*Development and Psychopathology* (2023), **35**, 1335–1345
doi:10.1017/S0954579421001231

Regular Article

# Fearful temperament in middle childhood predicts adolescent attention bias and anxiety symptoms: The moderating role of frontal EEG asymmetry

Ran Liu[1] and Martha Ann Bell[2]

[1]The Division of Child and Adolescent Psychiatry, Department of Psychiatry, Vagelos College of Physicians & Surgeons, Columbia University Irving Medical Center, New York, USA and [2]Department of Psychology, Virginia Tech, Blacksburg, USA

## Abstract

The current study provided first analyses of the moderating effect of baseline-to-task frontal EEG asymmetry on the associations between 9-year fearful temperament and adolescent attention bias to threat as well as anxiety symptoms. Participants include a community sample of 122 children (60 boys, 62 girls; $M_{age} = 14.66$ years; Range = 11.82–18.13 years). Baseline-to-task frontal EEG asymmetry at age 9 moderated the relation between fearful temperament at age 9 and adolescent anxiety symptoms. Specifically, fearful temperament predicted adolescent anxiety symptoms when children showed greater right activation from baseline to an executive function task, but not greater left activation. Baseline-to-task frontal EEG asymmetry moderated the association between fearful temperament and sustained (i.e., stimulus onset asynchrony is 1250 ms) but not automatic attention bias (i.e., stimulus onset asynchrony is 500 ms). Children with greater left frontal activation from baseline to task more efficiently direct attention away from threat. Adolescent automatic attention bias to threat was related to concurrent anxiety symptoms. These findings illustrate the importance of considering frontal EEG asymmetry to shape how fearful children process threat and to influence their behavioral problems.

**Keywords:** anxiety; attention bias to threat; fearful temperament; frontal EEG asymmetry

(Received 3 March 2021; revised 28 September 2021; accepted 28 September 2021; First Published online 13 December 2021)

Anxiety symptoms are highly prevalent among adolescents and significantly impair their functioning across various domains (e.g., Rapee et al., 2009). Identifying developmental antecedents of adolescent anxiety symptoms has significant theoretical and clinical implications. Previous developmental and clinical literature highlighted fearful temperament as an important vulnerability of anxiety symptoms (e.g., Buss et al., 2021). Fearful temperament is characterized by wariness, fear, and enhanced physiological reactivity in novel and threatening situations (Kagan et al., 1984). In the current study, we define fearful temperament as a withdrawal-related temperament umbrella that covers conceptually similar terms including fear, shyness, behavioral inhibition, and social withdrawal (Buss et al., 2021; Rubin et al., 2009; White et al., 2017). Previous research mainly studied the effect of fearful temperament in toddlerhood and early childhood (e.g., Chen et al., 2020). More investigation is needed to understand fearful temperament in middle childhood, as middle childhood is a critical period when children develop essential emotional and social skills that will prepare them for adolescence and adulthood.

Temperamentally fearful children typically show different attention patterns when processing threat and danger, manifesting as a tendency to allocate attention to threat and difficulties in disengaging from threat. (Cisler & Koster, 2010; Fu & Pérez-Edgar, 2019). In support, 4- to 7-year-old children with a higher level of shyness showed greater attention bias to social threat compared with less shy children (LoBue & Pérez-Edgar, 2014). Such atypical attention bias shapes how fearful children and adolescents interpret and respond to the environment thus characterizing them with anxiety symptoms (Fu & Pérez-Edgar, 2019; Lau & Waters, 2017; Todd et al., 2012). For instance, a meta-analysis study reported that children with anxiety showed a greater attention bias to threat, compared to controls ($d = 0.21$). This study was based on 38 selected articles involving 4221 children and adolescents (Dudeney et al., 2015). A recent study that examined the association between attention bias and anxiety symptoms in a large and international sample ($n = 1291$) revealed a positive relation between attention bias to threat and overall anxiety symptoms in children and adolescents aged 6–18 years (Abend et al., 2018). As such, attention bias to threat is a key process associated with anxiety symptoms among children and adolescents (Bar-Haim et al., 2007).

Despite the strong predictive effect of fearful temperament on attention bias and anxiety symptoms, not all fearful children will display attention bias to threat and develop anxiety symptoms (White et al., 2017). A fundamental goal of developmental psychopathology research is to elucidate the interactive effect of multilevel factors in the emergence and continuity of behavioral problems (Cicchetti & Rogosch, 2002). Previous research documents an

**Corresponding author:** Ran Liu, email: rl3206@cumc.columbia.edu

**Cite this article:** Liu, R. and Bell, M. A. (2023). Fearful temperament in middle childhood predicts adolescent attention bias and anxiety symptoms: The moderating role of frontal EEG asymmetry. *Development and Psychopathology* **35**: 1335–1345, https://doi.org/10.1017/S0954579421001231

association between frontal EEG asymmetry and attention bias to threat in adults (e.g., Grimshaw et al., 2014). More importantly, frontal EEG asymmetry plays a moderating role in the relation between fearful temperament and anxiety symptoms with left resting frontal EEG asymmetry mitigating the risk (Liu et al., 2021).

EEG is a noninvasive measurement of the brain's electrical activity. Frontal EEG asymmetry is indexed by the difference in EEG power within the alpha frequency band between left and right frontal electrodes. Source localization and neuroimaging studies suggest that the alpha oscillations used to indicate frontal EEG asymmetry are related to activity in the dorsal lateral prefrontal cortex (dlPFC), which is an important node in dorsal fronto-parietal network. Cognitive-motivational framework of anxiety proposed that effective goal-directed attentional control is critical in regulating threat salience-driven system, modifying threat-related attention bias, and reducing anxiety symptoms (Mogg & Bradley, 2018). dlPFC plays an important role in exerting top-down executive control of attention, with left dlPFC having a greater impact (Dubreuil-Vall et al., 2019). Moreover, left PFC has been suggested to inhibit subcortical circuitry, including the amygdala that is involved in threat detection and evaluation (Davidson, 2001; Johnstone et al., 2007). Therefore, children with greater left frontal activity may be better able to inhibit the interference of negative stimuli and are more engaged in task-related goals (Grimshaw & Carmel, 2014).

In support, previous research on adults demonstrated an association between frontal EEG asymmetry and attention bias to threat. For instance, young adults with right frontal EEG asymmetry displayed attention bias to threat if they also showed lower levels of right parietal EEG asymmetry; those with left frontal EEG asymmetry showed no attentional bias to threat (Grimshaw et al., 2014). Similarly, increased right frontal activation (i.e., increased right frontal asymmetry) from baseline to a stressful speech task was associated with attention bias to angry faces in young adults; those with increased left activation, however, did not show such attention bias to threat (Pérez-Edgar et al., 2013). Both studies demonstrated the association between frontal EEG asymmetry and attention bias to threat.

Attention bias is frequently measured by the dot-probe task, during which participants are assessed on whether they are faster in processing targets following threatening compared to neutral stimuli. Attention processes assessed with various durations of SOA (i.e., stimulus onset asynchrony between onset of the threat and onset of the target) may involve different neural underpinnings. Short SOA may indicate automatic attention bias that is tied to the orienting system and amygdala while long SOA may represent sustained attention bias that can be affected by top-down executive attention system comprising of PFC and anterior cingulate cortex (Cisler & Koster, 2010; Liu & Bell, 2020). As such, it is of great interest to examine how frontal EEG asymmetry impacts the potential for two types of attention bias. Previous study suggests that the SOA in the dot-probe task should be long enough to allow the strategic control of attention (i.e., 1250–1500 ms). We, therefore, applied 1250 ms to indicate sustained attention bias in this study. We hypothesized that frontal EEG asymmetry would moderate the relation between fearful temperament and sustained attention bias measured with a long SOA. Notably, the duration of computer-task-based "sustained" (i.e., over a second) in this study was much shorter than the definition of "sustained" that is usually seen in more naturalistic attention tasks.

Although being less studied, the associations between parietal EEG asymmetry and attention bias as well as psychopathology have also been reported. For example, relative greater right parietal asymmetry was associated with anxiety, and lower right parietal asymmetry was correlated with depression, especially if it is not co-morbid with anxiety (Mathersul et al., 2008; Metzger et al., 2004). Adults with right parietal asymmetry at baseline avoided both angry and happy faces; those with left parietal asymmetry exhibited vigilance to both emotions (Pérez-Edgar et al., 2013). Moreover, frontal and parietal asymmetry at baseline interactively predicted attention bias to threat (Grimshaw et al., 2014). As such, although we focused on frontal EEG asymmetry in this study, we also examined the effect of baseline-to-task parietal EEG asymmetry as a specificity analysis.

The current study aims to extend previous literature in multiple important ways. First, we aim to elucidate how frontal EEG asymmetry affects fearful children's automatic and sustained attention bias. We applied different SOAs in the dot-probe task to investigate the potentially different neural networks that are involved in automatic and sustained attention bias with a focus on PFC.

Second, we examine if the findings on frontal EEG asymmetry and attention bias with adults will hold for children and adolescents as well. This is critical as PFC rapidly matures across childhood and adolescence (e.g., Kolb et al., 2012). Therefore, the functional role of PFC or the efficiency in using PFC to regulate attention over threat may change with development. Only a handful of studies, however, examined how frontal EEG asymmetry influences attention bias in youth and the results are mixed (Heffer & Willoughby, 2020; Solomon et al., 2014). Therefore, we aim to examine the moderating effect of frontal EEG asymmetry on the association between fearful temperament and attention bias as well as anxiety symptoms from middle childhood to adolescence.

Third, previous frontal EEG asymmetry studies mainly focused on frontal EEG asymmetry measured at baseline (e.g., Grimshaw et al., 2014). The current study extends the literature by examining changes in asymmetrical frontal activity from resting state to a task that requires executive function, allowing us to capture activation in dlPFC during the dynamic exertion of attention control. We used a difference score in frontal EEG asymmetry during baseline and frontal EEG asymmetry during an executive function task to calculate this baseline-to-task frontal EEG asymmetry measure indicating asymmetric frontal activation from baseline to task.

### *Current study*

In sum, the current study has two main aims. First, we examine the relations among fearful temperament, automatic attention bias to threat, and anxiety symptoms. More importantly, we examine the interactive effect of fearful temperament and baseline-to-task frontal EEG asymmetry at 9 years on adolescent anxiety symptoms with automatic attention bias being controlled. We hypothesized that having greater left frontal activation would attenuate the relation between fearful temperament and anxiety symptoms. The interactive effect of fearful temperament and frontal EEG asymmetry on *automatic* attention bias is exploratory, given the prior limited research.

Second, we examine the relations among fearful temperament, sustained attention bias to threat, and anxiety symptoms. More importantly, we examine the interactive effect of fearful temperament and frontal EEG asymmetry on sustained attention bias. We expected that children with high fearful temperament but had greater left frontal activation would show no sustained attention bias to threat or tend to direct attention away from threat. We also examine the interactive effect of fearful temperament and baseline-to-task frontal EEG asymmetry at 9 years on adolescent anxiety symptoms with sustained attention bias being controlled. We hypothesized that having greater left frontal activation would attenuate the relation between fearful temperament and anxiety symptoms.

## Method

### Participants

Participants were children from a longitudinal investigation of cognition and emotion development across infancy and childhood. The original longitudinal study included three cohorts that began at 5 months and ended at 9 years of age. Children in two of the cohorts continued the longitudinal study when they were adolescents. These two cohorts represent half of the original longitudinal study, live in the same geographic region, and were assessed in the same research lab. The third cohort of children in the original longitudinal study was located at a different geographic location. The study for the third cohort ended with age 9 visits; thus, those children were not included in the current study. The two cohorts in the current study were recruited during infancy from a rural college town in the mid-Atlantic region, using mailing lists, media advertisements, flyers, and word of mouth. Cohort one children are, in general, 3–4 years older than cohort two children. This variability in age was due to funding schedules. The demographics of the two cohorts of participants reflect the demographics of the area in which the research laboratory was located.

For the current study, children visited our lab at 9 years of age. Of the 161 children (77 boys, 84 girls) participating at 9 years old, 78 (11–18 years of age) returned for the final visit of the study before the COVID-19 pandemic closed the lab. An additional 44 families participated by completing online questionnaires associated with the study after the lab closed. Families lost to attrition ($n = 39$) included those who could not be located, moved out of the area, declined participation, or did not respond to phone and letter requests to participate. No significant differences were found between families who did or did not participate with respect to child gender, race, and level of fearful temperament ($ps > .14$).

Two participants had a less than 50% accurate rate on the attention bias task and their scores were treated as missing values. Among the participants (60 boys, 62 girls) who contributed data, 92.7% were White, 1.6% were Asian, and 5.7% were multiracial/other. In addition, 4.9% were Hispanic, 95.1% were not Hispanic. Regarding maternal education level, 2.5 % of the mothers did not finish high school; .8% of the mothers graduated from high school; 12.4% had technical degrees; 32.2% had college degrees; 52.1% had postgraduate degrees. Children in cohort 1 ($n = 55$) and 2 ($n = 67$) did not differ on demographics and any of the study variables ($ps > .14$). No difference in level of anxiety was found between children who completed the questionnaires before and after the outbreak of COVID-19 ($p = .51$).

### Procedures

Children in cohort 1 visited our lab at age 9 from the summer of 2013 to the end of 2014. Children in cohort 2 visited our lab at age 9 from the summer of 2016 to the spring of 2017. Both cohorts of children visited our lab again from August 2019 to March 2020 to participate in the adolescent visit of our longitudinal research. The questionnaire-only families participated online from July 2020 to September 2020. When arriving at the research lab each time, children and their parents were greeted, and procedures were described by the researchers. After getting the signed consent and assent from parents and children, researchers began to place the ECG disposable electrodes and the EEG electrode cap on the children and administer various cognitive, socio-emotional, and academic achievement tests. Mothers sat in an adjoining room and completed questionnaires during the appointments. Children received a $ 20 gift certificate and mothers received a $75 gift certificate as compensation for participation at age 9. Children received $50 cash and mothers received $50 cash as compensation for the adolescent lab visit.

### Measures collected on the 9-year-old lab visit

#### Fearful temperament

Early Adolescent Temperament Questionnaire-Revised (EATQ-R; Ellis & Rothbart, 2001) is an assessment of temperament and behavior in children and adolescents containing 62 items in 10 subscales in the parent-report version. Parents responded on a 5-point Likert scale ranging from 1 = *almost never true* to 5 = *almost always true*. In the current study, the fear subscale of the EATQ was used to assess fearful temperament (6 items, e.g., "Worries about getting into trouble.") The Cronbach's alpha of fear subscale is .64.

#### Frontal EEG asymmetry

The baseline EEG was accomplished as the child watched a 3-min video (opening scene from *The Lion King*). The task EEG was recorded as the child engaged in an executive function task: visual search. The child was asked to find all the visual targets (i.e., stars) among other distractors within a specified time limit as the experimenter sat across from the child and watched. The task requires children's ability to engage attention and flexibility shift attention as needed, as well as skills to remember which targets have been found and to inhibit the tendency to continually point to the same target or point back to a previously found target.

EEG was recorded from 26 left and right scalp sites: frontal pole (Fp1, Fp2), medial frontal (F3, Fz, F4), lateral frontal (F7, F8), fronto-central (FC1, FC2, FC5, FC6), central (C3, C4), temporal (T7, T8), centro-parietal (CP1, CP2, CP5, CP6), medial parietal (P3, Pz, P4), lateral parietal (P7, P8), and occipital (O1, O2), all referenced to Cz during the recordings. EEG was recorded using a stretch cap (Electro-Cap Inc., Eaton, OH; E-1 series cap) with electrodes positioned to the International 10–20 system. After the cap was placed on the head, a small amount of abrasive gel was placed into each recording site and the scalp gently rubbed. Then, a small amount of conductive gel was placed into each site. Electrode impedances were measured and accepted if they were below 10 KΩ.

The electrical activity from each electrode was amplified using separate James Long Company Bioamps (James Long Company; Caroga Lake, NY). During data collection, the high pass filter was a single pole RC filter with a 0.1 Hz cut-off (3 dB or half-power point) and 6 dB per octave roll-off. The low pass filter was a two-pole Butterworth type with a 100 Hz cut-off (3 dB or half-power point) and 12 dB octave roll-off. Activity for each lead was displayed on the monitor of an acquisition computer. The EEG was digitized online at 512 samples/s for each channel to eliminate the effects of aliasing. The acquisition software was Snapshot-Snapstream (HEM Data Corp.; Southfield, MI) and the raw data were stored for later analyses. Prior to the recording of each subject a 10 Hz, 50 uV peak-to-peak sine wave was input through each

https://doi.org/10.1017/S0954579421001231 Published online by Cambridge University Press

amplifier. This calibration signal was digitized for 30 s and stored for subsequent analysis.

Spectral analysis of the calibration signal and computation of power at the 9 to 11 Hz frequency band was accomplished. These power figures were used to calibrate the power derived from the subsequent spectral analysis of the EEG. Next, EEG data were examined and analyzed using EEG Analysis software developed by James Long Company. Data were re-referenced via software to an average reference configuration. This re-referencing eliminates concerns that power values at each active site reflect interelectrode distance as much as they reflect electrical potential (Bell & Cuevas, 2012).

The average reference EEG data were artifact scored for eye movements using electrodes Fp1 and Fp2 to examine peak-to-peak criterion of 100 uV or greater (Myslobodsky et al., 1989). EEG data also were artifact scored for gross motor movements using a peak-to-peak criterion of 200 uV V or greater. Only artifact-free data were used in subsequent analyses. The amount of artifact-free data of baseline and task did not relate to any of the study variables ($rs < .18$, $ps > .13$). The data were then analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-s width and 50% overlap. EEG power was expressed as mean square microvolts and the data were transformed using the natural log (ln) to normalize the distribution.

Power was computed at the 8–10 Hz alpha frequency band. According to research that examined the power distribution in preschool children (Marshall et al., 2002), alpha corresponds to 6–9 Hz in 4-year-old children. The alpha band is typically shifted by 1–2 Hz from preschool children to school-age children based on their age-dependent peak frequencies (Niedermeyer, 1999). Therefore, alpha likely corresponds to 8–10 Hz in 9-year-old children. This frequency band has been used to assess frontal EEG asymmetry by previous research with children in the middle childhood age range (e.g., Vuga et al., 2008).

Baseline and task EEG asymmetries were calculated by subtracting the ln power at left hemisphere (F3, P3) from ln power at right hemisphere (F4, P4; Fox, 1994). Positive EEG asymmetry values indicate greater left activity (left frontal asymmetry) at baseline and at task; negative EEG asymmetry values indicated greater right activity (right frontal asymmetry) at baseline and at task as cortical activity is inversely related to alpha power (Reznik & Allen, 2018). Fifty-one children showed right frontal asymmetry at baseline and fifty-nine children showed left frontal asymmetry at baseline. Forty-seven children showed right frontal asymmetry during task and sixty-one children showed left frontal asymmetry during task. Baseline to task activation was calculated by subtracting the asymmetry scores at baseline from the asymmetry scores during task. Positive EEG asymmetry values indicated greater left activation from baseline to task; negative EEG asymmetry values indicated greater right activation from baseline to task. Forty-nine children showed greater right activation from baseline to task and sixty children showed greater left activation from baseline to task.

To calculate the reliability for frontal EEG asymmetry scores, we followed Clayson and Miller (2017)'s guidelines to examine test-retest reliability across sessions. In addition to the "baseline" video task used in these analyses, EEG was also recorded while children remained seated with eyes closed. Although both contexts captured children's brain activity when they are under a quiet and calm state, the "baseline" video task had visual and auditory information. Even so, the recording contexts with and without visual and auditory information were correlated at 9 years ($r = .44$, $p < .001$ for frontal asymmetry; $r = .33$, $p < .001$ for parietal asymmetry). Because the two "baseline" contexts were different with respect to visual and auditory information, we chose not to average across them because this would not be in the spirit of reliability of recording contexts (Clayson & Miller, 2017).

### *Measures collected on the adolescent lab visit*

#### *Attention bias*

Dot-probe task (Pérez-Edgar et al., 2010). The face stimuli were photographs of 20 different actors (10 male; 10 female) taken from the NimStim stimulus set (Tottenham et al., 2009). Stimuli were presented on a cathode-ray tube monitor viewed at a distance of 100 cm and presentation was controlled by the STIM stimulus presentation system from the James Long Company (Caroga Lake, NY). Each trial began with a 500 ms fixation cross presented at the center of the screen, followed by a horizontal face pair displayed for either 500 ms or 1250 ms. The face photographs were presented side by side equidistant from the fixation cross (subtending 0.8 × 0.8 degrees). Each face image subtended 8.8 × 7.6 degrees of visual angle and was centered 6.6 degrees to the left or right of the fixation cross. Immediately following the offset of the faces, a target arrow probe, pointing up or down, was presented for 500 ms, centered in the location of one of the previously presented faces. The arrow probe subtended 1.0 × 0.8 degrees of visual angle. Participants were asked to indicate as quickly and accurately as possible whether the arrow points up or down using a two-button box. The arrow presentation was replaced by a blank screen in which the participants have up to 750 ms to respond to the target orientation before the next trial began.

There were two types of face pairs: angry-neutral (256 trials) and neutral-neutral (128 trials). Trials were considered as congruent if the arrow appears in the same location as the angry face (128 trials) and incongruent if appearing in the location of the neutral face (128 trials). Participants received 10 practice trials. Trials were organized into blocks based on the face presentation durations. There was a total of 384 test trials divided into four blocks (i.e., two blocks of 500 ms assessing automatic attention bias and two blocks of 1250 ms assessing sustained attention bias). Within each block, face sex, angry face location (right/left), probe direction (up/down), and probe location (right/left) were counterbalanced. The trial order within a block was randomized. A short break was delivered between blocks.

Dot-probe trials with incorrect response and reaction times (RTs) less than 200 ms or more than 1250 ms were excluded from further analyses to avoid random responses or responses that may be influenced by distractions. In addition, RTs were averaged across block and RTs above and below three standard deviations of the mean RT were excluded from the mean RT calculation for each participant. On average, 119 congruent trials and 120 incongruent trials remained and were included in data analyses. Bias scores were calculated by subtracting mean RTs for congruent from mean RTs for incongruent trials, such that positive scores indicated attention bias towards threat and negative scores reflected attention away from threat. Split-half reliability with Spearman–Brown corrections is .72 ($p < .001$) for automatic attention bias scores and .40 ($p = .04$) for sustained attention bias scores.

#### *Anxiety symptoms*

The Revised Children's Anxiety and Depression Scale (RCADS; Chorpita et al., 2000) is a 47-item questionnaire that measures five anxiety subtypes (i.e., separation anxiety disorder, social phobia,

**Table 1.** Descriptive statistics and correlations of variables of interest

| | *M* | *SD* | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. Age | 14.66 | 1.94 | | | | | | | | |
| 2. Puberty | 2.91 | .80 | .60* | | | | | | | |
| 3. 9-year fear | 2.72 | .72 | −.09 | −.09 | | | | | | |
| 4. 9-year baseline FA | .01 | .19 | −.17 | −.20* | .03 | | | | | |
| 5. 9-year task FA | .01 | .18 | −.12 | −.22* | −.02 | .67* | | | | |
| 6. 9-year baseline-task FA | .00 | .16 | .10 | .04 | −.10 | −.47* | .34* | | | |
| 7. Adolescent automatic AB | −.19 | 20.16 | .03 | −.08 | −.13 | −.05 | −.04 | .03 | | |
| 8. Adolescent sustained AB | −.33 | 18.19 | .00 | −.06 | −.10 | .28* | .22 | −.15 | −.01 | |
| 9. Adolescent anxiety | 76.95 | 13.28 | .16 | .21* | .02 | −.08 | −.09 | −.01 | .23* | −.09 |

*Note.* FA = frontal EEG asymmetry, AB = attention bias to threat.
*$p < .05$.

generalized anxiety disorder, panic disorder, obsessive-compulsive disorder) and depression symptoms. Adolescents report the frequency of their symptoms on a 4-pointed Likert Scale (0 = *never*, 1 = *sometimes*, 2 = *often*, 3 = *always*). Previous studies showed good test-retest reliability, internal consistency, concurrent validity, and discriminant validity of the questionnaires in both clinical and non-clinical youth samples (e.g., Chorpita et al., 2005). The variable of interest in the current study was the total anxiety scores. The Cronbach's alpha of the total anxiety scale is .95.

### Pubertal status

Participants completed the Pubertal Developmental Scale (PDS; Petersen et al., 1988). PDS is a self-report with three questions measuring children's growth on height, pubic hair, and skin change for both sexes. Boys additionally completed two questions on facial hair and voice change; girls completed two additional questions on breath growth and menarche. Participants reported on a 4-point Likert scale from "1 = *has not yet begun*" to "4 = *seems completed*" except for menarche, which is a dichotomous item (i.e., 1 = *Yes*; 2 = *No*). Response "Yes" or "No" to this question was recoded as "4" and "1," respectively. Pubertal status was calculated by averaging across the five corresponding items for both boys and girls, respectively. The Cronbach's alpha in the current study is .89 for girls and .94 for boys.

### Data analysis strategy

First, a path model was examined to test the moderating effect of baseline-to-task frontal EEG asymmetry on the longitudinal relations between 9-year fearful temperament and adolescent *automatic* attention bias as well as anxiety symptoms. Second, a path model was examined to test the moderating effect of baseline-to-task frontal EEG asymmetry on the longitudinal relations between 9-year fearful temperament and adolescent *sustained* attention bias as well as anxiety symptoms. Path models were examined via Mplus (Version 8; Muthén & Muthén, 1998–2017). Considering adolescent girls are at higher risk of psychopathology compared with adolescent boys (Van Oort et al., 2009), gender was entered as a control variable in predicting adolescent attention bias and anxiety symptoms. Age was also controlled to account for the age range (i.e., 11–18 years old) of participants on the adolescent visits. Moreover, pubertal status was included as a covariate as its influence on anxiety symptoms (Carter et al., 2011)

Little's MCAR test failed to reject the hypothesis that the data were missing completely at random ($\chi^2$ (15, $N = 123$) = 21.19, $p = 0.13$). Full information at maximum likelihood was used to handle missing values. An maximum likelihood with robust standard errors estimator was used to account for possible non-normal distribution of the study variables. A nonsignificant chi-square statistic value, a comparative fit index (CFI) value greater than .95, and an standardized root mean square residual (SRMR) value less than .08 indicated good model fit (Hu & Bentler, 1999). If the interactive terms were significant in predicting attention bias or anxiety, one SD plus and minus the mean of EEG asymmetry values were used to plot variables and to test the statistical significance of each simple slope (Aiken et al., 1991).

## Results

### Preliminary analysis

Results revealed no significant associations between automatic attention bias to threat and fearful temperament ($r = -.13$, $p = .26$); automatic attention bias, however, was related to anxiety symptom ($r = .23$, $p = .05$). Results showed no significant associations between sustained attention bias to threat and fearful temperament ($r = -.10$, $p = .38$) or to anxiety symptoms ($r = -.09$, $p = .45$). Fearful temperament was not associated with anxiety symptoms ($r = .02$, $p = .81$). Baseline frontal EEG asymmetry was correlated with sustained attention bias ($r = .28$, $p = .02$). Pubertal status was correlated with anxiety symptoms ($r = .21$, $p = .03$; Table 1).

### Primary analyses

#### Aim 1: Effects of 9-year fearful temperament and frontal EEG asymmetry on adolescent automatic attention bias to threat (500 ms) and anxiety symptoms

The path model on automatic attention bias and anxiety symptoms had an acceptable fit, $\chi^2$ (1, $N = 122$) = 1.33, $p = .25$, CFI = .92, SRMR = .03 (see Figure 1 upper). Fearful temperament at 9 years did not predict adolescent anxiety symptoms ($b = .65$, $\beta = .05$, $p = .59$) and attention bias ($b = -1.46$, $\beta = -.07$, $p = .60$). Attention bias predicted anxiety symptoms ($b = .15$, $\beta = .23$, $p = .03$). Attention bias did not mediate the association between fearful temperament and anxiety symptoms ($b = -.22$, $p = .61$). Baseline-to-task frontal EEG asymmetry at 9 years did not moderate the relation between fearful temperament at 9 years

https://doi.org/10.1017/S0954579421001231 Published online by Cambridge University Press

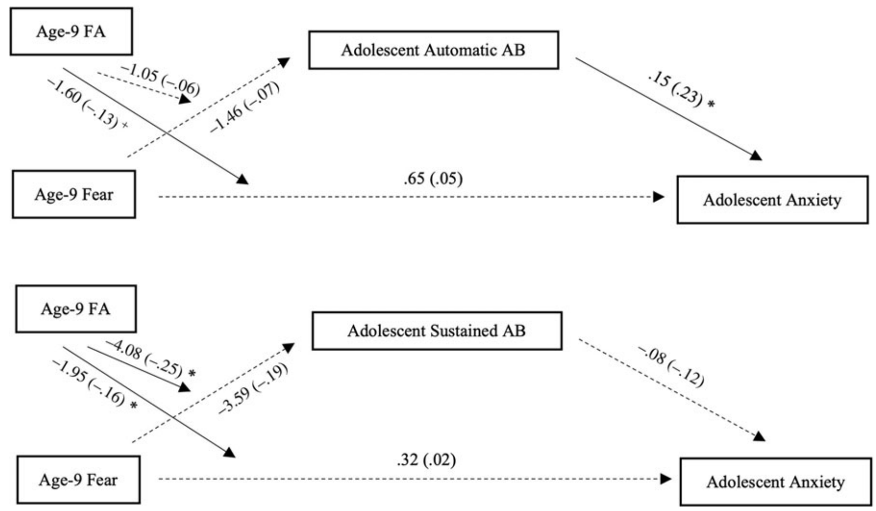


**Figure 1.** Path models of associations among fearful temperament, attention bias, anxiety, and the moderating effect of FA. FA = Frontal EEG asymmetry in visual search task "minus" Frontal EEG asymmetry in baseline, AB = Attention bias to threat. Upper figure represents model testing automatic attention bias (500 ms), lower figure represents model testing sustained attention bias (1250 ms). Numbers in parentheses represent standardized estimations. $^{+}p < .10$. $^{*}p < .05$.

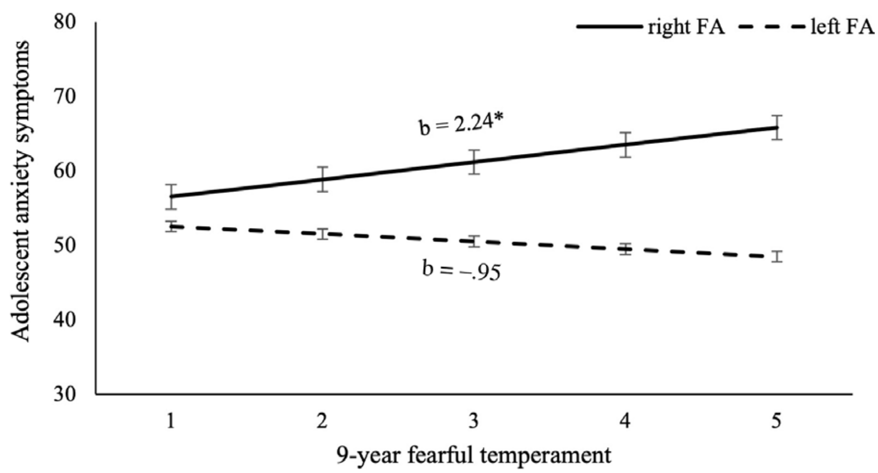


**Figure 2.** The effect of 9-year fearful temperament on adolescent anxiety symptoms with automatic attention bias (500 ms) being controlled at different patterns of frontal EEG activation from baseline to task. FA = Frontal EEG asymmetry in visual search task "minus" Frontal EEG asymmetry in baseline. Left FA (positive FA) = greater left activation from baseline to task; right FA (negative FA) = greater right activation from baseline to task. $^{*}p < .05$.

and adolescent *automatic* attention bias to threat ($b$ = −1.05, $\beta$ = −.06, $p$ = .68; Figure 1 upper). Baseline-to-task frontal EEG asymmetry marginally moderated the effect of 9-year fearful temperament on adolescent anxiety symptoms ($b$ = −1.60, $\beta$ = −.13, $p$ = .08). Although the moderation effect is marginally significant, we followed recommendations (Whisman & McClelland, 2005) to probe interaction terms at $p$-values of .10 and lower, given the difficulty in detecting significant moderation in the social sciences. We found that fearful temperament at 9 years predicted adolescent anxiety only when children showed greater right activation from baseline to task ($b$ = 2.24, $p$ = .05) but not greater left activation ($b$ = −.95, $p$ = .59; see Figure 2). Moreover, we tested the moderating effect of baseline frontal EEG asymmetry on relations among fearful temperament, automatic attention bias, and anxiety. We found that baseline frontal asymmetry did not moderate the effect of 9-year fearful temperament on adolescent anxiety symptoms or attention bias (see Appendix S1. Supplementary results).

### Aim 2: Effects of 9-year fearful temperament and frontal EEG asymmetry on adolescent sustained attention bias to threat (1250 ms) and anxiety symptoms

The path model on sustained attention bias and anxiety symptoms had an acceptable fit, $\chi^2$ (1, $N$ = 122) = 1.33, $p$ = .25, CFI = .93, SRMR = .03 (see Figure 1 lower). Fearful temperament at 9 years did not predict adolescent anxiety symptoms ($b$ = .32, $\beta$ = .02, $p$ = .79) and attention bias ($b$ = −3.59, $\beta$ = −.19, $p$ = .09). Attention bias did not predict anxiety symptoms ($b$ = −.08, $\beta$ = −.12, $p$ = .27). Attention bias did not mediate the association between fearful temperament and anxiety symptoms ($b$ = .30, $p$ = .39). In line with our expectations, baseline-to-task frontal EEG asymmetry at 9 years moderated the relation between fearful temperament at 9 years and adolescent *sustained* attention bias to threat ($b$ = −4.08, $\beta$ = −.25, $p$ = .05; Figure 1 lower). Specifically, fearful temperament predicted attention away from threat when children showed greater left activation from baseline to task ($b$ = −7.67, $p$ = .03). The association between fearful temperament and attention bias to threat was not significant when children showed greater right activation ($b$ = .49, $p$ = .84; see Figure 3 upper). In addition, baseline-to-task frontal EEG asymmetry moderated the effect of 9-year fearful temperament on adolescent anxiety symptoms ($b$ = −1.95, $\beta$ = −.16, $p$ = .04). Specifically, fearful temperament at 9 years predicted adolescent anxiety only when children showed greater right activation from baseline to task ($b$ = 2.26, $p$ = .05) but not greater left activation ($b$ = −1.63, $p$ = .35; see Figure 3 lower). Moreover, we tested the moderating effect of baseline frontal EEG asymmetry on relations among fearful temperament, sustained attention bias, and anxiety. Results suggested that fearful temperament predicted attention away from threat when children showed greater right baseline frontal asymmetry. Baseline frontal asymmetry, however, did not moderate the effect of 9-year fearful temperament on adolescent anxiety symptoms (see Appendix S1. Supplementary results).

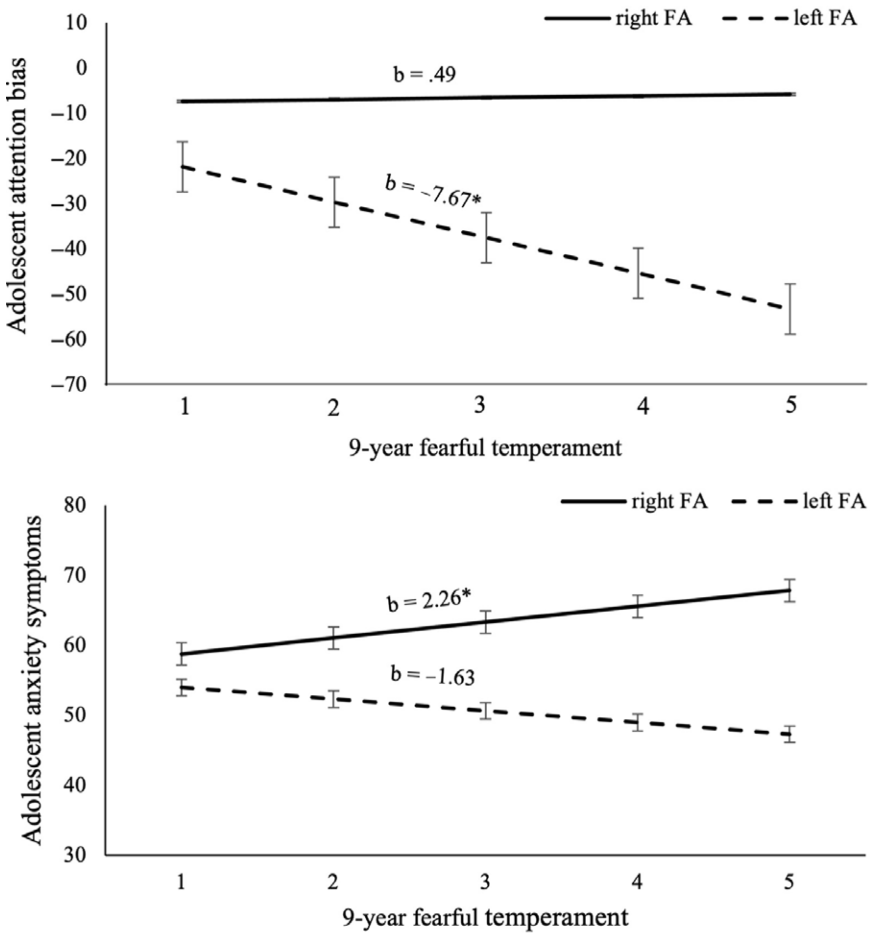


**Figure 3.** The effect of 9-year fear on adolescent sustained attention bias (1250 ms) and anxiety symptoms with sustained attention bias being controlled at different patterns of frontal EEG activation from baseline to task. FA = Frontal EEG asymmetry in visual search task "minus" Frontal EEG asymmetry in baseline. Left FA (positive FA) = greater left activation from baseline to task; right FA (negative FA) = greater right activation from baseline to task. Positive scores indicate attention bias to threat; negative scores indicate attention away from threat. $^*p < .05$.

### *The specificity of frontal EEG asymmetry in moderating the effect of fearful temperament on attention bias to threat and anxiety symptoms*

To test the specific moderating effect of frontal EEG asymmetry on the relation between fearful temperament and attention bias as well as anxiety, we examined if baseline-to-task parietal EEG asymmetry would also play a moderating role. Results revealed that parietal EEG activation from baseline to task did not moderate the association between fearful temperament and automatic ($b = -2.01$, $\beta = -.10$, $p = .29$) as well as sustained attention bias to threat ($b = -1.27$, $\beta = -.07$, $p = .45$). Moreover, parietal EEG asymmetry did not moderate the effect of fearful temperament on anxiety with automatic ($b = 1.46$, $\beta = .10$, $p = .16$) and sustained attention bias ($b = 1.31$, $\beta = .10$, $p = .22$) being controlled.

## Discussion

The current study examined the complex associations among child fearful temperament, attention bias to threat, and anxiety symptoms as well as the moderating effect of baseline-to-task frontal EEG asymmetry on the associations. Adolescent automatic attention bias to threat was related to concurrent anxiety symptoms. Although fearful temperament at age 9 did not significantly predict adolescent anxiety symptoms, the effect was moderated by children's baseline-to-task frontal EEG asymmetry at age 9. Specifically, fearful temperament predicted adolescent anxiety symptoms when children showed greater right activation from baseline to an executive function task, but not greater left activation. Fearful temperament at age 9 did not predict adolescent attention bias to threat; however, we found that frontal EEG activation from baseline to task moderated the association between fearful temperament and sustained but not automatic attention bias. Children with greater left frontal activation from baseline to task more efficiently direct attention away from threat that was presented for a longer SOA (i.e., 1250 ms).

Orienting toward threat was related to anxiety symptoms. This finding supports previous clinical research suggesting that attention bias to threat underlies the development of anxiety (e.g., Bar-Haim et al., 2007). Such attention bias could result from more distal factors, including genetic factors, environmental experiences, and temperament (Lau & Waters, 2017). Fearful temperament at age 9, however, did not predict attention bias in this study. To explain, participants in this study were a community sample of children who were not screened for having high fearful temperament. Therefore, the overall level of fearful temperament in the current sample was low to moderate and might not be salient enough to alter the way children process threat. It is also important to note that developmental research has shown mixed findings, with some studies failing to report the associations among fearful temperament, attention bias, and anxiety (e.g., White et al., 2017). The mixed findings may be due to the limitation of using reaction time to indicate attention bias, as previous studies reported low-reliability scores of reaction-time-based attention bias tasks (Price et al., 2015). A recent study found that children's behavioral inhibition was associated with greater attention bias to threat in the affective Posner task but not in the dot-probe task (Morales et al.,

https://doi.org/10.1017/S0954579421001231 Published online by Cambridge University Press

2017). Neuroimaging work suggests that fearful temperament and anxiety were related to distinct neural activities in response to threat instead of behavioral attention bias (Fu et al., 2017). Although the dot-probe task showed acceptable reliability in the current study, future research may want to use a multi-method approach to assess attention bias, including but not limited to behavioral measures, eye-tracking, and psychophysiological measures, which may aid in revealing the accurate functional role of attention bias in relating to temperament and psychopathology.

The finding that fearful temperament did not predict anxiety symptoms reflects the principle of multifinality, which highlights the variability of developmental outcomes linking to early fearful temperament (Cicchetti & Rogosch, 2002). Indeed, many children with fearful temperament do not develop anxiety in adolescences and adulthoods (e.g., Rapee, 2014). As such, it is of great theoretical and practical importance to study the risk and resilience factors that magnify or mitigate risks of psychopathology among fearful children (Degnan & Fox, 2007; Henderson et al., 2015). In support, we found that baseline-to-task frontal EEG asymmetry moderated the association between 9-year fearful temperament and adolescent anxiety symptoms. Particularly, compared with children who showed greater right activation from baseline to the attentional-control task, those who showed greater left frontal activation were at lower risk of anxiety in adolescence. The finding is consistent with previous neuroimaging research reporting that sufficient recruitment of left dlPFC-based cognitive control is associated with decreased risk of anxiety (e.g., Fitzgerald et al., 2013).

Baseline-to-task frontal EEG asymmetry moderated the association between 9-year fearful temperament and adolescent sustained attention bias. Specifically, fearful temperament predicted attention away from threat for children who showed greater left activation from baseline to task. This is consistent with the brain stimulation research demonstrating the different roles of right and left dlPFC in attentional control for threat. Particularly, high-frequency repetitive transcranial magnetic stimulation (rTMS) over the right dlPFC increased attentional allocation on threat, whereas rTMS over left dlPFC decreased the attentional engagement to threat (De Raedt et al., 2010). Attention bias to threat could result from hypersensitivity of an amygdala-based threat detection mechanism in combination with malfunction of the left lateral PFC that inhibits task-irrelevant threat processing (Bishop et al., 2007). As such, children with greater left frontal activation in response to a task that requires attentional control may be more efficient in suppressing the activity of subcortical systems that are involved in detecting threat and more flexible in disengaging from threat.

Interestingly, when testing baseline or resting frontal EEG asymmetry as a moderator between fearful temperament and attention bias, we found that fearful children tend to direct attention away from threat if they showed right resting frontal asymmetry. Resting frontal EEG asymmetry reflects children's motivational tendencies with right resting frontal asymmetry associating with withdrawal tendencies and left frontal asymmetry associating with approach tendencies (Harmon-Jones & Gable, 2018). This might explain why children in this study showed an avoidance of threat if they had right resting frontal asymmetry. The findings raised two important issues that need to be further explored in future research. First, although attention bias toward threat is a risk factor of anxiety, avoidance of threat has also been related to fearful temperament and anxiety disorders (Morales et al., 2015; Waters et al., 2014). In this study, however, sustained attention bias was not related to anxiety, and resting frontal asymmetry did not moderate the relation between fearful temperament and anxiety symptoms, which precluded us to infer whether such attention away from threat is beneficial or harmful in relation to later psychopathology. It is important for future study to examine the nature of attention bias as advantageous or disadvantages, when studying the effect of frontal asymmetry on attention bias (Liu & Bell, 2020). Second, the findings highlight the importance of differentiating between resting and task-related frontal EEG asymmetry as they might underlie different cognitive mechanisms. The baseline-to-task frontal activation in this study might reflect more of children's executive attention, compared with resting asymmetry, which indicates their general motivational tendencies. As most prior research has focused on resting frontal EEG asymmetry, more studies are needed to examine how asymmetric frontal activation from baseline to various tasks, which involves differential cognitive and emotional challenges, are related to fearful temperament and psychopathology.

Importantly, frontal EEG asymmetry moderated the effect of fearful temperament on sustained but not automatic attention bias in the current study. The result supports previous findings with adults showing that frontal EEG asymmetry was only associated with attention bias measured with a longer SOA (Grimshaw et al., 2014). The duration of SOA, however, was still shorter than the operational definition of "sustained" that is often used in more naturalistic attention tasks. The neurophysiological findings may also echo the behavioral literature proposing that threat should be presented for a certain amount of time to allow for executive attention playing a role (Lonigan & Vasey, 2009). Previous fMRI studies demonstrated different prefrontal cortex (PFC) and amygdala activities associated with attention bias that was measured with short and long SOAs in clinically anxious adolescence (Monk et al., 2008). More studies are needed to further examine the rapid PFC and limbic system processing that underlie both automatic and sustained attention bias (Pérez-Edgar et al., 2013). Of note, sustained attention bias was assessed with a 1250 ms SOA in this study to align with work by Lonigan and Vasey (2009). As PFC continually progresses across childhood, adolescence, and early adulthood, future studies need to take into account the effect of age when designing the attention bias task. For example, studies that focus on attention bias in younger children may want to consider utilizing a longer SOA (i.e., 1500 ms to 2000 ms) to fully capture the effect of PCF in regulating attention over threat given PFC is less mature in early childhood.

Despite the theoretical possibility of separating automatic attention bias to threat (AB) from sustained AB, it is difficult to quantify an SOA that exclusively characterizes automatic AB using behavioral measures based on reaction time. Researchers typically use an SOA of 500 ms or less in the dot-probe task to indicate automatic AB, as opposed to a longer SOA (e.g., 1250 ms) that is subject to effortful control. The feature of AB, however, might be affected by individual differences in the efficiency of exerting attentional control. As such, AB measured with a specific SOA may indicate an exclusively automatic process for some, while requiring effortful control for others. Note that in this study, we used 500 ms as the short SOA for replication, as it is the most frequently used duration in the dot-probe task. Five hundred ms, however, is still longer than many durations used in other studies (e.g., 17 ms in Monk et al., 2008). Future research should utilize other techniques, such as eye-tracking, to aid the measurement of automatic versus sustained attention bias by tracking the direction of an individual's initial fixation or the latency of orienting away from threat (Liu & Bell, 2020).

https://doi.org/10.1017/S0954579421001231 Published online by Cambridge University Press

The current study found no significant moderating effect of parietal EEG asymmetry on the association between fearful temperament and anxiety symptoms as well as attention bias to threat. This finding demonstrates the specificity of asymmetric activity in PFC in modulating threat-related bias and anxiety symptoms in our developmental study. Of note, previous research on adults suggested an association between parietal asymmetry and attention bias. For instance, left parietal EEG asymmetry predicted attention bias to threat and right parietal EEG asymmetry predicted attention away from threat (Pérez-Edgar et al., 2013). It is possible that the functional role of parietal cortex changes with age (Chang et al., 2016). More research is needed to replicate the findings, given the current study is the first one examining how parietal EEG asymmetry is associated with fearful temperament and attention bias among children and adolescents.

The findings of the current study should be interpreted in light of several limitations. First, the sample in the current study lacks racial and socioeconomic diversity. The majority of participants are from well-educated Caucasian families. Therefore, findings from this study may not be generalizable to other populations. Second, the current study focused on total anxiety symptoms. Clinical research reported that subtypes of anxiety disorders might differentially relate to attention bias. For example, fear-related disorders (e.g., social anxiety) were related to attention avoidance of threat (Waters et al., 2014). As such, it remains an important direction for future research to examine the subtypes of anxiety and how they are associated with attention bias. Third, the current sample has a relatively wide age range (i.e., 11 to 18 years). Although we included adolescent age as a covariate, future research may want to assess psychopathology at a narrower age range given the variation in symptoms across adolescence. Fourth, parental mental health is not available in the current study. Future research should include it as a covariate if possible. Fifth, both fearful temperament and anxiety symptoms were measured with questionnaires, albeit from different reporters. It would be optimal to use multiple methods to assess fearful temperament in childhood, especially considering the low reliability of the fearful temperament measure in the current study.

In conclusion, this study represents a first step in examining the moderating effect of baseline-to-task frontal EEG asymmetry on the association between fearful temperament in middle childhood and attention bias to threat as well as anxiety symptoms in adolescence. Fearful children with greater left frontal activation from baseline to an executive function task show more efficiency in directing attention away from threat and have fewer anxiety symptoms. These findings illustrate the importance of considering frontal EEG asymmetry to shape how fearful children process threat and to influence their behavioral problems. These findings shed light on the complex processes that underlie the development of anxiety symptoms, which provide guidelines on the screening and intervention services for adolescents at higher risk for anxiety.

**Supplementary material.** The supplementary material for this article can be found at https://doi.org/10.1017/S0954579421001231

**Acknowledgements.** We thank the research assistants for helping with data collection. We are grateful to the families for their participation in our research.

**Funding statement.** Portions of this research were supported by grant R01 HD049878 from the *Eunice Kennedy Shriver* National Institute of Child Health and Human Development (NICHD). The content of this manuscript is solely the responsibility of the authors and does not necessarily represent the official views of the NICHD or the National Institutes of Health.

**Conflicts of interest.** None.

## References

**Abend, R., Voogd, L. de, Salemink, E., Wiers, R. W., Pérez-Edgar, K., Fitzgerald, A., White, L. K., Salum, G. A., He, J., Silverman, W. K., Pettit, J. W., Pine, D. S., & Bar-Haim, Y.** (2018). Association between attention bias to threat and anxiety symptoms in children and adolescents. *Depression and Anxiety*, *35*, 229–238. https://doi.org/10.1002/da.22706

**Aiken, L. S., West, S. G., & Reno, R. R.** (1991). *Multiple regression: Testing and interpreting interactions*. Sage.

**Bar-Haim, Y., Lamy, D., Pergamin, L., Bakermans-Kranenburg, M. J., & van IJzendoorn, M. H.** (2007). Threat-related attentional bias in anxious and nonanxious individuals: A meta-analytic study. *Psychological Bulletin*, *133*, 1–24. https://doi.org/10.1037/0033-2909.133.1.1

**Bell, M. A., & Cuevas, K.** (2012). Using EEG to study cognitive development: Issues and practices. *Journal of Cognition and Development: Official Journal of the Cognitive Development Society*, *13*, 281–294. https://doi.org/10.1080/15248372.2012.691143

**Bishop, S. J., Jenkins, R., & Lawrence, A. D.** (2007). Neural processing of fearful faces: Effects of anxiety are gated by perceptual capacity limitations. *Cerebral Cortex*, *17*, 1595–1603. https://doi.org/10.1093/cercor/bhl070

**Buss, K. A., Cho, S., Morales, S., McDoniel, M., Webb, A. F., Schwartz, A., Cole, P. M., Dorn, L. D., Gest, S., & Teti, D. M.** (2021). Toddler dysregulated fear predicts continued risk for social anxiety symptoms in early adolescence. *Development and Psychopathology*, *33*, 252–263. https://doi.org/10.1017/S0954579419001743

**Carter, R., Silverman, W. K., & Jaccard, J.** (2011). Sex variations in youth anxiety symptoms: Effects of pubertal development and gender role orientation. *Journal of Clinical Child & Adolescent Psychology*, *40*, 730–741. https://doi.org/10.1080/15374416.2011.597082

**Chang, T.-T., Metcalfe, A. W. S., Padmanabhan, A., Chen, T., & Menon, V.** (2016). Heterogeneous and nonlinear development of human posterior parietal cortex function. *NeuroImage*, *126*, 184–195. https://doi.org/10.1016/j.neuroimage.2015.11.053

**Chen, X., Fu, R., Li, D., Chen, H., Wang, Z., & Wang, L.** (2020). Behavioral inhibition in early childhood and adjustment in late adolescence in China. *Child Development*, *92*, 994–1010. https://doi.org/10.1111/cdev.13463

**Chorpita, B. F., Moffitt, C. E., & Gray, J.** (2005). Psychometric properties of the revised child anxiety and depression scale in a clinical sample. *Behaviour Research and Therapy*, *43*, 309–322. https://doi.org/10.1016/j.brat.2004.02.004

**Chorpita, B. F., Yim, L., Moffitt, C., Umemoto, L. A., & Francis, S. E.** (2000). Assessment of symptoms of DSM-IV anxiety and depression in children: A revised child anxiety and depression scale. *Behaviour Research and Therapy*, *38*, 835–855. https://doi.org/10.1016/S0005-7967(99)00130-8

**Cicchetti, D., & Rogosch, F. A.** (2002). A developmental psychopathology perspective on adolescence. *Journal of Consulting and Clinical Psychology*, *70*, 6–20. https://doi.org/10.1037//0022-006X.70.1.6

**Cisler, J. M., & Koster, E. H. W.** (2010). Mechanisms of attentional biases towards threat in anxiety disorders: An integrative review. *Clinical Psychology Review*, *30*, 203–216. https://doi.org/10.1016/j.cpr.2009.11.003

**Clayson, P. E., & Miller, G. A.** (2017). Psychometric considerations in the measurement of event-related brain potentials: Guidelines for measurement and reporting. *International Journal of Psychophysiology*, *111*, 57–67. https://doi.org/10.1016/j.ijpsycho.2016.09.005

**Davidson, R. J.** (2001). The neural circuitry of emotion and affective style: Prefrontal cortex and amygdala contributions. *Social Science Information*, *40*, 11–37. https://doi.org/10.1177/053901801040001002

**De Raedt, R., Leyman, L., Baeken, C., Van Schuerbeek, P., Luypaert, R., Vanderhasselt, M. A., & Dannlowski, U.** (2010). Neurocognitive effects of HF-rTMS over the dorsolateral prefrontal cortex on the attentional processing of emotional information in healthy women: An event-related fMRI study. *Biological Psychology*, *85*, 487–495. https://doi.org/10.1016/j.biopsycho.2010.09.015

**Degnan, K. A., & Fox, N. A.** (2007). Behavioral inhibition and anxiety disorders: Multiple levels of a resilience process. *Development and Psychopathology*, *19*, 729–746. doi: 10.1017/S0954579407000363

**Dubreuil-Vall, L., Chau, P., Ruffini, G., Widge, A. S., & Camprodon, J. A.** (2019). tDCS to the left DLPFC modulates cognitive and physiological correlates of executive function in a state-dependent manner. *Brain Stimulation*, *12*, 1456–1463. https://doi.org/10.1016/j.brs.2019.06.006

**Dudeney, J., Sharpe, L., & Hunt, C.** (2015). Attentional bias towards threatening stimuli in children with anxiety: A meta-analysis. *Clinical Psychology Review*, *40*, 66–75. https://doi.org/10.1016/j.cpr.2015.05.007

**Ellis, L. K., & Rothbart, M. K.** (2001). Revision of *the early adolescent temperament questionnaire*. Paper presented at the 2001 meeting of the Society for Research in Child Development, Minneapolis, MN, April.

**Fitzgerald, K. D., Liu, Y., Stern, E. R., Welsh, R. C., Hanna, G. L., Monk, C. S., Phan, K. L., & Taylor, S. F.** (2013). Reduced error-related activation of dorsolateral prefrontal cortex across pediatric anxiety disorders. *Journal of the American Academy of Child & Adolescent Psychiatry*, *52*, 1183–1191. https://doi.org/10.1016/j.jaac.2013.09.002

**Fox, N. A.** (1994). Dynamic cerebral processes underlying emotion regulation. In N. A. Fox (Ed.), *The development of emotion regulation: Biological and behavioral considerations. Monographs of the society for research in child development* (pp. 152–166). Society for Research in Child Development.

**Fu, X., & Pérez-Edgar, K.** (2019). Threat-related attention bias in socioemotional development: A critical review and methodological considerations. *Developmental Review*, *51*, 31–57. https://doi.org/10.1016/j.dr.2018.11.002

**Fu, X., Taber-Thomas, B. C., & Pérez-Edgar, K.** (2017). Frontolimbic functioning during threat-related attention: Relations to early behavioral inhibition and anxiety in children. *Biological Psychology*, *122*, 98–109. https://doi.org/10.1016/j.biopsycho.2015.08.010

**Grimshaw, G. M., & Carmel, D.** (2014). An asymmetric inhibition model of hemispheric differences in emotional processing. *Frontiers in Psychology*, *5*, 489. https://doi.org/10.3389/fpsyg.2014.00489

**Grimshaw, G. M., Foster, J. J., & Corballis, P. M.** (2014). Frontal and parietal EEG asymmetries interact to predict attentional bias to threat. *Brain and Cognition*, *90*, 76–86. https://doi.org/10.1016/j.bandc.2014.06.008

**Harmon-Jones, E., & Gable, P. A.** (2018). On the role of asymmetric frontal cortical activity in approach and withdrawal motivation: An updated review of the evidence. *Psychophysiology*, *55*, e12879. https://doi.org/10.1111/psyp.12879

**Heffer, T., & Willoughby, T.** (2020). A longitudinal study investigating trajectories of sensitivity to threat over time and their association with alpha asymmetry among children and adolescents. *Developmental Cognitive Neuroscience*, *46*, 100863. https://doi.org/10.1016/j.dcn.2020.100863

**Henderson, H., Pine, D. & Fox, N** (2015). Behavioral inhibition and developmental risk: A dual-processing perspective. *Neuropsychopharmacology*, *40*, 207–224. https://doi.org/10.1038/npp.2014.189

**Hu, L., & Bentler, P. M.** (1999). Cutoff criteria for fit indexes in covariance structure analysis: Conventional criteria versus new alternatives. *Structural Equation Modeling: A Multidisciplinary Journal*, *6*, 1–55. https://doi.org/10.1080/10705519909540118

**Johnstone, T., Van Reekum, C. M., Urry, H. L., Kalin, N. H., & Davidson, R. J.** (2007). Failure to regulate: Counterproductive recruitment of top-down prefrontal-subcortical circuitry in major depression. *Journal of Neuroscience*, *27*, 8877–8884.

**Kagan, J., Reznick, J. S., Clarke, C., Snidman, N., & Garcia-Coll, C.** (1984). Behavioral inhibition to the unfamiliar. *Child Development*, *55*, 2212–2225. https://doi.org/10.2307/1129793

**Kolb, B., Mychasiuk, R., Muhammad, A., Li, Y., Frost, D. O., & Gibb, R.** (2012). Experience and the developing prefrontal cortex. *Proceedings of the National Academy of Sciences*, *109*, 17186–17193. https://doi.org/10.1073/pnas.1121251109

**Lau, J. Y. F., & Waters, A. M.** (2017). Annual research review: An expanded account of information-processing mechanisms in risk for child and adolescent anxiety and depression. *Journal of Child Psychology and Psychiatry*, *58*, 387–407. https://doi.org/10.1111/jcpp.12653

**Liu, R., & Bell, M. A.** (2020). Fearful temperament and the risk for child and adolescent anxiety: The role of attention biases and effortful control. *Clinical Child and Family Psychology Review*, *23*, 205–228. https://doi.org/10.1007/s10567-019-00306-z

**Liu, R., Calkins, S. D., & Bell, M. A.** (2021). Frontal EEG asymmetry moderates the associations between negative temperament and behavioral problems during childhood. *Development and Psychopathology*, *33*, 1016–1025. https://doi.org/10.1017/S0954579420000309

**LoBue, V., & Pérez-Edgar, K.** (2014). Sensitivity to social and non-social threats in temperamentally shy children at-risk for anxiety. *Developmental Science*, *17*, 239–247. https://doi.org/10.1111/desc.12110

**Lonigan, C. J., & Vasey, M. W.** (2009). Negative affectivity, effortful control, and attention to threat-relevant stimuli. *Journal of Abnormal Child Psychology*, *37*, 387–399. https://doi.org/10.1007/s10802-008-9284-y

**Marshall, P. J., Bar-Haim, Y., & Fox, N. A.** (2002). Development of the EEG from 5 months to 4 years of age. *Clinical Neurophysiology*, *113*, 1199–1208. https://doi.org/10.1016/S1388-2457(02)00163-3

**Mathersul, D., Williams, L. M., Hopkinson, P. J., & Kemp, A. H.** (2008). Investigating models of affect: Relationships among EEG alpha asymmetry, depression, and anxiety. *Emotion*, *8*, 560. https://doi.org/10.1037/a0012811

**Metzger, L. J., Paige, S. R., Carson, M. A., Lasko, N. B., Paulus, L. A., Pitman, R. K., & Orr, S. P.** (2004). PTSD arousal and depression symptoms associated with increased right-sided parietal EEG asymmetry. *Journal of Abnormal Psychology*, *113*, 324. https://doi.org/10.1037/0021-843X.113.2.324

**Mogg, K., & Bradley, B. P.** (2018). Anxiety and threat-related attention: Cognitive-motivational framework and treatment. *Trends in Cognitive Sciences*, *22*, 225–240. https://doi.org/10.1016/j.tics.2018.01.001

**Monk, C. S., Telzer, E. H., Mogg, K., Bradley, B. P., Mai, X., Louro, H. M. C., Chen, G., McClure-Tone, E. B., Ernst, M., & Pine, D. S.** (2008). Amygdala and ventrolateral prefrontal cortex activation to masked angry faces in children and adolescents with generalized anxiety disorder. *Archives of General Psychiatry*, *65*, 568–576. https://doi.org/10.1001/archpsyc.65.5.568

**Morales, S., Pérez-Edgar, K.E. & Buss, K.A** (2015). Attention biases towards and away from threat mark the relation between early dysregulated fear and the later emergence of social withdrawal. *Journal of Abnormal Child Psychology*, *43*, 1067–1078. https://doi.org/10.1007/s10802-014-9963-9

**Morales, S., Taber-Thomas, B. C., & Pérez-Edgar, K. E.** (2017). Patterns of attention to threat across tasks in behaviorally inhibited children at risk for anxiety. *Developmental Science*, *20*, e12391. https://doi.org/10.1111/desc.12391

**Muthén, L. K., & Muthén, B. O.** (1998–2017). *Mplus user's guide*. Muthén & Muthén.

**Myslobodsky, M. S., Coppola, R., Bar-Ziv, J., Karson, C., Daniel, D., van Praag, H., & Weinberger, D. R.** (1989). EEG asymmetries may be affected by cranial and brain parenchymal asymmetries. *Brain Topography*, *1*, 221–228. https://doi.org/10.1007/BF01129599

**Niedermeyer, E.** (1999). Maturation of the EEG: Development of waking and sleep patterns. In E. Niedermeyer & F. H. L. da Silva (Eds.), *Electroencephalography: Basic principles, clinical applications, and related fields* (pp. 189–214). Williams & Wilkins.

**Pérez-Edgar, K., Bar-Haim, Y., McDermott, J. M., Chronis-Tuscano, A., Pine, D. S., & Fox, N. A.** (2010). Attention biases to threat and behavioral inhibition in early childhood shape adolescent social withdrawal. *Emotion*, *10*, 349–357. https://doi.org/10.1037/a0018486

**Pérez-Edgar, K., Kujawa, A., Nelson, S. K., Cole, C., & Zapp, D. J.** (2013). The relation between electroencephalogram asymmetry and attention biases to threat at baseline and under stress. *Brain and Cognition*, *82*, 337–343. https://doi.org/10.1016/j.bandc.2013.05.009

**Petersen, A. C., Crockett, L., Richards, M., & Boxer, A.** (1988). A self-report measure of pubertal status: Reliability, validity, and initial norms. *Journal of Youth and Adolescence*, *17*, 117–133. https://doi.org/10.1007/BF01537962

**Price, R. B., Kuckertz, J. M., Siegle, G. J., Ladouceur, C. D., Silk, J. S., Ryan, N. D., Dahl, R. E., & Amir, N.** (2015). Empirical recommendations for improving the stability of the dot-probe task in clinical research. *Psychological Assessment*, *27*, 365–376. https://doi.org/10.1037/pas0000036

**Rapee, R. M.** (2014). Preschool environment and temperament as predictors of social and nonsocial anxiety disorders in middle adolescence. *Journal of the American Academy of Child & Adolescent Psychiatry*, *53*, 320–328. https://doi.org/10.1016/j.jaac.2013.11.014

**Rapee, R. M., Schniering, C. A., & Hudson, J. L.** (2009). Anxiety disorders during childhood and adolescence: Origins and treatment. *Annual Review* *of Clinical Psychology*, *5*, 311–341. https://doi.org/10.1146/annurev.clinpsy.032408.153628

**Reznik, S. J., & Allen, J. J. B.** (2018). Frontal asymmetry as a mediator and moderator of emotion: An updated review. *Psychophysiology*, *55*, e12965. https://doi.org/10.1111/psyp.12965

**Rubin, K. H., Coplan, R. J., & Bowker, J. C.** (2009). Social withdrawal in childhood. *Annual Review of Psychology*, *60*, 141–171. https://doi.org/10.1146/annurev.psych.60.110707.163642

**Solomon, B., O'Toole, L., Hong, M., & Dennis, T. A.** (2014). Negative affectivity and EEG asymmetry interact to predict emotional interference on attention in early school-aged children. *Brain and Cognition*, *87*, 173–180. https://doi.org/10.1016/j.bandc.2014.03.014

**Todd, R. M., Cunningham, W. A., Anderson, A. K., & Thompson, E.** (2012). Affect-biased attention as emotion regulation. *Trends in Cognitive Sciences*, *16*, 365–372. https://doi.org/10.1016/j.tics.2012.06.003

**Tottenham, N., Tanaka, J. W., Leon, A. C., McCarry, T., Nurse, M., Hare, T. A., Marcus, D. J., Westerlund, A., Casey, B., & Nelson, C.** (2009). The NimStim set of facial expressions: Judgments from untrained research participants. *Psychiatry Research*, *168*, 242–249. https://doi.org/10.1016/j.psychres.2008.05.006

**Van Oort, F. V. A., Greaves-Lord, K., Verhulst, F. C., Ormel, J., & Huizink, A. C.** (2009). The developmental course of anxiety symptoms during adolescence: The TRAILS study. *Journal of Child Psychology and Psychiatry*, *50*, 1209–1217. https://doi.org/10.1111/j.1469-7610.2009.02092.x

**Vuga, M., Fox, N. A., Cohn, J. F., Kovacs, M., & George, C. J.** (2008). Long-term stability of electroencephalographic asymmetry and power in 3 to 9 year-old children. *International Journal of Psychophysiology*, *67*, 70–77. https://doi.org/10.1016/j.ijpsycho.2007.10.007

**Waters, A., Bradley, B., & Mogg, K.** (2014). Biased attention to threat in paediatric anxiety disorders (generalized anxiety disorder, social phobia, specific phobia, separation anxiety disorder) as a function of 'distress' versus 'fear' diagnostic categorization. *Psychological Medicine*, *44*, 607–616. doi: 10.1017/S0033291713000779

**Whisman, M. A., & McClelland, G. H.** (2005). Designing, testing, and interpreting interactions and moderator effects in family research. *Journal of Family Psychology*, *19*, 111. https://doi.org/10.1037/0893-3200.19.1.111

**White, L. K., Degnan, K. A., Henderson, H. A., Pérez-Edgar, K., Walker, O. L., Shechner, T., Leibenluft, E., Bar-Haim, Y., Pine, D. S., & Fox, N. A.** (2017). Developmental relations among behavioral inhibition, anxiety, and attention biases to threat and positive information. *Child Development*, *88*, 141–155. https://doi.org/10.1111/cdev.12696