The relation between electroencephalogram asymmetry and attention biases to threat at baseline and under stress

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ABSTRACT

Electroencephalogram (EEG) asymmetry in the alpha frequency band has been implicated in emotion processing and broad approach-withdrawal motivation systems. Questions remain regarding the cognitive mechanisms that may help elucidate the observed links between EEG asymmetry and patterns of socioemotional functioning. The current study observed frontal EEG asymmetry patterns at rest and under social threat among young adults ($N = 45$, $M = 21.1$ years). Asymmetries were, in turn, associated with performance on an emotion-face dot-probe attention bias task. Attention biases to threat have been implicated as potential causal mechanisms in anxiety and social withdrawal. Frontal EEG asymmetry at baseline did not predict attention bias patterns to angry or happy faces. However, increases in right frontal alpha asymmetry from baseline to the stressful speech condition were associated with vigilance to angry faces and avoidance of happy faces. The findings may reflect individual differences in the pattern of response (approach or withdrawal) with the introduction of a mild stressor. Comparison analyses with frontal beta asymmetry and parietal alpha asymmetry did not find similar patterns. Thus, the data may reflect the unique role of frontal regions, particularly the dorsolateral prefrontal cortex, in cognitive control and threat detection, coupled with ruminative processes associated with alpha activity.

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1. Introduction

For some individuals, stimuli that are perceived to be novel or ambiguous are categorized as threatening and trigger a withdrawal response (e.g., avoiding strangers in a social setting). In contrast, for others, the initial bias is marked by curiosity and an approach motivation (e.g., actively making new acquaintances). One of the strongest biological correlates of this 'affective style' is frontal electroencephalogram (EEG) asymmetry in the alpha frequency band (Davidson, 1995). Withdrawal is linked to greater right frontal EEG activity at rest and in the face of emotional provocation (Coan & Allen, 2004a; Harmon-Jones, Gable, & Peterson, 2010). This bias is evident in healthy children and adults (Coan, Allen, & Harmon-Jones, 2001; Fox, 1991), individuals at increased temperament- or trait-linked risk for anxiety and depression (Fox et al., 1995; Schmidt, 1999), and individuals with a current or past history of mood disorder (Allen & Kline, 2004; Kentgen et al., 2000). In contrast, greater left frontal EEG activity has been linked to approach tendencies, involving both positive emotions, such as

joy (Ekman & Davidson, 1993), and negative emotions, such as anger (Harmon-Jones, 2007).

The strength of the EEG asymmetry data suggests that this biological marker serves as an important moderator of emotion processes throughout the lifespan, across contexts, and in the face of both adaptive and maladaptive functioning. However, despite this extensive literature a number of questions concerning the role of EEG asymmetry and evident individual differences in emotion and motivational tendencies still remain. First, while the general pattern is robust (Davidson, 2004), not all studies have found the expected asymmetry-emotion relation (e.g., Pizzagalli, Shackman, & Davidson, 2003; Reid, Duke, & Allen, 1998). One explanation for these inconsistencies may be that they emerge due to undetected differences in state or trait influences and the affective context of testing (Harmon-Jones et al., 2010).

Much of the literature linking EEG asymmetries to emotion processing has relied on baseline levels of activity at rest, presumably reflecting a stable trait-level tendency to show withdrawal or approach biases (dispositional model; Coan & Allen, 2004b). In an alternate conceptualization, EEG asymmetry is a marker of an individual's ability or strategy to adapt to the specific demands of a situation (capability model; Coan, Allen, & McKnight, 2006). Thus, in a study of individual responses to threat, the dispositional

model would look to asymmetries evident at rest, while the capability model would examine EEG patterns when the individual is concurrently experiencing a threatening or stressful situation.

The current study worked to compare these models by assessing EEG asymmetry patterns in healthy young adults at baseline and while preparing to give a speech—a potential social threat. In addition, we measured the change in EEG asymmetry between baseline and speech preparation (Coan & Allen, 2004a). Recent work has indicated that the link between baseline asymmetry and patterns of social withdrawal are modest in healthy young adults (Cole, Zapp, Nelson, & Pérez-Edgar, 2012). However, under conditions of stress, the association between asymmetry and social withdrawal is strengthened—reflecting the individual's underlying motivational bias in response to challenge. To compare the dispositional and capability models in the current study we had participants prepare for a short speech. Public speaking is viewed as a social threat by both children and adults (Childs, Vicini, & De Wit, 2006; Schmidt, Fox, Schulkin, & Gold, 1999) and increases both reported and physiological levels of anxiety and stress (Davidson, Marshall, Tomarken, & Henriques, 2000; Westenberg et al., 2009).

An additional limitation of the EEG asymmetry research is the reliance on self-reported or clinician-diagnosed differences in affective or psychiatric state. More information is needed on biological and cognitive mechanisms that may work in tandem with EEG asymmetry to shape observed behavior (Miskovic & Schmidt, 2010). We therefore looked to see if patterns of EEG asymmetry, either at rest or in response to stress, are associated with a cognitive mechanism known to shape broad patterns of socioemotional functioning. Thus, the main analysis examined how individual differences in EEG asymmetry were associated with performance on an emotion-face attention bias task (Mogg, Bradley, De Bono, & Painter, 1997). We focused on attention based on past studies suggesting that biases to threat are causally linked to patterns of socioemotional functioning (Bar-Haim, 2010; Bar-Haim, Lamy, Pergamin, Bakermans-Kranenburg, & van IJzendoorn, 2007). In line with information processing models (Crick & Dodge, 1994), attention may act as a filter, determining which aspects of the environment are available for elaborated processing, interpretation, and implementation. When this filter is biased to attend to threat, cascading processes may lead the individual to judge the environment as threatening, prompting a retreat that may be manifest in social withdrawal or anxiety (Shechner et al., 2012).

The few EEG asymmetry studies examining attention have primarily looked to the emotional Stroop task as a marker of threat-related processing biases (MacLeod, 1991). In this task, participants are asked to ignore the affective content of the presented words and instead note the color of the font. However, the response patterns observed with this task may be due to later interpretive or lexical processes that are unrelated to attentional biases (Algom, Chajut, & Lev, 2004). A recent study (Miskovic & Schmidt, 2010) examined frontal baseline EEG asymmetry and performance in a modified Posner attention task (Posner & Cohen, 1984) using angry and happy emotion faces as cues. Their data indicated that right frontal EEG asymmetry scores at baseline were positively related to biases to angry faces, but not happy faces. However, characterizing levels of relative bias in this task is difficult as only one face is presented at a time.

The dot-probe task (MacLeod, Mathews, & Tata, 1986), in contrast, specifically captures the distribution of participants' attention to simultaneously presented affective stimuli, most often emotion faces. It has also been previously linked to individual differences in socioemotional functioning (Bar-Haim et al., 2007; Pérez-Edgar et al., 2010a, 2011; Wilson, MacLeod et al., 2006) and underlying biomarkers of risk, including frontolimbic connectivity (Hardee et al., in press; Monk et al., 2006, 2008), allelic status

(Pérez-Edgar et al., 2010b; Pergamin-Hight et al., 2012), and cortisol stress response (Applehans & Luecken, 2006). In the current study, participants were presented with two faces side-by-side (one emotionally evocative and one neutral). Participants were asked to indicate the direction of a subsequent target (an arrow) that appeared in the same (congruent) or opposite (incongruent) location of the emotion face. If an individual was faster to respond to congruent cues versus incongruent cues, we inferred a bias toward threat. The opposite pattern indicated an avoidance of threat.

Although the emotion faces were irrelevant to successful task performance, growing evidence suggests that individuals at risk for emotional distress (e.g., anxiety) have greater difficulty recruiting cognitive control mechanisms to ignore task-irrelevant stimuli (Bishop, Duncan, Brett, & Lawrence, 2004). To our knowledge, only one published study to date has compared differences in EEG asymmetry to performance in the dot-probe task. Schutter and colleagues (Schutter, Putman, Hermans, & van Honk, 2001) found no relation between frontal EEG asymmetry at baseline and attention bias—which may be linked to the specific protocol employed (e.g., the use of a vocal response mechanism to note reaction times [RTs]).

The current study was designed to address some of the outlined empirical gaps by examining the relation between EEG asymmetry—both at baseline and in preparation for a stressful task—and attention biases to emotion. Given the complexity of the design and measures, a number of potential analyses were available. We compared the specific predictions generated by the dispositional and capability models. The dispositional model would suggest that EEG asymmetry at baseline would be most closely tied to performance in the dot-probe task. Specifically, we predicted that right frontal EEG asymmetry at baseline would be associated with greater attention biases to threat. The capability model, in contrast, would suggest that the relation would be strongest during speech preparation. A corollary analysis examined the relation between change in EEG asymmetry patterns across conditions and attention bias patterns.

Much of the literature has focused on frontal asymmetry in the alpha (8–13 Hz) frequency band. Less is known concerning asymmetries in the parietal region or in other EEG frequency bands, such as beta (13–30 Hz). However, there are some data to suggest that each may contribute to observed individual differences in emotion processing (d'Alfonso, van Honk, Hermans, Postma, & de Haan, 2000; Keller et al., 2000; Schutter et al., 2001; van Honk, Schutter, Putman, de Haan, & d'Alfonso, 2003). In order to examine the specificity of the findings for frontal alpha EEG asymmetry, two parallel set of analyses were completed using parietal alpha asymmetry and frontal beta asymmetry as predictors of attention bias patterns.

2. Methods

2.1. Participants

Participants were 59 undergraduate students ($M = 21.3$ years, SD = 5.6 years; 23 male) in the psychology research pool at a large public university. Participants were primarily Caucasian, Non-Hispanic (66.1%) with the remaining participants self-identifying as Asian/Pacific Islander (13.6%), African–American (11.95%), and Hispanic (8.5%). The study was approved by the University Institutional Review Board. All participants enrolled on a voluntary basis and received course credit. Prior to beginning the study, each participant met with a research assistant who provided a description of the study and obtained informed consent.

Four participants were excluded for failing to complete the attention bias dot-probe task; an additional two participants were

excluded for poor performance (accuracy <75%). Five participants declined to participant in the EEG portion of the study and an additional three experienced technical difficulties during EEG collection providing no useable data.

The final sample of 45 participants (M = 21.1 years, SD = 5.34, 19 male) with data from both the dot-probe task and at least one portion of the EEG data collection did not differ from the larger pool in age or gender (p's > 0.36). However, the final sample was proportionally more Caucasian (77%).

2.2. Dot-probe task

Most studies have relied on relatively moderate face presentation times (e.g., 500 ms) that allow for more elaborate cortical processing (Monk et al., 2006; Pourtois, Schwartz, Seghier, Lazeyras, & Vuilleumier, 2006). However, the literature suggests that patterns of vigilance and avoidance to threat may shift with increasing exposure to the stimulus of interest (Mogg et al., 1997; Mogg, Bradley, Miles, & Dixon, 2004). In addition, unique patterns of frontolimbic activity have been associated with masked (Carlson, Reinke, & Habib, 2009) or rapid (Monk et al., 2008) presentation of faces (e.g., 17 ms), versus standard presentation times (e.g., 500 ms; Monk et al., 2006). As an exploratory examination of this issue we therefore used two face presentation times in our dot-probe paradigm—500 ms and 17 ms.

The dot-probe task consisted of 192 experimental trials, presented in four blocks of 48 trials each, with experimental conditions randomized within-trials across the four blocks.

Each trial began with a central fixation cross for 500 ms. A face pair was then shown for either 17 ms (followed by a mask for 483 ms) or 500 ms (no mask). The mask consisted of a scrambled neutral face, matching the unscrambled emotion faces in luminosity and black/white ratio. Following the presentation of the cue, a small white arrow (directed up or down) appeared for 1100 ms in the location previously occupied by one of the face pictures. Participants pressed one of two response keys to indicate the direction of the arrow on the screen. The inter-trial interval varied randomly from 750 to 1250 ms.

Face pairs presented at each trial consisted of black and white photos depicting angry, happy, and neutral emotional expressions, obtained from the NimStim face stimulus set (Tottenham et al., 2009). Each emotion was paired with a neutral photograph (i.e., Angry/Neutral, Happy/Neutral, or Neutral/Neutral) and presented for a total of 64 trials each. Trials were designated as congruent if the arrow appeared in the same location as the affective face (i.e., Angry or Happy) and incongruent if the arrow appeared in the location of the neutral face. Face sex, trial congruency, probe presentation time (17 or 500 ms), probe direction (up or down), and probe location (right or left) were counterbalanced throughout the 192 test trials.

RTs and response errors were collected for each trial. Prior to analyses, trials with incorrect responses or extreme values (±2 SD) were removed. Analyses focused on the relative bias patterns evident across the emotional (Angry or Happy) faces. Bias scores were calculated by subtracting the mean RT during congruent trials from the mean RT for incongruent trials. Positive values indicate vigilance for the emotion stimuli, and negative scores indicate avoidance of the emotion stimuli.

2.3. Stress response

2.3.1. Baseline

Participants were seated in a comfortable chair in the electrophysiology testing room. They were then asked to sit quietly for 1 min with eyes open followed by 1 min with eyes closed. These instructions were then repeated for a total of 4 min of baseline data. Analyses relied on the eyes closed condition in order to maximize alpha power.

2.3.2. Speech preparation

Participants were told that they would have to give a short speech about their most embarrassing moment. They were then shown a 2-min video of a purported prior participant (in actuality, the video was of a confederate) giving her embarrassing speech (Cole et al., 2012). The research assistant then gave the participant 2 min to silently prepare and rehearse his or her own speech. EEG signals were collected during this preparation time.

After giving the speech (no EEG was collected during this period due to movement artifact), participants then rated the quality of their speech and their affect in response to the procedure. There were no significant relations for the self-ratings with EEG asymmetry (p's > 0.15) or dot-probe performance (p's > 0.27).

2.4. EEG data

2.4.1. EEG acquisition

EEG data acquisition and analysis were carried out with the SCAN software package (NeuroScan, Texas, USA). Sixty-four channels of EEG and EOG were recorded from the scalp with a Neuro-Scan quick-cap (AgCl electrodes) referenced to an electrode approximately 2 cm posterior to Cz. Horizontal (HEOG) and vertical (VEOG) eye movements were monitored with electrodes placed at the external canthi of each eye and above and below the left eye. Attempts were made to keep all impedances below 10 kΩ. The data from each channel were digitized at a 500 Hz sampling rate (High pass 0.10 Hz; Low pass 40 Hz).

2.4.2. EEG processing

The digitized EEG data were manually inspected and channels with unreliable EEG signals were removed. The data were then re-referenced via the software to give 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: rise-time 100 ms, fall-time 150 ms, peak 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. There were no relations between the amount of EEG data excluded/included in the analyses and the core measures of interest in the study (p's > 0.48).

2.4.3. EEG data analysis

Analyses focused on the homologous frontal (F3 & F4) electrodes traditionally used for asymmetry calculations (Allen, Coan, & Nazarian, 2004). For each electrode site, alpha power was computed as the natural logarithm of power in the 8–13 Hz frequency band during the eyes-closed and speech preparation conditions. Asymmetry scores were then calculated by subtracting alpha from the left electrode (lnF3) from the corresponding electrode over the right hemisphere (lnF4). In the same manner, parietal alpha asymmetry was calculated using activity in the P3 and P4 electrodes in the 8–13 Hz frequency band. Finally, frontal beta asymmetry was calculated using activity in the F3 and F4 electrodes from the 13–30 Hz frequency band.

For frontal alpha asymmetry a positive score reflects greater relative left-sided activity (or greater right-sided power), whereas a negative score reflects greater relative right-sided activity (or greater left-sided power). This is because alpha power is thought to be inversely related to brain activity (Davidson, 2004). In contrast, beta power is thought to directly reflect neuronal activity (Nunez, 2000), with positive correlations between PET perfusion

and EEG beta power (Cook, O'Hara, Uijtdehaage, Mandelkern, & Leuchter, 1998).

Inter-correlations and mean values for the asymmetry scores can be found in Table 1.

2.5. Self-report measures of anxiety and depression

Parallel studies have extensively reported links between anxiety, depression, EEG asymmetry, and attention bias patterns. We therefore looked to see if our findings held above and beyond individual differences in anxiety and depressive symptoms in our generally healthy sample. Accordingly, we had participants complete standard measures of these constructs.

2.5.1. Beck Anxiety Inventory (BAI)

The BAI (Beck, Epstein, Brown, & Steer, 1988) is a 21-item self-report questionnaire that assesses frequency of anxiety symptomatology, with a range of 0–63. In the current study, scores were generally low (Mean = 10.02, SD = 9.15, range 0–45). There were no significant correlations with the EEG asymmetry (p's > 0.28) or dot-probe (p's > 0.12) measures.

2.5.2. Beck Depression Inventory (BDI)

The BDI (Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) is a 21-item, self-report scale, which assesses the severity of depressive symptomatology. Scores may range from 0 to 63. In the current study scores were generally low (Mean = 6.02, SD = 5.76, range 0–24). There were no significant correlations with the EEG asymmetry (p's > 0.34) or dot-probe (p's > 0.30) measures.

3. Statistical analysis

Analyses focused on attention bias patterns during the dot-probe task using a 2 (Emotion Face: Angry/Happy) by 2 (Presentation Time: 17 ms/500 ms) repeated-measures ANCOVA incorporating continuous asymmetry scores from the baseline and speech preparation conditions. This design allowed us to fully capture the range of asymmetry values across the sample while directly comparing responses to the emotion faces.

In our analyses, we initially incorporated numerous demographic and individual difference measures that we believe may have influenced the pattern of the data. These include sex, handedness (N = 2 left-handed based on continuous scores derived from the Edinburgh Handedness Inventory; Oldfield, 1971), baseline

BAI and baseline BDI scores. In each case, the measures were included as an additional covariate in the ANCOVAs. As none of these influenced the pattern of results, they were subsequently removed from the analyses for ease of presentation. In the case of handedness, we also completed the ANCOVAs with and without the two left-handed participants. Again, the findings were unchanged; as such, they were retained in the analyses presented below.

4. Results

4.1. Frontal alpha EEG asymmetry

4.1.1. Attention patterns to happy and angry faces at baseline and during speech preparation

There were no significant effects involving EEG asymmetry for the baseline (p's > 0.15) and speech preparation (p's > 0.30) conditions. We did find a three-way face-by-baseline-by-speech preparation interaction, $F(1,36) = 5.39$, $p = 0.03$, $d = 0.78$. To better understand this complex relation we then repeated the analysis, now using the change in relative EEG asymmetry between the baseline and speech preparation conditions (difference score) in the ANCOVA. Here, we found a face by EEG activation interaction, $F(1,36) = 9.38$, $p = 0.004$, $d = 1.04$.

To illustrate this two-way interaction, individuals with right frontal EEG activation in response to stress (score became more negative, i.e., more right sided) had happy and angry bias scores that differed significantly from one another, $F(1,22) = 10.67$, $p = 0.004$, $d = 1.39$. Follow-up one-sample t-tests (versus zero) indicated that this group displayed significant vigilance to angry faces (9.62 ms), $t(23) = 2.34$, $p = 0.03$, $d = 1.00$, and avoidance of happy faces (−13.75 ms), $t(23) = −2.41$, $p = 0.02$, $d = 1.03$ (Fig. 1).

In contrast, participants with increased left frontal asymmetry (i.e., scores became more positive) in response to the speech task displayed no significant bias to either angry (−3.42 ms) or happy (−2.18 ms) faces, $F(1,13) = 0.14$, $p = 0.72$, $d = 0.21$.

4.1.2. Effect of face presentation time on EEG-attention bias relations

The emotion face by presentation time by EEG asymmetry interaction did not reach significance, $F(1,36) = 1.96$, $p = 0.17$, $d = 0.47$. Although the interaction was non-significant, our initial review of the literature suggested that presentation time may impact observed patterns of attention. As an exploratory analysis, we therefore re-ran the emotion face by EEG asymmetry ANCOVA separately for the 17 ms and 500 ms presentation times. For 500 ms,

Table 1
Pattern of EEG asymmetry for the frontal electrodes calculated for alpha (8–13 Hz) power. Negative scores reflect right frontal activity and positive scores reflect left frontal activity. (a) Correlations between asymmetry scores at baseline and in preparation for the embarrassing speech. (b) Mean frontal alpha EEG asymmetry scores (with standard deviations) for the full sample and individually for participants showing increases in right and left frontal EEG activity.

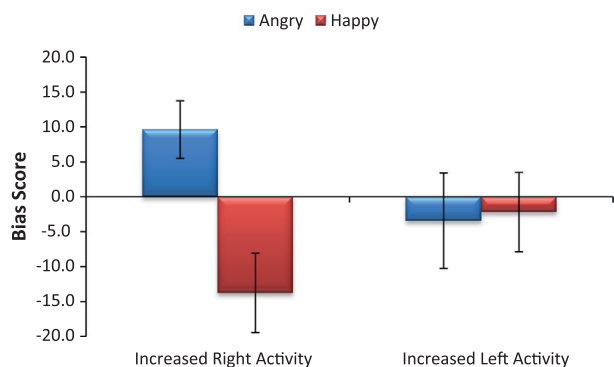| (a)	Baseline	Speech preparation	Change in activity	Angry 500 ms	Happy 500 ms	Angry 17 ms	Happy 17 ms
Baseline	1.00						
Speech Preparation	0.018	1.00					
Change	−0.268[+]	0.958[**]	1.00				
Angry 500 ms	−0.027	−0.067	−0.146	1.00			
Happy 500 ms	−0.011	0.042	0.098	−0.206	1.00		
Angry 17 ms	−0.228	−0.097	−0.021	−0.410[**]	−0.135	1.00	
Happy 17 ms	0.151	0.085	0.065	−0.253[+]	0.035	0.111	1.00
(b)		Full sample		Increased right			Increased left
Baseline		0.009 (0.158)		0.049 (0.129)			−0.071 (0.171)
Speech preparation		0.058 (0.515)		−0.157 (0.196)			0.386 (0.703)
Change in activity		0.049 (0.553)		−0.206 (0.190)			0.456 (0.679)

[+] $p < 0.10$.
[*] $p < 0.05$.
[**] $p < 0.001$.

Fig. 1. Bias scores for the angry and happy faces presented separately for individuals who displayed right frontal alpha activation between baseline and speech preparation and individuals with little change or left frontal alpha activation.

the face by EEG asymmetry interaction approached significance, $F(1,36) = 3.87$, $p = 0.06$, $d = 0.66$, again driven by a bias toward angry faces and away from happy faces in individuals with right frontal EEG activation. In contrast, the equivalent analysis for the 17 ms presentation did not approach significance, $F(1,36) = 0.82$, $p = 0.37$, $d = 0.30$.

4.2. Frontal beta EEG asymmetry

The ANCOVAs for frontal beta EEG asymmetry failed to find any significant asymmetry-linked findings for the baseline (p's > 0.30) or speech preparation (p's > 0.17) conditions; there were no significant findings for change in asymmetry (p's > 0.50).

4.3. Parietal alpha EEG asymmetry

There was a main effect of asymmetry group at baseline, $F(1,36) = 5.46$, $p = 0.03$, $d = 0.74$, such that individuals with right parietal activity avoided both emotion faces (-6.87 ms) and individuals with left activity showed a small bias towards both happy and angry faces (3.86 ms).

There were no significant asymmetry-linked interactions while preparing the speech (p's > 0.06) or when examining activation (p's > 0.16).

5. Discussion

Frontal EEG asymmetry patterns have been consistently linked to broad patterns of affective style (Davidson, 2004) and to the relative strength of approach and withdrawal motivation systems (Harmon-Jones et al., 2010). The current study sought to extend this work by examining the potential association between EEG asymmetry and attention biases to positive and negative emotion faces. We expected that such a relation might exist given that both measures have been associated with the presence and course of social withdrawal and anxiety in children and adults (Bar-Haim et al., 2007; Coan & Allen, 2004b). As a further test of the dispositional and capability models (Coan et al., 2006) we incorporated measures taken at rest and while preparing for a speech task.

In summary, *change* in frontal alpha EEG activity was associated with attention biases to threat in the dot probe task. This relation was not evident individually for either baseline asymmetry or asymmetry during speech preparation. This pattern of null findings for the frontal baseline measure is in line with Schutter et al. (2001). In addition, the findings appear to be somewhat specific to frontal alpha asymmetry as parallel analyses with frontal beta and parietal alpha asymmetries did not find a direct relation with EEG activation. There was a main effect of parietal alpha asymmetry with right asymmetry associated with avoidance and left asymmetry with vigilance, regardless of affect. This is consistent with suggestions that parietal asymmetry is sensitive to the affective (rather than valence) components of a task and reflects the deployment of alerting attention (Fan, McCandliss, Sommer, Raz, & Posner, 2002).

Based on the current data, it appears that the pivotal measure for frontal alpha activity is the change in EEG activity with the introduction of a potential stressor, rather than the absolute beginning or endpoint measure of EEG asymmetry. In line with the capability model (Coan et al., 2006), asymmetry shifts in response to stress or challenge may reflect an individual's prototypical response to the intermittent stressors normally encountered in day-to-day life. An increase in left frontal alpha activity (regardless of the nominal asymmetry score) may reflect an adaptive response with the individual engaging the task at hand; an increase in right frontal alpha activity, in contrast, may reflect maladaptive withdrawal responses. Indeed, as expected, an increase in right frontal EEG activity was later associated with increased attention biases to angry faces and avoidance of happy faces.

This relation may be rooted in the activation patterns of underlying neural systems. In particular, frontal alpha EEG asymmetry has been linked to activity in the dorsolateral prefrontal cortex (dlPFC; Pizzagalli, Sherwood, Henriques, & Davidson, 2005). Left dlPFC activity has been associated with cognitive control and the down regulation of negative affect (Davidson, 2004). In contrast, right dlPFC activity is linked to threat-related vigilance and the capacity to detect threat-related cues (Kalin, Larson, Shelton, & Davidson, 1998). Indeed, alternately suppressing the right and left frontal regions with repetitive transcranial magnetic stimulation (rTMS) shifts patterns of approach and withdrawal behaviors in healthy adults (d'Alfonso et al., 2000). Our data suggest that the functional consequences of activation in these two systems is better captured by the system's response to stress, rather than at rest—in line with the predictions of the capability model (Coan et al., 2006).

In addition, by using two face presentation times (17 ms and 500 ms) we were also able to note the potential chronometry of the attention bias effect. Here, individuals with right frontal EEG alpha activation displayed attention biases to threat for both masked and unmasked faces. Although the interaction with presentation time was not significant, exploratory post hoc analyses suggest that our observed pattern of bias toward threat may be stronger with longer presentation times. This suggests that the response to threat may vary from the earliest stages of processing through presentation times allowing for greater elaboration (Mogg et al., 2004). Our findings also echo fMRI studies in clinically anxious adolescents (Monk et al., 2006, 2008) and healthy adults (Carlson et al., 2009; Pourtois et al., 2006) noting that differing patterns of prefrontal cortex and limbic activation emerges across face presentation times. A larger more robust sample will be needed to assess the pattern of rapid cortical and subcortical processing that may underlie our emerging pattern of data (Pessoa & Adolphs, 2010).

The current design allowed us to contrast individual responses in the face of a mild stressor. Alpha activity reflects mechanisms that support vigilance and rumination (Andersen, Moore, Venables, & Corr, 2009) while suppressing appetitive behaviors (Knyazev & Slobodskaya, 2003). The speech task used here was chosen due to its efficacy in increasing levels of social stress. To speculate, it may be that individuals presenting with increased right frontal activity may be more prone to ruminations and distress when contemplating the impending speech task. Left frontal alpha activation may suggest that an individual uses the same time window to affirmatively prepare for the challenge of the upcoming task—a reflection of an approach motivation.

A number of limitations should be considered when interpreting the findings of the current study. First, our study relied on a relatively small non-clinical sample. As such, we could not capture the full spectrum of affective functioning, limiting full generalizability. Indeed, our generally healthy participant pool may not have been ideally-suited to find baseline effects predicted by the dispositional model. However, our findings do indicate that the observed relations in activation are not dependent on extreme levels of distress or vulnerability to distress. Our positive associations suggest that the inconsistencies found in the literature may arise from the widespread use of baseline-only designs with non-clinical or low-risk samples.

Second, we employed only angry faces as a measure of threat and/or negative affect. Although this approach is in line with much of the literature (Bar-Haim et al., 2007; Fox & Pine, 2012), we cannot say if the current results also extend to other negative emotions, such as fear or disgust.

Third, standardized measures of anxiety were not collected pre- and post-speech. As such, we cannot quantify subjective affective responses to our presumably stressful speech condition. However, prior work (Cole et al., 2012) suggests that the speech task alters the relation between patterns of social withdrawal and EEG asymmetry, suggesting that the manipulation does indeed impact experienced levels of stress.

Fourth, data were collected in a single testing session. Therefore, we cannot comment on the stability of the EEG-attention bias relation over time. Indeed, an exciting new line of work suggests that training attention bias away from threat decreases subsequent levels of anxiety or distress (Hakamata et al., 2010; See, MacLeod, & Bridle, 2009; Wilson, MacLeod, Mathews, & Rutherford, 2006). It is unknown whether EEG asymmetry patterns would also be affected.

Nevertheless, the current study adds to our understanding of the role EEG asymmetry may play in emotion processing, building on theory while comparing empirical relations within a single sample. In doing so, the data suggest that frontal asymmetry within a specific context and change in asymmetry across contexts each reflect related, but distinct, motivational and emotional processes. These associations are evident in cognitive processes (i.e., attention biases) also linked to socioemotional functioning. In particular, a frontal EEG alpha response to threat marked by withdrawal and rumination was associated with attention biases to threat. Future work, in both children and adults, will be able to examine the specificity and stability of the current findings across time and context. Our data suggest that individual differences in response to challenge may give greater insight into underlying motivational systems and the mechanisms by which they impact observed patterns of behavior.

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