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Frontal EEG and emotion regulation: Electrocortical activity in response to emotional film clips is associated with reduced mood induction and attention interference effects

Tracy A. Dennis *, Beylul Solomon

Hunter College, The City University of New York, United States

ABSTRACT

Frontal EEG activity is thought to reflect affective dispositions, but may also reflect the emotional demands of a specific context combined with the capability to regulate emotions in that context. The present study examined this hypothesis by testing whether frontal EEG activity during mood inductions versus a resting baseline predicted emotion regulation. EEG was recorded while participants ($N = 66$, 40 females) received a fearful, sad, or neutral mood induction. Emotion regulation was measured following the mood inductions as self-reported change in negative mood and as attention interference in a task with mood-congruent emotional distracters. Greater frontal EEG activity during the mood inductions versus baseline was associated with more effective emotion regulation: less post-induction sadness and anxiety and reduced mood-congruent attention interference effects. Effects did not differ between the left and right hemispheres. Results support the hypothesis that frontal EEG activity reflects both emotional context and emotion-regulatory capabilities.

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1. Introduction

Greater left frontal EEG activity measured during resting conditions has been associated with a disposition for behavioral approach and the expression of approach-related emotions such as happiness and anger, whereas relatively greater resting right frontal EEG activity has been associated with a disposition for behavioral withdrawal and the expression of avoidance-related emotions such as sadness, fear, and anxiety (e.g., Coan and Allen, 2004; Harmon-Jones and Allen, 1998; Hugdahl and Davidson, 2003; Schmidt and Fox, 1998). Such findings have been used to support the dispositional view of frontal EEG, and are consistent with research on traumatic brain injury due to stroke showing that damage to the left frontal cortex compromises the ability to down-regulate negative emotion (House et al., 1989; Watson et al., 1995), although a meta-analysis of lesion studies failed to support this hypothesis (Carson et al., 2000).

Complementing this dispositional view, the capability model of frontal EEG asymmetry suggests that while EEG activity may reflect such general affective dispositions, individual differences in frontal EEG may more accurately be thought of as emerging from the interaction between the emotional demands of a specific situation and the emotion-regulatory abilities of the individual in that context (Coan et al., 2006). Therefore, while the dispositional view examines EEG under resting conditions, the capability model and others argue that frontal EEG should be measured in specific emotional contexts in order to better measure an individual's capacity to respond emotionally (Coan and Allen, 2003; Coan et al., 2001; Davidson et al., 1990; Harmon-Jones et al., 2003). For example, Coan et al. (2006) found that frontal EEG asymmetry during a fear induction (directed facial actions) relative to baseline was a better predictor of negative affectivity. On the other hand, positive affectivity was predicted equally well by EEG during a resting and joy induction condition. Thus, the linkages between EEG and affect might be particularly sensitive to the context of measurement for negative emotions.

Frontal EEG activity, however, may reflect not only the degree to which an individual is capable of an emotional response in a specific context, but the degree to which they are able to inhibit those responses. Indeed, because frontal EEG activity should reflect at least in part activity of the prefrontal cortex, there is a strong likelihood that EEG asymmetry will be associated with emotion regulation capacity (Davidson, 2004). Researchers examining the neural correlates of emotion regulation have emphasized the role of the prefrontal cortex (e.g., Johnstone et al., 2007; Ochsner et al., 2002, 2004; Wager et al., 2008), and suggest several competing predictions about the lateralization of effects. For example, one study documented that healthy controls showed greater activation in left

* Corresponding author at: Department of Psychology, Hunter College, City University of New York, 695 Park Avenue, New York, NY 10065, United States. Tel.: +1 212 650 3878; fax: +1 212 650 3931.
   E-mail address: tracy.dennis@hunter.cuny.edu (T.A. Dennis).

but not right ventrolateral prefrontal cortex activation (vPFC) when using cognitive emotion regulation to reduce negative emotion (Johnstone et al., 2007). In contrast, other studies have documented bilateral vPFC activation (Ochsner and Gross, 2007) and right vPFC activation (Wager et al., 2008) when using cognitive emotion regulation to reduce negative emotion. The latter study further found that greater right vPFC activation was correlated with reductions in self-report of negative emotion (Wager et al., 2008).

Given these contrasting findings in terms of the lateralization of PFC activation during emotion regulation, the current study examined several possibilities. First, EEG asymmetry effects could emerge such that individuals who respond to a negative mood induction (compared to baseline) with greater right frontal activity may be more likely to both experience and regulate negative emotions in that context – thus resulting in reduced negative affect. Although consistent with Wager et al. (2008), this prediction is in direct contrast to the dispositional view, which would posit that this pattern of EEG would be associated with increased negative affect. Therefore, a second possibility is that individuals who respond to a mood induction with greater left frontal activity may show improved regulatory ability. This prediction is in line with previous neuroimaging research (Johnstone et al., 2007), with EEG asymmetry research documenting the role of left frontal activity in enhanced emotion regulatory behavior (startle modulation; Henriques and Davidson, 1990), and with research on the emotional implications of stroke-related damage to the left frontal hemisphere (House et al., 1989; Watson et al., 1995). On the other hand, damage to both frontal lobes has been linked to heightened emotional disruptions (Bramham et al., 2009; Hornak et al., 2003) Indeed, consistent with findings from Ochsner and Gross (2007), a third possibility is that bilateral EEG activity will be most closely associated with the ability to regulate negative emotions. In the present study, we examined whether asymmetric or bilateral effects would emerge by testing whether greater right, left, or bilateral frontal EEG activity during a negative mood induction (sadness and fear), compared to baseline, was associated with reduced self-report of negative affect after the induction.

Most studies of EEG asymmetry and emotion measure subjective affect, and only rarely test regulatory capacity in the context of emotional demands, such as the regulation of cognition and attention in relation to negative mood. For example, anxious mood is associated with preferential attention towards negative emotional stimuli and difficulty disengaging attention once it is captured (Compton, 2003; Fox et al., 2001, 2002; MacLeod and Mathews, 1988). Mood congruence may amplify such attentional biases (Gilboa-Schechtman et al., 2000; Williams et al., 1996); namely negative emotional information that is congruent with a specific negative mood increases attentional interference effects (Easterbrook, 1959; Hanoch and Vitouch, 2004; Leith and Baumeister, 1996; Meinhardt and Pekrun, 2003), particularly when the emotional information distracts from the target attention task (Compton, 2003). In particular, mood induction of fear and anxiety has been associated with reduced orienting and executive attention performance following fear-related stimuli (Keogh and French, 1999; Mogg et al., 1992). Similar mood-congruent patterns have been reported in relation to depressed mood (Gilboa-Schechtman et al., 2000; Joormann et al., 2007; Ladouceur et al., 2005; Whitehouse et al., 2000) and anxiety (Eastwood et al., 2003; Fenske and Eastwood, 2003; Fox et al., 2001; Mogg et al., 1992; Schupp et al., 2003).

Few studies of emotional interference assess multiple aspects of attention in a single paradigm (Callejas et al., 2004; Fan et al., 2002). This is a critical goal because emotional factors may differentially influence separable attention capacities such as alerting, orienting, and executive attention (Fan et al., 2002; Posner and Petersen, 1990). Orienting may be particularly sensitive to affec-

tive interference. For example, research shows disrupted ability to shift attention away from threat once it is engaged (Fox et al., 2008). This difficulty disengaging and shifting attention is thought to play a key causal role in anxiety disorders (Mathews and MacLeod, 2002; Mogg and Bradley, 2004).

If greater frontal EEG activity is associated with an enhanced capacity to regulate negative emotions, then it should also result in decreased attention-interference by mood congruent emotional stimuli. The present study tested this hypothesis. In the current study, we measured attention interference by emotional distracters by modifying the ANT: each trial was preceded by fearful, sad, or neutral faces. Faces occurred prior to the target attention task and gave no information about the timing or content of the upcoming trial (Dennis and Chen, 2007a,b; Dennis et al., 2008). Faces were chosen because they are emotionally salient and socially significant; however, since they were task-irrelevant, interference effects linked to faces are likely to reflect emotional distractibility and capture of attention. Before completing the attention task, participants took part in one of three mood induction conditions (film clips portraying fearful, sad, or neutral situations). This design allowed us to assess EEG during a resting baseline and during the mood inductions in relation to the efficacy of the mood induction, as well as in relation to the impact of mood induction on attention performance when emotional stimuli were congruent or incongruent with the mood induction.

The *first prediction* was that participants showing greater frontal EEG activity during a negative mood induction versus baseline will be more capable of regulating subjective negative emotions; therefore they will report reduced rather than enhanced subjective negative affect following the mood induction. We will test whether effects are stronger for activity in the left or right hemisphere, or if effects are bilateral. The *second prediction* was that mood-congruent attention interference effects will emerge, but will be reduced for those showing increased frontal EEG activity during the face-congruent negative mood induction versus baseline (e.g., attention performance following fearful faces will be facilitated when participants show greater EEG activity during the fear mood induction). We will again test for differences or similarities between the hemispheres.

2. Method

2.1. Participants

Sixty-nine undergraduate students (28 men and 41 women) participated in this experiment as part of a class requirement for an introduction to psychology course at a college in New York City. Two participants were excluded from analyses because they were left-handed, and one was excluded due to poor quality EEG recording, leaving a final sample size of 66 (40 women). Participants were between the ages of 18 and 59 (M = 22.86, SD = 7.99). According to self-report, participant race/ethnicity was as follows: 26 Caucasian, 13 Hispanic, 21 Asian, and 6 African American. Participants were screened for psychological or neurological impairments through open-ended self-report.

2.2. Materials and procedures

On arrival to the session, participants gave informed consent. Participants spent approximately 2 h in the laboratory and completed a series of questionnaires immediately after consent procedures. Following the questionnaire period, scalp electrodes were applied after which participants took part in one of three mood inductions (fearful, sad, or neutral) and completed the attention task with emotional distracters. The following number of participants was assigned to each mood induction: 20 for the fearful mood induction, 24 for the sad mood induction, and 22 for the neutral mood induction.

2.2.1. Questionnaires

To measure individual differences in pre-induction mood, participants completed state and trait versions of the State Trait Anxiety Inventory (STAI; Spielberger, 1983) and the Beck Depression Inventory (BDI; Beck et al., 1961). Averages scores and ranges for depressed mood were M = 8.41, SD = 6.57, range = 0–34, and for trait anxiety were M = 41.64, SD = 7.61, range = 26–59. These scores were consistent with those reported for a normative sample of adults and college students. Internal con-

(a)

Fear   Sad   Neutral

(b)

No cue   Center cue   Double cue   Spatial cue

(c)

Neutral   Congruent   Incongruent

(d)

Face

Cue

Target

50 msec

D1 = 600 - 1300 msec

100 msec

400 msec

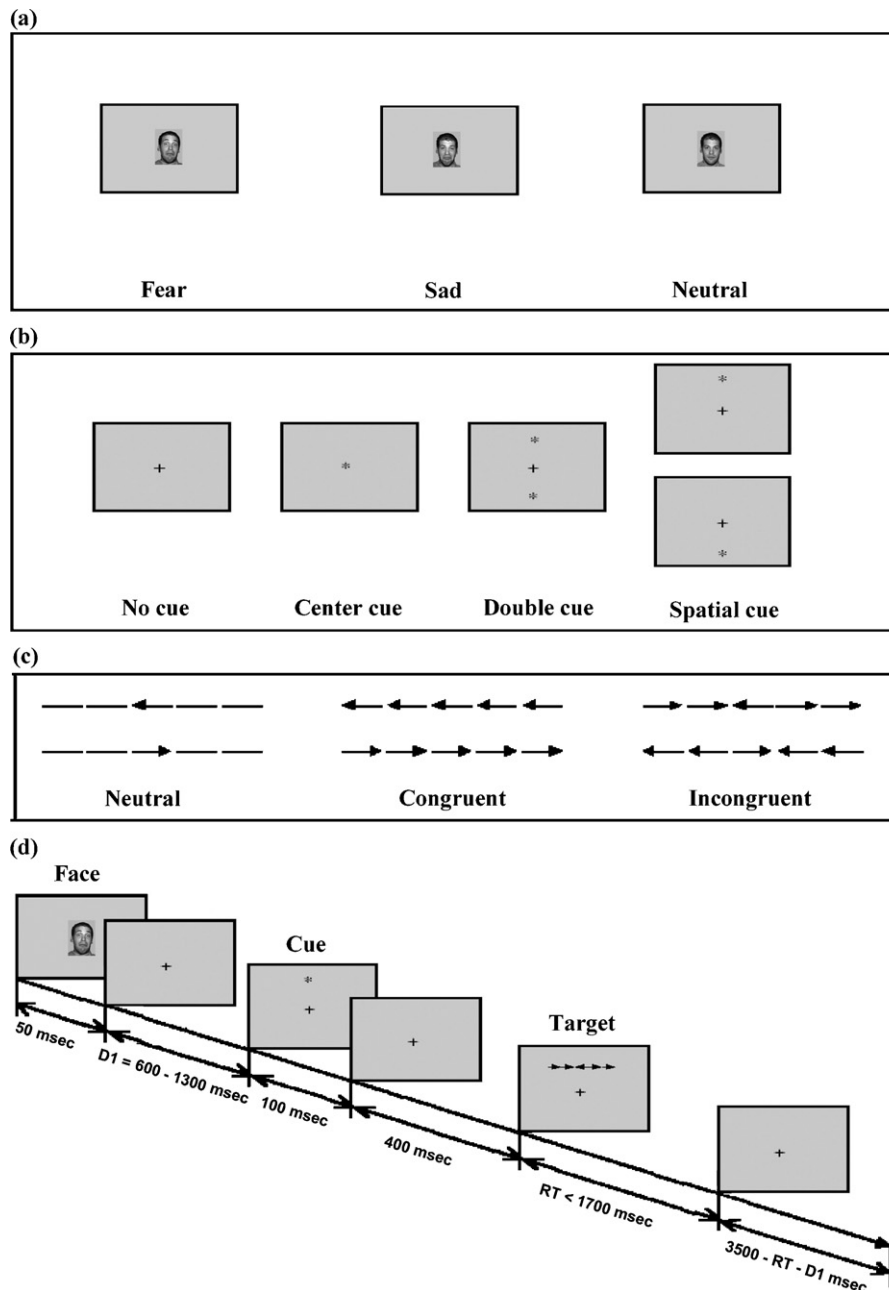RT < 1700 msec

3500 - RT - D1 msec

Fig. 1. Diagram of the Attention Network Test, modified to include emotionally distracting faces.

sistency for the depressed mood scale was $\alpha = .84$ and for the trait anxiety scale was $\alpha = .63$.

The state anxiety version of the STAI was completed again after the mood induction as a measure of differences in levels of state anxiety before versus after the mood induction. To measure pre- and post-induction sadness, participants completed the Differential Emotions Scale (DES; Izard, 1977) both at the outset of the laboratory visit and again after the mood induction. The latter scale consisted of asking, "How much do the following words describe how you feel right now or generally: downhearted, sad, discouraged" on a 5-point Likert scale with 1 indicating "Not at all" to 5 indicating "Very Strongly." Average state anxiety before all mood inductions was $M = 40.29$, $SD = 8.04$, range $= 23–61$ and after was $M = 37.50$, $SD = 7.97$, range $= 19–57$. Average sadness before all mood inductions was $M = 5.50$, $SD = 3.10$, range $= 3–15$ and after all mood inductions was $M = 4.89$, $SD = 2.65$, range $= 3–15$. Participants in each of the three mood conditions did not vary in self-report of state and trait mood at baseline.

2.2.2. Mood induction

Following the questionnaire period, participants were moved to a dark, semisoundproof room in which they remained for the duration of the experiment. Here they viewed either the fearful, neutral, or sad mood induction clip (see Appendix A).

For each condition, two film segments representing the same mood were joined to make one 4- to 6-min clip. The order of the segments was counterbalanced across subjects within each condition. All stimuli, including mood induction, were presented on an IBM computer running Windows XP, equipped with a 14-in. IBM monitor and a mouse. The software used was E-Prime version 1.1, a commercial experiment-generating application created by Psychology Software Tools (Psychological Software Tools, Pittsburgh, PA). Participants viewed the screen from a distance of approximately 65 cm and about 35° of visual angle horizontally and vertically.

2.2.3. Attention task

After the questionnaire period and mood inductions, participants were administered a modified version of the Attention Network Test (ANT; Fan et al., 2002). The ANT combines a cued reaction time and flanker task. It quantifies the efficiency of three attention systems, alerting, orienting, and executive attention, by measuring how response times to the target arrow are influenced by alerting and spatial cues and flankers, and the congruence or incongruence of the arrows flanking the central target arrow. Responses were collected via two buttons on the mouse.

The ANT was modified by including faces as emotional distracters (for a full description, see Dennis and Chen, 2007a,b; Dennis et al., 2008). As seen in Fig. 1,

fearful, sad, or neutral faces are presented for 50 ms before each trial of the task. Faces provide no information about the attention task. Following the face, a valid cue is presented, followed by the target arrow, which randomly appears either above or below the fixation cross and is surrounded on the left and right by four "flanker" arrows. Participants indicate with one of two alternative button presses whether the central target arrow points left or right.

Cues are no cues, double cues (asterisk appears simultaneously above and below the fixation cross), center cues (asterisk appears superimposed over the fixation cross), and spatial cues (asterisk appears above or below the fixation cross to indicate the location of the subsequent target). Cues modulate whether subjects are alerted to the impending stimulus, and whether subjects are oriented ahead of time to the location of the target. Congruent flankers point in the same direction as the central target arrow, incongruent flankers point in the opposite direction, and neutral flankers have no directional information.

Efficiency of the three attention networks, alerting, orienting, and executive attention, is determined by measuring how response times to the flanker displays are influenced by alerting cues, spatial cues, and flanker type (see Fan et al., 2002 for additional details). Using correct trials only, the efficiency of *alerting* is calculated as reaction time (RT) following no cue – RT double cue. The double cue was used because it diffuses attention between the two potential target locations while alerting the participant to the arrival of the target. Higher scores indicate greater alerting efficiency due to the presence of cues. The efficiency of *orienting* is calculated as RT following center cue – RT spatial cue. Higher scores indicate greater orienting efficiency due to the presence of spatially predictive information of one cue, while controlling for alerting effects in the other. The efficiency of *executive attention* is calculated in terms of conflict interference: RT to incongruent flankers – RT to congruent flankers. Higher scores indicate greater conflict interference or *less* efficient executive attention.

The experiment consisted of a 24-trial full-feedback practice block (reaction time, whether answer was correct, and cumulative success rate) followed by three blocks of feedback-free trials (182 trials per block). Block order was counterbalanced across subjects. Each trial consisted of six events: (1) face presented over the central fixation cross at the beginning of each trial (fearful, sad, or neutral; 50 ms); (2) fixation period (variable 600–1300 ms); (3) cue condition (no cue, center cue, double cue, spatial cue; 100 ms); (4) fixation period (400 ms); (5) simultaneously presented target and flanker stimuli (terminated at response up to 1700 ms); and (6) post-target fixation period (varied, based on the first fixation and reaction time for that trial). Each trial lasted for 4050 ms. One face type was presented per block.

Faces were taken from a battery developed by the Research Network on Early Experience and Brain Development (Tottenham et al., 2009), and were selected based on normative ratings of the faces for emotional facial expressions. Participants were informed that there would be faces presented at the beginning of each trial of the task, but were not instructed to attend or not attend. Because faces were completely unrelated and uninformative for performance of the primary ANT task, this design provides a simple but effective way to examine the effect of task-irrelevant emotional stimuli on attention performance.[1]

2.3. Psychophysiological recording and data reduction

EEG activity was recorded continuously via 64 Ag/AgCl active scalp electrodes embedded in an elasticized nylon ECI cap and from two electrodes placed on the right and left mastoids. Eye movements were monitored by electro-oculogram (EOG) signals from electrodes placed approximately 1 cm above and below the left eye and from electrodes 1 cm lateral to each eye. As per BioSemi system design (BioSemi, Amsterdam NL), the ground electrode during acquisition was formed by the Common Mode Sense active electrode and the Driven Right Leg passive electrode. Recordings were referenced off-line to an average reference. Analyses were also conducted with EEG data referenced offline to the Cz electrode. Results were identical to those reported here, except for one significant difference between hemispheres for the analyes on changes in self-report of anxious mood. This difference is footnoted below.[2]

EEG and EOG signals were amplified with a band pass of .16–100 Hz by BioSemi ActiveTwo amplifier and sampled at 512 Hz. The raw EEG epochs were passed

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[1] At the completion of the attention task, participants rated each distracter face using the Self-Assessment Mannequin technique (Lang et al., 1998). Faces were rated on a 1–5 scale for arousal, with 5 indicating highly arousing, and a 1–5 scale for valence, with 1 being very positive and 5 being very negative. Sad faces ($M = 3.97$, $SD = 0.67$) and neutral faces ($M = 3.99$, $SD = 0.72$) were rated as more arousing than fearful faces ($M = 3.69$, $SD = 0.69$; $t(65) = 4.78$, $p < .001$ and $t(65) = 3.45$, $p < .001$, respectively); on the other hand, sad faces were rated as more negative ($M = 3.38$, $SD = 0.83$) than fearful faces ($M = 3.05$, $SD = 0.75$; $t(65) = 5.46$, $p < .001$) and neutral faces ($M = 2.97$, $SD = 0.44$; $t(65) = 4.06$, $p < .001$).

[2] When a Cz reference was used, a significant difference between the hemispheres emerged for EEG during the fearful mood induction: the association between EEG activity and anxious mood was significantly greater in the right versus left hemisphere during the fearful mood induction, $p < .01$.

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through a computerized artifact scan batch. Trials with EEG or EOG activity remaining above ±100 μV were excluded from further analysis.

EEG was measured during rest and during the mood induction period. Resting EEG was measured while subjects sat quietly during eight 1-min periods, with the counterbalanced order of the eyes-open (O) or eyes-closed (C) conditions across participants (C, O, O, C, O, C, C, O or O, C, C, O, C, O, O, C). Participants were instructed to remain still and to blink or move their eyes and body as little as possible during the recording periods. All artifact-free EEG data were transformed to raw power scores using a Fast Fourier Transformation (FFT), with a Hanning window of 1-s width and 50% overlap. Power (microvolts-squared) was computed in the alpha frequency band (8–13 Hz), and these values were averaged across 1-s segments. The following number of artifact-free epochs were available for analysis in the baseline and mood inductions: baseline $M = 213.62$, $SD = 127.85$; mood induction $M = 149.87$, $SD = 86.78$. Average alpha power values at target recording sites were then log transformed using the natural log: fronto-polar (Fp1, Fp2), frontal (F3, F4), temporal (T7, T8), and parietal (P3, P4). Cortical alpha power is considered to be inversely correlated with cortical activity; therefore, higher EEG scores suggest less activity (Davidson and Tomarken, 1989). Because the focus of analyses was to compare effects of EEG during baseline versus mood induction conditions rather than EEG in anterior versus posterior regions, EEG from leads in the mid-frontal region (F3, F4) was used to measure frontal asymmetry and EEG from leads in the parietal region (P3, P4) was used to measure posterior asymmetry.

3. Results

3.1. Effects of mood induction on EEG asymmetry

Using the log transformed EEG power in the alpha bandwidth from frontal (F3, F4) and posterior (P3, P4) recording sites during baseline and the mood inductions we conducted a repeated-measure ANOVA to examine the impact of the mood induction on EEG asymmetry. Time (baseline versus mood induction) and Hemisphere (left versus right) as the within-subjects variables and mood induction (fear, sad, neutral) as the between-subjects variable.

No significant effects emerged for posterior electrodes. In contrast, for frontal electrodes, there was a significant interaction between Time and Hemisphere, $F(1,66) = 7.80$, $p = .007$, partial $\eta^2 = .11$. Although EEG alpha power decreased from baseline to each mood induction in both frontal hemispheres (indicating expected increases in neural activity during the mood inductions), activity was reduced (alpha power increased) in the right hemisphere in all conditions (baseline left hemisphere $M = 9.46$, $SD = 13.04$, baseline right hemisphere $M = 10.80$, $SD = 13.80$; fear left hemisphere $M = 2.97$, $SD = 2.90$, fear right hemisphere $M = 3.49$, $SD = 2.96$; sad left hemisphere $M = 2.82$, $SD = 2.73$, sad right hemisphere $M = 3.56$, $SD = 2.87$; neutral left hemisphere $M = 2.82$, $SD = 2.35$, neutral right hemisphere, $M = 2.94$, $SD = 1.82$). There were no effects of mood induction on frontal EEG alpha power. Thus, counter to predictions, fear and sad mood inductions were not related to greater right frontal asymmetry compared to the neutral mood induction.

3.2. Analytic plan

Unless otherwise noted, subsequent hypotheses were tested with linear mixed effects models (Laird and Ware, 1982) using the SPSS version 15.0 mixed model procedure (Peugh and Enders, 2005). Analyses were conducted separately for frontal and posterior electrodes. Because no significant effects emerged for posterior electrodes, only analyses for anterior electrodes are reported below. The first model predicted change in self-report of sadness (induction – baseline), and the second model predicted change in self-report of state anxiety/fear (induction – baseline); therefore, more positive change scores indicate greater sadness or anxiety following the mood induction. The third model predicted attention performance following fearful, sad, or neutral faces. For each model, EEG activity (the inverse of power) was the predictor. Within-subjects fixed effects were Hemisphere (left or right) and Time (measurement during baseline or induction) nested within mood induction (fearful, sad, and neutral). Subjects were the random effects. Linear mixed models are particularly well-suited for

Table 1
ANOVA table for linear mixed models fixed effects.

	Sadness	Anxiety	Orienting
Mood induction (MI) df (2, 7,104)	$F = 61.90^{***}$	$F = 25.39^{***}$	$F = 14.56^{***}$
Hemisphere (H) df (1, 7,104)	Ns	Ns	Ns
Time (T) df (1, 7,104)	$F = 24.43^{***}$	$F = 53.38^{***}$	$F = 23.85^{***}$
H within MI df (2, 7,104)	$F = 4.84^{*}$	Ns	Ns
T within MI df (2, 7,104)	$F = 43.36^{***}$	$F = 3.98^{*}$	$F = 12.02^{***}$
H × T within MI df (3, 7,104)	Ns	Ns	Ns
T × Face (F) within MI df (12, 7,104)	--	--	$F = 50.24^{***}$

Outcome variables are sadness change scores, anxiety change scores, and orienting performance.
* $p < .05$.
*** $p < .001$.

repeated measurements within the same subject that can lead to positive correlations between measurements (e.g., EEG from different hemispheres and times). This analytic approach provided the opportunity to estimate whether EEG activity during baseline versus mood induction influenced the effects of mood induction on self-report of emotional state and attention interference by emotional distracters. In addition, by examining right and left frontal EEG separately, we could test for significant differences between the two hemispheres, which an asymmetry difference score does not reveal. The linear mixed model yields an ANOVA table of overall effects, and estimates for simple and interaction effects.

3.3. Mood induction effects on self-report of emotional state

We first tested whether the mood inductions were associated with self-reported changes in sadness and state anxiety. As seen from the ANOVA results in Table 1, there were significant main effects of mood induction on both sadness and state anxiety change scores. Inspection of intercepts shows that participants reported more sadness following the sad mood induction compared to the fearful and neutral mood inductions (between-group *t*-tests *p*'s < .001; sad = 0.68, SE = 0.05; fear = −1.16, SE = 0.05; neutral = −1.25, SE = 0.06; coefficients all significantly different from zero, *p*'s < .001). However, participants reported lower state anxiety following all the mood inductions, although this association was greatest for the neutral mood induction (between group *t*-tests *p*'s < .001; fear = −1.92, SE = 0.10; sad = −2.05, SE = 0.10; neutral = −3.90, SE = 0.12; all significantly different from zero, *p*'s < .001). Thus, according to self-report, the sad and neutral mood inductions appeared to be effective, whereas the fearful mood induction may not have been in terms of subjective anxiety.

We next tested the hypothesis that frontal EEG activity will moderate the impact of mood inductions on subjective sadness and anxiety: as EEG activity increases during the negative mood inductions versus baseline, individuals should regulate more effectively and thus report reduced sadness and anxiety. *To interpret effects, direction of associations should be reversed (reflecting that activity is the inverse of alpha power).*

3.3.1. Sad mood

The effect of mood induction on sad mood was moderated by a significant interaction with EEG measurement Time and with Hemisphere (Table 1). As predicted, as EEG activity increased during the sad mood induction, subjective sadness decreased (Table 2). This association was significantly greater for EEG during the mood induction compared to baseline. No other associations between EEG and self-report of sadness reached significance. Although there was a significant overall interaction between mood induction and Hemisphere, no individual comparisons between the left and right hemispheres reached significance.

3.3.2. Anxious mood

The effect of mood induction on anxious mood was moderated by a significant interaction with EEG measurement Time (Table 1). As predicted, as EEG activity increased during the fearful mood induction, state anxiety decreased (Table 3). This association was significantly greater for EEG during the mood induction compared to baseline. This same pattern emerged for the sad mood induction: as EEG activity increased during the sad mood induction, state anxiety decreased. This effect was significantly greater during the

Table 2
Estimates of the association between EEG frontal power (in the left and right hemispheres at baseline and during the mood inductions) and self-report of sadness.

	Hemisphere		
	Left	Right	L-R
Fearful mood induction			
Baseline (*B*)	0.01 (0.01)	0.003 (0.01)	Ns
Induction (*I*)	−0.02 (0.03)	−0.04 (0.03)	Ns
I − B	Ns	Ns	
Sad mood induction			
Baseline (*B*)	0.06 (0.01)***	0.06 (0.01)***	Ns
Induction (*I*)	0.29 (0.03)***	0.32 (0.03)***	Ns
I − B	0.23***	0.26***	
Neutral mood induction			
Baseline (*B*)	0.03 (0.01)	0.02 (0.01)	Ns
Induction (*I*)	0.05 (0.04)	0.04 (0.04)	Ns
I − B	Ns	Ns	

Note: Estimates (*B*, standard error of *B*, and significant *p* values) of the EEG fixed effects on self-report of sadness are shown in this table. The dependent variable is baseline to post-mood-induction sadness change scores (induction − baseline), with more positive scores indicating increases in sadness after the mood induction. *I − B* is the difference between the *B* values in the induction versus baseline.
*** $p < .001$.

Table 3
Estimates of the association between EEG frontal power (in the left and right hemispheres at baseline and during the mood inductions) and self-report of anxiety.

	Hemisphere		
	Left	Right	L-R
Fearful mood induction			
Baseline (*B*)	0.23 (0.02)***	0.18 (0.02)***	Ns
Induction (*I*)	0.63 (0.07)***	0.51 (0.07)***	Ns
I − B	0.40***	0.33***	
Sad mood induction			
Baseline (*B*)	0.15 (0.02)***	0.13 (0.02)***	Ns
Induction (*I*)	0.55 (0.07)***	0.49 (0.06)***	Ns
I − B	0.40***	0.36***	Ns
Neutral mood induction			
Baseline (*B*)	−0.08 (0.03)*	−0.06 (0.03)*	Ns
Induction (*I*)	−0.03 (0.08)	−0.05 (0.09)	Ns
I − B	Ns	Ns	

Note: Estimates (*B*, standard error of *B*, and significant *p* values) of the EEG fixed effects on self-report of anxiety are shown in this table. The dependent variable is baseline to post-mood-induction anxiety change scores (induction − baseline), with more positive scores indicating increases in anxiety after the mood induction. *I − B* is the difference between the *B* values in the induction versus baseline. **$p < .01$.
* $p < .05$.
*** $p < .001$.

Table 4
Attention performance scores following each face type.

	Mood induction			
	Fearful (*N* = 20)	Sad (*N* = 24)	Neutral (*N* = 22)	Total
Alerting				
Fear	9.55 (46.51)	20.30 (42.63)	19.57 (39.44)	16.80 (42.44)
Sad	11.52 (57.05)	13.50 (36.99)	19.17 (33.66)	14.79 (42.57)
Neutral	1.70 (111.99)	18.64 (43.50)	8.81 (44.38)	10.23 (70.86)
Orienting				
Fear	−.01 (48.51)	26.44 (45.77)	19.07 (42.87)	15.97 (46.32)
Sad	37.42 (33.49)	18.59 (54.08)	42.21 (43.87)	32.17 (45.77)
Neutral	36.51 (48.73)	39.48 (52.74)	34.84 (48.26)	37.03 (49.34)
Executive				
Fear	116.67 (67.54)	96.75 (51.11)	96.12 (49.82)	102.58 (56.10)
Sad	148.55 (106.51)	108.91 (53.84)	118.16 (65.62)	124.00 (77.55)
Neutral	113.39 (49.36)	96.23 (59.39)	123.01 (67.12)	110.36 (59.57)

Note: Values are means and standard deviations (in parentheses).

sad mood induction compared to baseline. No significant effects emerged for the neutral mood induction, although greater EEG activity at baseline prior to the neutral mood induction was associated with increased reports of state anxiety. In summary, consistent with hypotheses, as EEG activity increased during the fearful mood induction, self-report of anxious mood decreased; this effect, however, was not specific to the fearful mood induction, and there were no differences between the hemispheres.[2]

3.4. Behavioral data: attention performance following emotional distracters

Table 4 shows mean attention scores (alerting, orienting, and executive attention, correct trials only) for all faces and mood induction conditions. Error rates varied between 3% and 4%. Log transformations were applied to attention scores to correct for non-normal distributions. Analyses conducted with transformed versus untransformed data were virtually identical. Therefore, non-transformed data were used and reported below.

It was hypothesized that participants receiving fearful and sad mood inductions would show enhanced attention interference effects following presentation of mood-congruent fearful and sad emotional faces. This first analysis examined behavioral performance without taking individual differences in EEG activity into account. Repeated measures ANOVAs were conducted: 3 (mood induction: fear, sad, neutral) × 3 (emotional face: fear, sad, neutral) for alerting, orienting, and executive attention scores separately. Where assumptions of sphericity were violated, Greenhouse–Geisser corrections are reported.

No significant effects emerged for alerting. For orienting, the significant main effect of emotional face ($F(2,126) = 6.67$, $p = .002$, partial eta$^2 = .10$) showed that orienting was less efficient following fearful compared to sad and neutral faces (both p's < .01). As predicted, the significant mood induction × emotional face interaction ($F(4, 126) = 2.70$, $p = .049$, partial eta$^2 = .08$) emerged (see Fig. 2). Within the fearful mood induction, orienting following fearful faces was less efficient compared to orienting following sad ($t(19) = 2.91$, $p = .009$) and neutral faces ($t(19) = 2.79$, $p = .012$). Orienting following fearful faces, however, did not significantly differ among the mood inductions, although there was a trend ($p = .10$) such that orienting following fearful faces was significantly less efficient when participants received the mood-congruent fear induction compared to the sad mood induction. In addition, within the sad mood induction, orienting following sad faces was less efficient compared to orienting following neutral faces ($t(23) = 2.97$, $p = .007$). Also, orienting following sad faces was significantly less efficient when participants received the mood-congruent sad mood induction compared to when they received the fearful ($t(42) = 2.23$, $p = .03$) or neutral mood induction, ($t(44) = 2.42$, $p = .02$). Thus, behavioral

interference effects of fearful and sad faces were maximal when mood inductions were congruent with the emotional face.

For executive conflict interference, there was a main effect of emotional face ($F(1.82, 114.47) = 3.09$, $p = .054$, partial eta$^2 = .05$). Conflict was reduced, and thus executive attention more efficient, following fearful compared to sad faces ($p = .014$).

3.5. EEG and attention performance following emotional distracters

The next hypothesis was that as EEG activity increases during the negative mood inductions, mood congruent attention interference effects will be reduced. Given that behavioral data showed a significant interaction between emotional face and mood induction only for orienting, we focused solely on EEG as a predictor for orienting following fearful, sad, and neutral faces. As seen from the ANOVA results in Table 1, there were significant main effects of Mood Induction, Time, Time within Mood Induction and Time by Face within Mood Induction. Table 5 shows simple effects and significant differences between EEG during inductions versus baseline. There were no significant differences between EEG power in the left and right hemispheres for any comparisons and thus these are not reported in Table 5. All comparisons between coefficients were made within the linear mixed effects model; those that reached significance and are reported below were all $p < .01$.

The top third of Table 5 shows associations between EEG power and orienting following each face type for participants in the fearful mood induction. As EEG activity increased in both hemispheres during the fear induction, orienting following fearful faces became more efficient, particularly for EEG during the induction versus baseline. Associations between EEG and orienting following fearful faces were significantly greater for the fearful compared to sad
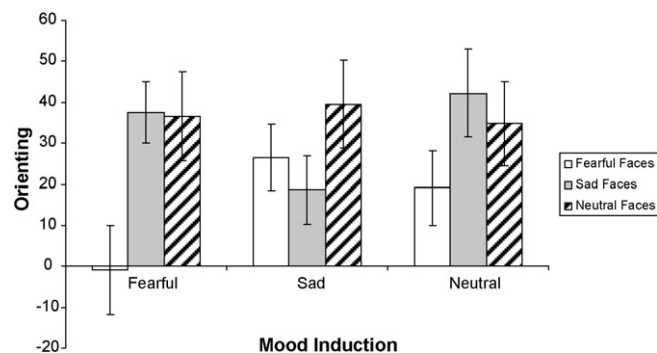

Fig. 2. Orienting efficiency (+SE) for trials following fearful, sad, or neutral face for participants in the fearful (*n* = 20), sad (*n* = 24), or neutral (*n* = 22) mood inductions.

Table 5
Estimates of the association between EEG frontal power (in the left and right hemispheres at baseline and during the mood inductions) and orienting following fearful, sad, and neutral faces.

	Orienting – fearful faces		Orienting – sad faces		Orienting – neutral faces	
	Left hemisphere	Right hemisphere	Left hemisphere	Right hemisphere	Left hemisphere	Right hemisphere
Fear						
Baseline (B)	−2.74 (0.26)***	−2.37 (0.23)***	−0.18 (0.26)	−0.27 (0.23)	−0.23 (0.26)	−0.34 (0.23)
Induction (I)	−9.46 (0.80)***	−8.92 (0.74)***	0.11 (0.80)	−0.15 (0.74)	−0.19 (0.80)	−0.84 (0.74)
$I − B$	−6.72***	−6.55***	Ns	Ns	Ns	Ns
Sadness						
Baseline (B)	−0.58 (0.23)*	−0.38 (0.20)*	−1.31 (0.23)***	−0.96 (0.20)***	−0.05 (0.23)	0.11 (0.20)
Induction (I)	−2.15 (0.80)**	−1.00 (0.69)	−2.51 (0.80)***	−2.39 (0.69)***	2.05 (0.80)**	1.31 (0.69)†
$I − B$	Ns	Ns	Ns	−1.43*	2.10**	Ns
Neutral						
Baseline (B)	−1.80 (0.33)***	−1.58(0.28)***	1.48 (0.33)***	1.21 (0.28)***	0.01 (0.33)	0.03 (0.28)
Induction (I)	−6.49 (0.90)***	−5.82 (0.96)***	2.19 (0.90)*	3.21 (0.96)***	−1.49 (0.90)*	−0.16 (0.96)
$I − B$	−4.69***	−4.24***	Ns	2.00*	Ns	Ns

Note: Estimates (B, standard error of B, and significant p values) of the EEG fixed effects on orienting following fearful, sad, and neutral faces are shown in this table.

† $p < .06$.
* $p < .05$.
** $p < .01$.
*** $p < .001$.

and neutral mood inductions. Within the fearful mood induction, these associations were significant only for fearful faces. Therefore, greater EEG activity during the fear induction was associated with facilitated orienting following mood-congruent fearful faces, thus reversing the behavioral interference effects.

The middle third of Table 5 shows associations between EEG power and orienting following each face type for participants in the sad mood induction. As EEG activity increased in both hemispheres, orienting following sad faces became more efficient but so did orienting following fearful faces. Within the sad mood induction, these associations were significantly greater for EEG during the induction compared to baseline in the right hemisphere, and for orienting following sad versus fearful and neutral faces. Indeed, EEG during the sad mood induction was associated with *less* efficient orienting following neutral faces. Moreover, these facilitation effects were significantly greater for the sad compared to fearful and neutral mood inductions. In summary, greater EEG activity during the sad mood induction had the strongest facilitation effects on orienting following mood-congruent sad faces.

The bottom third of Table 5 shows associations between EEG power and orienting following each face type for participants in the neutral mood induction. As EEG activity increased in the left hemisphere during the neutral mood induction, orienting following neutral faces became more efficient. The difference between the induction and baseline, however, did not reach significance. This same effect emerged for orienting following fearful faces, but in both hemispheres, and was significantly stronger than that for neutral faces. The inverse pattern emerged for the association between EEG during the neutral mood induction and orienting following sad faces – orienting was *less* efficient as EEG activity increased. In summary, EEG activity during the neutral mood induction was associated with facilitated orienting following neutral and fearful faces, but with attentional interference after sad faces.

4. Discussion

Frontal EEG activity simultaneously reflects the nature of an emotional demand and individual differences in emotional capabilities. The present study examined this premise in the context of mood induction effects on emotional state and mood-congruent emotional interference effects. Consistent with the capability model (Coan et al., 2006), greater EEG activity during the negative mood inductions compared to baseline was a stronger predictor of changes in emotion: reduced subjective sadness and anxiety following the mood induction. We also found that mood-congruent

attention interference effects emerged when behavioral responses alone were examined. A very different picture emerged, however, when EEG activity was taken into account. These mood congruent interference effects were reduced for participants who showed enhanced bilateral EEG activity during inductions compared to baseline EEG. No significant asymmetry effects emerged for any of the analyses. Taken together, results provide some of the first evidence that frontal EEG activity measured during negative mood inductions, compared to EEG measured during baseline, is a better predictor of emotion regulatory capability in specific emotional contexts.

Dispositional and capability models of frontal EEG asymmetry are not mutually exclusive. Indeed, results provided evidence for both, although they favor the capability model. For example, EEG during baseline and the mood inductions was associated with changes in self-report of subjective affect and with orienting performance, but effects were significantly stronger when EEG was measured during the mood inductions. This underscores the premise that EEG reflects both a specific emotional demand and the regulatory capacities of the individual to meet that demand (Coan et al., 2006). Moreover, the present findings are potentially important in drawing attention to the association between frontal EEG activity and the recruitment of regulatory control mediated by the prefrontal cortex. Research on EEG asymmetries frequently target frontal brain areas, but this research has progressed with a dearth of explicit links to research on the functions of the prefrontal cortex, such as cognitive control and emotion regulation (Davidson, 2004).

The present study introduced a novel methodology to evaluate associations between EEG activity and attention interference effects in multiple domains of attention. Behavioral findings showed mood-congruent attention interference for orienting, but not alerting or executive attention. In and of itself, these findings contribute to a small body of research regarding induced mood and the negative impact of unpleasant emotional stimuli on attention (Eastwood et al., 2003). Results also suggest that attention interference effects may vary across distinct attention systems and should be carefully examined before drawing general conclusions about how negative stimuli influence attention (Dennis and Chen, 2007a; Fan et al., 2002). By examining individual differences in EEG, results further show that the degree to which an emotionally salient context recruits electrocortical responses reflects regulatory capacity, not only emotional reactivity. This also provides a complementary perspective on well-documented resource allocation models (Meinhardt and Pekrun, 2003) in which heightened

affective arousal prioritizes emotional processing over attention performance, thus taxing the cognitive resources available for shifting and inhibiting attention, resulting in reduced performance (Compton, 2003; Hanoch and Vitouch, 2004). Instead, findings of this study suggest that if the individual is able to recruit cortical resources during an emotional challenge, they may be able to use those resources to improve the regulation and focus of attention during similar emotional contexts.

Counter to what dispositional models of EEG asymmetry would suggest, we did not find that greater right frontal EEG activity was specifically associated with the capacity to regulate emotion and attention in relation to the negative mood inductions. This raises several interesting possibilities and directions for future research. One possibility is that the intensity of the stimuli used in the mood inductions may have not been salient enough to result in significant hemispheric differences (Pickens et al., 2001). Another possibility is that EEG activity across hemispheres was associated with the recruitment of prefrontally mediated cognitive control to support emotion regulation during the mood induction (Davidson, 2002), which might in turn reduce hemispheric differences. Indeed, previous neuroimaging research on emotion regulation and the prefrontal cortex has documented patterns of bilateral activation during the use of cognitive emotion regulation strategies (Goldin et al., 2008; Ochsner and Gross, 2007).

Also, according to self-report, it was not clear whether the fear and neutral mood inductions were effective. Specifically, in addition to the absence of mood induction effects on EEG asymmetry, the fearful mood induction was not associated with any increases in negative mood, and the neutral induction, which consisted of nature documentaries, may have actually had a positive mood induction effect. Indeed, the relative ineffectiveness of the fearful mood induction may explain why greater EEG activity during the fear induction was associated with reduced anxiety *and* sadness, rather than being specifically related to anxiety; this is in contrast to effects of the sad mood induction and EEG activity, which were specific to sadness. Thus, in the present study, the effects for the sad mood induction may represent the strongest test of the capability versus dispositional model. Moreover, by not having a measure of fear per se (anxious state was measured) we may have reduced our ability to detect fear-specific mood induction effects. Future research should increase the range of self-report measures used to assess mood and should employ alternative or combined emotional manipulations, including directed facial actions and autobiographical writing, in order to optimize the salience of the emotional context in which EEG is measured.

In summary, this was among the first studies to demonstrate that frontal EEG activity in response to negative mood inductions, compared to EEG during a resting baseline, reflects the capacity to respond to and regulate emotional states and to regulate attention in the face of emotional distractions. This highlights the need for future research that emphasizes the context in which EEG is measured, and expands the measurement of affective individual difference to include the ability to inhibit and regulate emotions and attention. Such research has implications for understanding both normative individual differences related to approach and withdrawal and affective disruptions in mood and anxiety disorders.

Acknowledgments

Appendix A.

Film clip (target emotion)	Duration (s)	Description (*feature film title*, company, year)
Boy in hallway (fear)	82	A boy plays with toys in the middle of a large, empty hallway; suddenly, a ball rolls up to him; the boy rises to explore and finds an open door; he is just about to enter (from *The Shining*, Warner Bros. Inc., 1980)
Basement chase (fear)	216	A female FBI agent interrogates a suspected killer in his home; he runs into the basement; she takes out her gun and follows him, discovering a dead body in a bathtub (from *Silence of the Lambs*, Orion pictures, 1991)
Boy crying (sadness)	205	A boxer lies a table in a locker room; a young boy goes to him and he dies; the boy cries loudly and begs the other men in the room to bring him back; they react with uneasiness (from *The Champ*, MGM, 1979)
Mother deer dies (sadness)	124	A mother deer and her fawn are grazing in a field when they startle and start to run; the mother is shot and dies; a large stag appears and the fawn cries (from *Bambi*, Walt Disney Productions, 1942)
Squirrels (neutral)	145	A documentary in which the feeding habits of grey squirrels are discussed (from "Chisellers," *The Life of Mammals, Episode 4*, BBC Video, 2003)
Monkeys (neutral)	112	A documentary which describes the social behavior of gelada monkeys (from "The Social Climbers," *The Life of Mammals, Episode 9*, BBC Video, 2003)

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