral face pairs. These attention bias scores indicate the degree to which each subject avoids or shows vigilance toward threatening faces. A negative bias score suggests that the participant directed their attention away from the corresponding emotional stimuli, while a positive value implies the subject's attention is deployed toward the emotion face.

Child Behavior Questionnaire

Attention focusing was assessed via parent-report with the Child Behavior Questionnaire (CBQ) (Rothbart et al., 2001). This questionnaire includes 195 items designed to gauge patterns of reactivity and regulation in children aged 3 to 7 years old. Parents are asked to indicate how well statements (e.g. Often prefers to watch rather than join other children in playing) describe their children using a 7-point Likert scale with 1 (*extremely untrue*) to 7 (*extremely true*). Reported alpha values for attention focusing range from 0.67 with 4-5 year olds to 0.69 with 6-7 year olds (Rothbart et al., 2001). Children were median split into Low (N=15) and High (N=17) attention focusing groups.

Results

Analyses

The analyses for these data relied on both an ANOVA and a regression model to represent EEG asymmetry values as categorical and continuous variables. In the literature, EEG asymmetry values have been represented both ways in studies demonstrating significant, theory-driven results (Harmon-Jones et al., 2010).

ANOVA. A three-factor mixed-measures ANOVA was carried out including EEG asymmetry (right or left) and attention focusing (low or high) as between-subjects variables; affective face (threat or happy) as a within-subjects variable; and attention bias scores as the dependent variable.

There was a significant main effect of face type, $F(1, 27)=5.04$, $p=0.03$, $d=0.85$, such that happy bias scores indicated avoidance while threat bias scores pointed to vigilance (-17.15 vs. 10.2; See Table 1). The significant main effect of attention focusing also indicated that bias scores (to both happy and angry faces) were also significantly higher (vigilant) for the low, versus the high, attention focusing group, $F(1, 27)=5.19$, $p=0.03$, $d=0.85$ ($M=13.33$ vs. -19.71).

Children with right versus left frontal EEG asymmetry were not significantly different in their attention bias scores, $F(1, 27)=1.03$, $p=0.32$, $d=0.43$. The interaction between EEG asymmetry and face type was also non-significant, $F(1, 27)=0.64$, $p=0.8$,

d=0.18, suggesting those with right-asymmetry were not more vigilant to threat faces.

The three-way interaction between EEG asymmetry, attention focusing, and affective face was not significant, $F(1, 27)=0.34$, $p=0.56$, $d=0.13$, indicating that attention did not moderate the influence of EEG asymmetry on bias to threat.

Regression. A multiple linear regression was conducted to predict attention bias scores. The predictors were entered hierarchically in the following order: (i) EEG asymmetry values, (ii) attention focusing scores, and (iii) an interaction term of EEG asymmetry by attention focusing. Predictive measures were mean-centered for use in the regression. Two separate models were completed for bias scores to threat and happy faces.

In predicting attention biases to threat, the first full model accounted for 37.4% of the total variance, $F(3,30)=5.38$, $p=0.005$ (see Table 2). EEG asymmetry significantly predicted attention biases, accounting for 13% of the variance, $\Delta F(1, 29)=4.33$, $p=0.046$. This reflected a significant negative zero-order correlation between EEG asymmetry and attention biases to threat, $r(31)=-0.36$, $p=0.046$ (see Table 3). The main effect of attention focusing was significant with 11.2% of the variance explained, $\Delta F(1, 28)=4.14$, $p=0.05$. Further, attention focusing was not related to age in our sample, $r(31)=-.1$, $p=.59$.

The interaction between EEG asymmetry and attention focusing significantly predicted threat bias scores, $\Delta F(1, 27)=5.71$, $p=0.02$. Given our *a priori* hypotheses, we further examined this interaction by dividing the sample in to the high and low attention focusing groups noted above. For the children with low levels of attention focusing, the correlation between EEG asymmetry and attention bias to threat was non-significant, *r*(15)=-0.23, *p*=0.42. However, for the children with high levels of attention focusing increases in right frontal EEG asymmetry were associated with increases in attention biases to threat, *r*(16)=-0.57, *p*=0.02.

The equivalent regression model predicting happy bias scores was non-significant, $F(3,30)=2.58$, $p=0.07$, accounting for only 22.3% of the variance (see Table 2). None of the predictors (individually or in interaction) were significant, ΔF's < 3.24, ΔR's < 9.3%, p's > 0.08.

Discussion

The current study predicted that young children with right frontal EEG asymmetry at baseline would exhibit greater vigilance to angry faces than children with left asymmetry due their inherent predilection for emotionally salient social stimuli, particularly if the stimulus represents potential threat. While this tendency to direct attention to social threats can be detrimental for early social and emotional development, this process may be circumvented by emerging regulatory capabilities. Specifically, we expected that hyper-reactive young children with strong attentional control skills would show weaker biases toward threat. We further examined the specificity of these relations by directly comparing biases toward threatening (angry faces) and appetitive (happy faces) social stimuli.

In line with previous research in young children, our overall sample displayed more vigilance toward threatening faces than happy faces. This tendency to direct attention toward negatively charged or threatening stimuli has been found not only in young children and adolescents at risk for poor socioemotional development (Kujawa et al., 2010; Perez-Edgar et al., 2007, 2010, 2011), but also in broad samples of young children and adults (LoBue & DeLoache, 2008). Our results suggest that preferential attention biases to threat, known to be a risk factor for mood disorders (Mogg et al., 1995; Perez-Edgar et al., 2010), may already be evident in early childhood.

Using EEG asymmetry as a dichotomous variable (left or right), children with right frontal EEG asymmetry were not more vigilant to threatening faces. However, when represented as a continuous construct, participants with higher levels of right frontal EEG asymmetry were associated with a stronger attention bias toward threatening faces, in support of our first hypothesis. This also reflects previous research predicting attention bias to threat from frontal EEG asymmetry values in adult samples (Miskovic & Schmidt, 2010). The disparity between these analyses is likely due to the reduction of variance in creating left and right asymmetry categories (Coan & Allen, 2004). EEG asymmetry groupings may be effective in samples that represent the two extremes of left and right activation, but may fail when EEG asymmetry values reflect a continuous spectrum. The degree to which a sample represents the population in terms of frontal EEG asymmetry values could explain some of the mixed results in research investigating the relationship between temperament and attention bias (Bar-Haim et al., 2007; Wald et al., in press; Waters et al., 2010).

When median split into two groups, attention focusing did not moderate the influence of EEG asymmetry on bias to threat. However, using attention focusing as a continuous factor, a relationship between EEG asymmetry and attention bias did indeed emerge. Low levels of attention focusing were associated with bias toward threat and high levels predicted bias away from threat. Further, frontal EEG asymmetry significantly predicted attention biases to threat only for young children with high levels of attention focusing abilities. Thus, attentional control was a significant moderator in this model, but not in the expected manner (Schutter et al., 2001; Miskovic & Schmidt, 2010). Based on the literature, we predicted that the development of effortful control skills would reduce the natural tendency of children with right frontal EEG asymmetry to direct their attention to threat (Lonigan & Vasey, 2009). In previous research, we have found that effortful control measures can assuage the intensity of bias to threat for highly negative adult participants (Zapp et al., under review). Attention focusing was thought to act as this moderator for participants just entering school (Rueda, Posner, & Rothbart, 2005; Zhou et al., 2007).

However, our data indicated that participants with low levels of attention focusing were more vigilant to angry faces than their peers, regardless of their baseline frontal EEG asymmetry pattern. This tendency to remain vigilant to threatening faces could have overshadowed any link between reactivity and bias to threat in the low attention focusing group. Attention focusing does not appear to mitigate this natural affinity for salient stimuli, rather becomes the gateway through which the respective attention bias patterns of young children with right and left EEG asymmetry can emerge. A certain level of attention control may be necessary in young childhood for the relation between right frontal EEG participants and threat vigilance, as well as left frontal EEG asymmetry and threat avoidance, to emerge over the course of a laboratory task, such as the one used here. Thus attention focusing can simultaneously act as a risk factor for threat bias in children with higher levels of right frontal EEG asymmetry and a protective factor against threat bias in children with left frontal EEG asymmetry.

There are a few limitations to consider when considering the results of our study. Most importantly, due to the difficulty of obtaining viable EEG data from a very young population, a large percentage of our sample was excluded from the final analysis. While the excluded subjects did not differ from the analysis sample on the central factors of analysis, the missing data prevented us from comparing these two groups on frontal EEG asymmetry values. While it is possible that the missing EEG data not collected for participants reflects the same distribution as those for whom it was obtained, it is possible that there is a selection bias. That is, participants who refused to wear the EEG cap could represent a subsample of young children that are more reactive and withdrawn, thus possibly presenting with more right frontal EEG asymmetry than the participants included in our analysis.

Second, all of our measures were assessed concurrently during one visit and our assessments of cognition, behavior, and psychophysiological functioning could have fluctuated if our data were collected and averaged over several visits (Harmon-Jones et al., 2010). Further, attention focusing skills were solely determined from parental report and caregivers may not have been as accurate a source of information for this basic cognitive ability (Simonds et al., 2007). Finally, in studies employing the dot probe task with emotional stimuli, there is inconsistency in the use of presentation times, particularly for young subjects (Bar-Haim et al., 2007). Our findings could have been quite different if young children were exposed to emotional faces for a variety of long and short presentation times (Waters et al., 2010).

In summary, this research plays a role in the developmental models of attention bias posited by Field and Lester (2010). The integral bias model suggests that all infants are born with innate biases toward or away from threat and these do not change over time; the moderation model suggests that attention biases are a normal phenomenon for all children early in life and then either increase or decrease with time based on individual characteristics; while the acquisition model suggests that only some young children will develop attention biases to threat based on individual traits (Field & Lester, 2010). Longitudinal research is required to differentiate the moderation and acquisition models, but the findings of the current study indicate that attention focusing and EEG asymmetry are both factors which influence the development of attention bias to threat in young childhood. While our results add to the complex framework relating psychophysiological and cognitive measures to social and emotional information processing in childhood, future studies should test the veracity of the moderating influence of attention on EEG asymmetry and threat bias in samples of young children. It is imperative that researchers look beyond the assumptions of all bias to threat being maladaptive and all approach behavior being beneficial in the complex relationship between approach behaviors and avoidance behaviors in early development (Amodio et al., 2008; Coan & Allen, 2004).

Table 1. Demographic characteristics, EEG Asymmetry, Attention Bias, and Attention Focusing scores for the analysis sample as well as Low and High Attention focusing (AF) groups and Right and Left EEG Asymmetry groups. Significance markings reflect results of separate ANOVAs between groups (*p* < .05).

	Overall (n=31)	**Low AF (n=15)**	**High AF (n=16)**	**Right EEG (n=14)**	**Left EEG (n=17)**
Age	5.58 (.62)	5.73 (.46)	5.47 (.72)	5.60 (.51)	5.59 (.71)
Gender (M/F)	16/15	9/6	7/10	9/6	7/10
EEG Asymmetry	-.005 (.33)	.013 (.32)	-.02 (.35)	-.24* (.31)	.21* (.17)
Threat Bias	8.20 (46.48)	30.26* (38.17)	-7.55* (48.03)	19.33 (50.97)	2.09 (43.27)
Happy Bias	-17.24 (60.19)	-4.83 (56.68)	-28.08 (62.77)	-13.06 (47.70)	-20.76 (70.7)
Attention Focusing	4.86 (1.03)	4.06* (.79)	5.66* (.53)	5.16 (.88)	4.69 (1.15)

Table 2. Regression models predicting Threat and Happy Bias scores. Standardized beta weights, R square change and rate of F change for each of the predictors are presented. Significance markings for *p* < .05.

Predictor		**Threat Bias**	
	β	**ΔR^2**	**ΔF**
EEG Asymmetry	-.361	.130	4.34*
Attention Focusing	-.335	.112	4.14*
Interaction Term	-1.18	.132	5.70*
		Happy Bias	
	β	**ΔR^2**	**ΔF**
EEG Asymmetry	-.232	.054	1.65
Attention Focusing	-.275	.076	2.43
Interaction Term	-1.52	.093	3.24

Table 3. Correlation matrix for EEG Asymmetry, Attention Bias, and Attention Focusing scores for the analysis sample. Significance markings for $p < .05$.

	EEG Asymmetry	Attention Focusing	Threat Bias	Happy Bias
EEG Asymmetry	1			
Attention Focusing	-.005	1		
Threat Bias	-.361*	-.333	1	
Happy Bias	-.232	-.274	.222	1

References

References

Amodio, D., Master, S., Yee, C., & Taylor, S. (2008). Neurocognitive components of the behavioral inhibition and activation systems: Implications for theories of self-regulation. *Psychophysiology, 45*, 11-19.

Bar-Haim, Y., Holoshitz, Y., Eldar, S., Frenkel, T., Muller, D., Charney, D., Pine, D., Fox, N, & Wald, I. (2010). Life-threatening danger and suppression of attention bias to threat. *American Journal of Psychiatry, 167*, 694-698.

Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M.J., & van IJzendoorn, M.H. (2007). Threat-related attentional bias in anxious and non-anxious individuals: A meta-analytic study. *Psychological Bulletin, 133*, 1-24.

Baving, L., Laucht, M., & Schmidt, M. (2002). Frontal brain activation in anxious school children. *Journal of Child Psychology and Psychiatry, 43*, 265-274.

Bell, M. & Wolfe, C. (2007). The cognitive neuroscience of early socioemotional development. In C. Brownell and C. Kopp (Eds.), *Socioemotional development in the toddler years* (pp. 345-370). New York, NY: Guilford Press.

Belsky, J., Fearon, R., & Bell, B. (2007). Parenting, attention and externalizing problems: Testing mediation longitudinally, repeatedly and reciprocally. *Journal of Child Psychology and Psychiatry, 48*, 1233-1242.

Bjorklund, D. & Harnishfeger, K. (1995). The evolution of inhibition mechanisms and their role in human cognition and behavior. In F. Dempster & C. Brainerd (Eds.), *Interference and inhibition in cognition* (pp. 141-173). San Diego, CA: Academic Press.

Bradley, B., Mogg, K., Falla, S., & Hamilton, L. (1998). Attentional bias for threatening facial expressions in anxiety: Manipulation of stimulus duration. *Cognition and Emotion, 12*, 737-753.

Bradley, B.P., Mogg, K., White, J., Groom, C., & de Bono, J. (1999). Attentional bias for emotional faces in generalized anxiety disorder. *British Journal of Clinical Psychology, 38*, 267-278.

Brosch, T., Sander, D., Pourtois, G., & Scherer, K. (2008). Beyond fear: Rapid spatial orienting toward positive emotional stimuli. *Psychological Science, 19*, 362-372.

Buss, A., Schumacher, J., Dolski, I., Kalin, N., Goldsmith H., & Davidson, R. (2003). Right frontal brain activity, cortisol, and withdrawal behavior in 6-month-old infants. *Neuroscience, 117*, 11-20.

Calkins, S. (2007). The emergence of self-regulation: Biological and behavioral control mechanisms supporting toddler competencies. In C. Brownell & C. Kopp (Eds.), *Socioemotional development in the toddler years* (pp. 261-284). New York, NY: Guilford Press.

Carlson, J. & Reinke, K. (2008). Masked fearful faces modulate the orienting of covert spatial attention. *Emotion, 8*, 522-529.

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

Dannlowski, U., Ohrmann, P., Konrad, C., Katharina, D., Bauer, J., Kugel, H., Hohoff, C., et al. (2008). Reduced amygdala prefrontal coupling in major depression: Association with MAOA genotype and illness severity. *International Journal of Neuropsychopharmacology, 12*, 11-22.

Davidson, R. (2004). What does the prefrontal cortex "do" in affect: Perspectives on frontal EEG asymmetry research. *Biological Psychology, 67*, 219-233.

Davidson, R., & Fox, N. (1982). Asymmetrical brain activity discriminates between positive and negative affective stimuli in human infants. *Science, 218*, 1235-1237.

Davidson, R., & Fox, N. (1989). Frontal brain asymmetry predicts infants' response to maternal separation. *Journal of Abnormal Psychology, 98*, 127-131.

Diego, M., Field, T., & Hernandez-Reif, M. (2001). Bis/Bas scores are correlated with frontal EEG asymmetry in intrusive and withdrawn depressed mothers. *Infant Mental Health Journal, 22,* 665-675.

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

Feng, X., Shaw, D., Kovacs, M., Lane, T., O'Rourke, F., & Alarcon, J. (2008). Emotion regulation in preschoolers: The roles of behavioral inhibition, maternal affective behavior, and maternal depression. *Journal of Child Psychology and Psychiatry, 49*, 132-141.

Field, A. & Lester, K. (2010). Is there room for 'development' in developmental models of information processing biases to threat in children and adolescents? *Clin Child Fam Psychol Rev, 13*, 315-322.

Field, T., Martinez, A., Nawrocki, T., Pickens, J., Fox N., & Schanberg, S. (1998). Music shifts frontal EEG in depressed adolescents. *Adolescence, 129*, 109-116.

Fox, N., Copelan, R., Rubin, K., Porges, S., Calkins, S., Long, J., Marshall, T., & Stewart, S. (1995). Frontal activation asymmetry and social competence at four years of age. *Child Development, 66*, 1770-1784.

Fox, N., Henderson, H., Perez-Edgar, K., & White, L. (2008). The biology of temperament: An integrative approach. In C. Nelson and M. Luciana (Eds), *Cognitive Developmental Neuroscience* (pp. 839-853). Cambridge, MA: MIT Press.

Fox, N., Henderson, H., Rubin, K., Calkins, S., & Schmidt, L. (2001). Continuity and discontinuity of behavioral inhibition and exuberance: Psychophysiological and behavioral influences across the first four years of life. *Child Development, 72*, 1-21.

Fox, N. & Reeb B. (2008). Effects of early experience on the development of cerebral asymmetry and approach-withdrawal. In A Elliot (Ed.) *Handbook of approach and avoidance motivation,* (pp. 35-49). New York, NY, US: Psychology Press.

Goldsmith, H.H., Buss, A.H., Plomin, R., Rothbart, M.K., Thomas, A., Chess, S. et al. (1987). Roundtable: What is temperament? Four approaches. *Child Development, 58*, 506-529.

Harmon-Jones, E., Gable, P., & Peterson, C. (2010). The role of frontal cortical activity in emotion-related phenomena: A review and update. *Biological Psychology, 84*, 451-462.

Harmon-Jones, E., & Sigelman, J., (2001). State anger and prefrontal brain activity: Evidence that insult-related relative left-prefrontal activation is associated with experienced anger and aggression. *Journal of Personality and Social Psychology, 80*, 797–803.

Henriques, J., & Davidson, R. (1991). Left frontal hypoactivation in depression. *Journal of Abnormal Psychology, 100*, 535-545.

Kagan, J., Reznick, S., & Snidman, N. (1987). The physiology and psychology of behavioral inhibition in children. *Child Development, 58*, 1459-1473.

Kajawa, A., Torpey, D., Kim, J., Hajcak, G., Rose, S., Gotlib, I., & Klein, D. (2010). Attentional biases for emotional faces in young children of mothers with chronic or recurrent depression. *Journal of Abnormal Psychology, 39*, 125-135.

Kim S. & Hamaan, S. (2007). Neural correlates of positive and negative emotion regulation. *Journal of Cognitive Neuroscience, 19*, 776-798.

Kochanska, G., Coy, K., & Murray, K. (2001). The development of self-regulation in the first four years of life. *Child Development, 72*, 1091-1111.

LoBue, V. & DeLoache, J. (2008). Detecting the snake in the grass: Attention to fear-relevant stimuli by adults and young children. *Psychological Science, 19*, 284-289.

Lonigan, C., Vasey, M., Phillips, B., & Hazen, R. (2004). Temperament, anxiety, and the processing of threat-relevant stimuli. *Journal of Clinical Child & Adolescent Psychology, 33*, 8-20.

Lonigan, C. & Vasey, M. (2009). Negative affectivity, effortful control, and attention to threat-relevant stimuli. *Journal of Abnormal Child Psychology, 37*, 387-399.

Miskovic, V., & Schmidt, L. (2010). Frontal brain electrical asymmetry and cardiac vagal tone predict biased attention to social threat. *International Journal of Psychophysiology, 75*, 332-338.

Mogg, K., & Bradley, B. (1998). A cognitive-motivational analysis of anxiety. *Behaviour Research and Therapy, 36*, 809-848.

Mogg, K., Bradley, B., & Williams, R. (1995). Attentional bias in anxiety and depression: The role of awareness. *British Journal of Clinical Psychology, 4*, 17-36.

Mogg, K., Philippot, P., & Bradley, B.P. (2004). Selective attention to angry faces in clinical social phobia. *Journal of Abnormal Psychology, 113*, 160-165.

Perez-Edgar, K. & Fox, N. (2005). Temperament and anxiety disorders. *Child Adolesc Psychiatric Clin N Am, 14*, 681– 706.

Perez-Edgar, K., Roberson-Nay, R., Hardin, M., Poeth, K., Guyer, A., Nelson, E. et al. (2007). Attention alters neural responses to evocative faces in behaviorally inhibited adolescents. *NeuroImage, 35*, 1538-1546.

Perez-Edgar, K., Bar-Haim, Y., McDermott, J., Chronis-Tuscano, A., Pine, D., & Fox, N. (2010). Attention biases to threat and behavioral inhibition in early childhood shape adolescent social withdrawal. *Emotion, 10*, 349-357.

Pérez-Edgar, K., Reeb-Sutherland, B., Martin McDermott, J., White, L., Henderson, H., Degnan, K., et al. (in press). Attention biases to threat link behavioral inhibition to social withdrawal over time in very young children. *J Abnorm Child Psychol*.

Posner, M. & Rothbart, M. (2007). *Educating the Human Brain.* Washington, DC: American Psychological Association.

Puliafico, A. & Kendall, P. (2006). Threat-related attentional bias in anxiety-disordered youth: A review. *Clinical Child and Family Psychology Review, 9*, 162-180.

Quirk, G., Likhtik, E., Pelletier, J., & Pare, D. (2003). Stimulation of medial prefrontal cortex decreases the responsiveness of central amygdala output neurons. *Journal of Neuroscience, 23*, 8800–8807.

Rapee, R. (2002). The development and modification of temperamental risk for anxiety disorders: Prevention of a lifetime of anxiety? *Biological Psychiatry, 52*, 947-957.

Reinholdt-Dunne, M., Mogg, K., & Bradley, B. (2009). Effects of anxiety and attention control on processing pictorial and linguistic emotional information. *Behaviour Research and Therapy, 47*, 410-417.

Rothbart, M. K., Ahadi, S. A., Hershey, K. L., & Fisher, P. (2001). Investigations of temperament at 3-7 years: The Children's Behavior Questionnaire. *Child Development, 72*, 1394-1408.

Rothbart, M. & Derryberry, D. (1981). Development of individual differences in temperament. In M. Lamb and A. Brown (Eds), *Advances in Developmental Psychology, vol 1* (pp. 37-86). Hillsdale, NJ: Erlbaum.

Rothbart, M., Ellis, L., & Posner, M. (2004). Temperament and self-regulation. In R. Baumeister and K. Vohs (Eds), *Handbook of self-regulation: Research, theory, and applications* (pp. 357-370). New York, NY: Guilford Press.

Rothbart, M. K., & Posner, M. I. (2006). Temperament, attention, and developmental psychopathology. In D. Cicchetti & D. J. Cohen (Eds.), *Developmental Psychopathology. 2nd Edition. Vol 2. Developmental neuroscience* (pp. 465–501). Hoboken, NJ: John Wiley & Sons

Rothbart, M., Sheese, B., & Posner, M. (2007). Executive attention and effortful control: Linking temperament, brain networks, and genes. *Child Development Perspectives, 1*, 2-7.

Rueda, M., Posner, M., & Rothbart, M. (2005). The development of executive attention: Contributions to the emergence of self-regulation. *Developmental Neuropsychology, 28*, 573-594.

Schmidt, L. A., Fox, N. A., Schulkin, J., & Gold, P. W. (1999). Behavioral and psychological correlates of self-presentation in temperamentally shy children. *Psychological Science, 2*, 40–44.

Schutter, D. J. L., Putman, P., Hermans, E., & van Honk, J. (2001). Parietal electroencephalogram beta asymmetry and selective attention to angry facial expressions in healthy human subjects. *Neuroscience Letters, 314*, 13-16.

Schwartz, C., Wright, C., Shin, L., Kagan J., & Rauch, S. (2003). Inhibited and uninhibited infants “grown up”: Adult amygdalar response to novelty. *Science, 300*, 1952-1953.

Silva, J., Pizzagalli, D., Larson, C., Jackson, D., & Davidson, R. (2002). Frontal brain asymmetry in restrained eaters. *Journal of Abnormal Psychology, 111*, 676-681.

Simonds, J., Kieras, J., Rueda, R., & Rothbart, M. (2007). Effortful control, executive attention, and emotional regulation in 7–10-year-old children. *Cognitive Development, 22*, 474-488.

Stroop, J. R. (1935). Studies of interference in serial verbal reactions. *Journal of Experimental Psychology, 18*, 643-662.

Thibodeaua, R., Jorgensena R., & Kima, S. (2006). Depression, anxiety, and resting frontal EEG asymmetry: A meta-analytic review. *Journal of Abnormal Psychology, 115*, 715-729.

Thompson, R. & Goodvin, R. (2007). The cognitive neuroscience of early socioemotional development. In C. Brownell & C. Kopp (Eds.), *Socioemotional development in the toddler years* (pp. 320-344). New York, NY: Guilford Press.

Tottenham, N., Tanaka, J., Leon, A., McCarry, T., Nurse, M., Hare, T., Marcus, D., Westerlund, A., Casey, B., & Nelson, C. (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research, 168*, 242-249.

Vuga, M., Fox, N., Cohn, J., Kovacs, M., & George, C. (2008). Long-term stability of electroencephalographic asymmetry and power in 3 to 9 year-old children. *International Journal of Psychophysiology, 67*, 70-77.

Wald, I., Shechner, T., Bitton, S., Holoshitz, Y., Charney, D., Muller, D., Fox, N., Pine, D., & Bar-Haim, Y. (in press). Attention bias away from threat during life threatening danger predicts PTSD symptoms at one-year follow-up. *Depression and Anxiety*.

Wang, H. & Fan, J. (2007). Human attentional networks: A connectionist model. Journal of *Cognitive Neuroscience, 10*, 1678-1689.

Waters, A., Kokkoris, L., Mogg, K., Bradley, B., & Pine, D. (2010). The time course of attentional bias for emotional faces in anxious children. *Cognition & Emotion, 7*, 1173-1181

Zapp, D. J., Pérez-Edgar, K., Cole, C., & Nelson, S. K. (under review). Attentional control modulates attention bias for affective faces across presentation time.

Zhou, Q., Hofer, C., Eisenberg, N., Reiser, M., Spinrad, T.& Fabes, R. (2007). The developmental trajectories of attention focusing, attentional and behavioral persistence, and externalizing problems during school-age years. *Developmental Psychology, 43*, 369-385.

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