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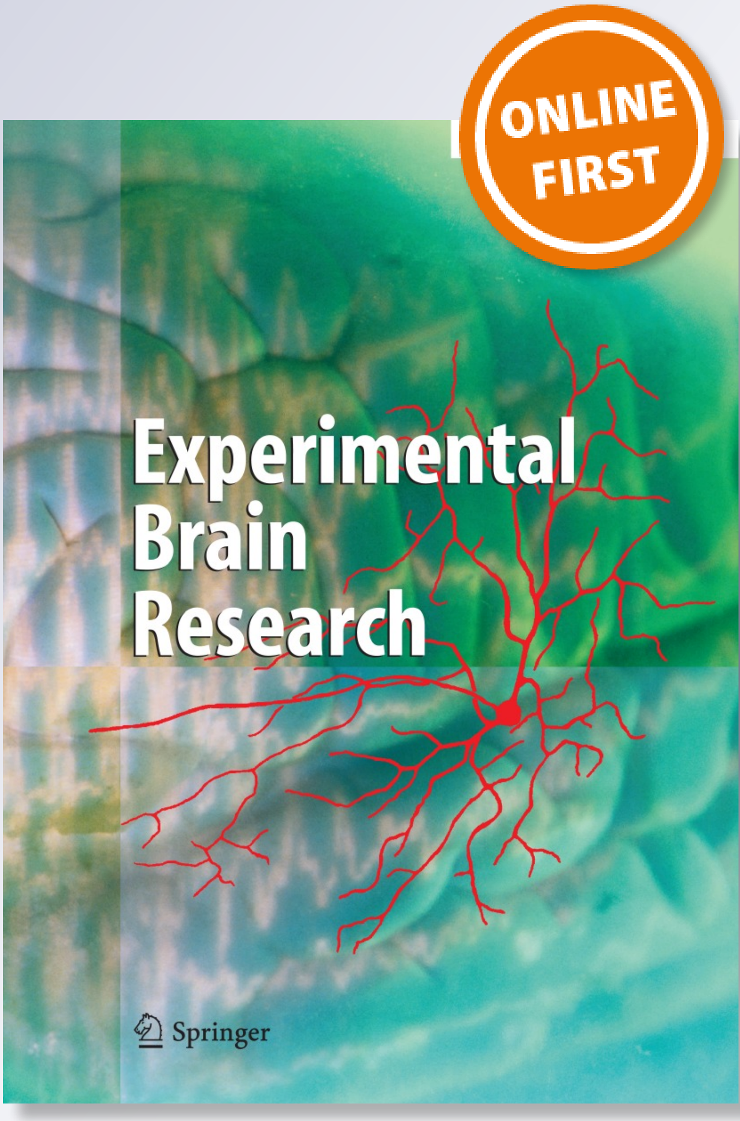

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RESEARCH ARTICLE

Affective motivational direction drives asymmetric frontal hemisphere activation

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Abstract Decades of research have shown that the left- and right-frontal cortical regions are asymmetrically involved in affective processing. Specifically, this past work has demonstrated that greater left-frontal activation is related to positive-approach, and greater right-frontal activation is related to negative-withdrawal. However, much of this past work confounded motivation and affective valence. The current experiment sought to illuminate whether frontal asymmetry is related to motivation or affective valence by examining frontal-lateralized late positive potentials (f-LPPs) and frontal cortical alpha power activation to approach-positive, approach-negative, and withdrawal-negative affects in the same participants. Results revealed that f-LPPs to approach-positive and approach-negative pictures were larger in left- (vs. right-) frontal regions, whereas f-LPPs to withdrawal-negative pictures did not differ between frontal regions. In addition, midline LPPs to approach-positive and approach-negative pictures related to greater left-frontal cortical activation. Together, these results suggest that greater relative left-frontal activation is associated with positive and negative approach-motivated states in the same participants. More broadly, these results are consistent with conceptual models that asymmetric hemisphere activation is related to motivational direction, rather than affective valence.

Keywords Approach motivation · Withdrawal motivation · Hemispheric activation · EEG

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The valence model of hemispheric activity

Decades of past research have shown that the human brain is asymmetrically involved in affective and motivational processing (for a review, see Harmon-Jones et al. 2010). Much of this past work has demonstrated that greater left hemisphere activity is associated with positive affect, whereas greater right hemisphere activity is associated with negative affect. This early work suggests that motivational direction is synonymous with affective valence: approach with positive affect and withdrawal with negative affect (Balconi et al. 2012; Watson et al. 1999).[1]

Early support for this view emerged from studies in which hemispheric activity in the frontal cortex was shown to be asymmetrically related to affective processing. Greater right hemisphere activation was related to withdrawal-motivated states and traits (e.g., depression), whereas greater left hemisphere activation was related to approach-motivated states and traits (e.g., euphoria; Terzian and Cecotto 1959). Other research has measured asymmetric activation using electroencephalography (EEG) to record alpha frequency band power, which is inversely related to regional brain activity (Cook et al. 1998;

[1] We conceptualize motivation as the impetus an organism experiences to go toward versus the motivation to freeze or move away. Approach motivation has been associated with the behavioral approach system (BAS; Gray 1970, 1987; Gray and McNaughton 2000), behavioral activation system (also BAS; Fowles 1987), or a behavioral facilitation system (Depue and Collins 1999). Withdrawal motivation has been associated with the behavioral inhibition system (BIS; Gray 1970, 1987). This system is thought to modulate reactions to aversive stimuli and generate negative affective states such as fear and anxiety. The distinct motivational responses to approach or avoid are inherent in affective responses.

Davidson et al. 1990a).[2] This research demonstrated that relative left-frontal activation is associated with approach-positive affects (Ahern and Schwartz 1985; Tomarken et al. 1992), whereas relative right-frontal activation is associated with withdrawal-negative affects (Buss et al. 2003; Davidson et al. 1990b; Silva et al. 2002; Tomarken et al. 1990; Wheeler et al. 1993).

Support for the motivational model of hemispheric activity

Although there is much research supporting the valence model of hemispheric activation, recent research suggests that past work may have confounded affective valence with motivational direction. That is, previous research only examined the influence of approach-positive and withdrawal-negative affects. However, recent research suggests that motivation, rather than valence, influences asymmetric cortical activity. Specifically, greater left- than right-frontal activation is related to approach motivation (Schutter et al. 2008), regardless of affective valence.

Anger is a negative affect associated with approach motivation (for a review, see Carver and Harmon-Jones 2009). Anger occurs from the disruption of approach-motivated states and is associated with approach behaviors such as self-assurance, strength, and bravery (Izard 1991; Lerner and Keltner 2001). In relation to fontal asymmetry, greater trait and state anger relate to increased left-frontal activation and decreased right-frontal activation (Harmon-Jones 2004, 2007; Harmon-Jones et al. 2008; Harmon-Jones and Sigelman 2001; Harmon-Jones et al. 2004). If anger is an approach-motivated affective state, then it should evoke similar neurophysiological activity as approach-motivated positive states. In contrast, neurophysiological activity during anger states should be distinguished from withdrawal-motivated negative states.

Using EEG-derived event-related potentials, early neural measures of approach motivation have also supported the motivational direction model of frontal asymmetry. The LPP is a relatively rapid index of motivated attentional processing (for reviews, see Ferrari et al. 2008; Hajcak et al. 2012; Olofsson et al. 2008) and is larger to motivationally relevant (vs. neutral) pictures (Bradley 2009; Gable and Harmon-Jones 2010, 2013a; Gable and Poole 2012a; Lang 1995).

Past studies have suggested that the LPP at midline centroparietal sites may have different neural substrates from that of the asymmetrical frontal LPP. The centroparietal LPP has been linked to activation in the visual cortex and amygdala (Sabatinelli et al. 2007, 2013). In contrast, the frontal LPP may stem from prefrontal activation (Moratti et al. 2011). Positive socially relevant concepts (e.g., love) evoke larger left-frontal LPPs, whereas negative socially relevant concepts (e.g., terrorism) evoke larger right-frontal LPPs (Cunningham et al. 2005). In addition, approach-motivated positive (vs. neutral) pictures evoke greater left- than right-frontal LPP amplitudes, and approach-motivated negative (anger) pictures evoke greater left-frontal LPP amplitudes than neutral pictures (Gable and Harmon-Jones 2010).

In sum, both frontal asymmetry and the LPP assess aspects of motivational processing. Indeed, recent research has related EEG frontal asymmetry and LPP amplitudes (Gable and Poole 2012a). Midline LPP amplitudes to anger pictures predicted greater left-frontal activation toward anger pictures, but not neutral pictures. This finding suggests that the LPP to approach-motivated stimuli is related to state neurophysiological measures of approach motivation.

The current experiment

Previous findings are limited by the fact that past empirical work has not examined neurophysiological similarities and differences between approach-positive, approach-negative, and withdrawal-negative states within the same participants, using multiple neurophysiological measures. In order to provide further support of the motivational direction model, affects similar in motivational direction should evoke similar patterns of frontal asymmetry regardless of affective valence. In contrast, affects dissimilar in motivational direction should evoke different patterns of frontal asymmetry even if affects are the same valence. Therefore, we designed the current experiment to address this gap in past research on affect and frontal asymmetry by testing whether approach-positive (e.g., desire), approach-negative (e.g., anger), and withdrawal-negative (e.g., disgust) affects enhance asymmetric cortical activity as measured by the LPP and alpha frequency band power.

Based on the pervading perspective that frontal activation is associated with emotional valence, arousal was synonymous with the intensity of affective valence: All high arousing/high intensity positive emotions should evoke greater left-frontal activation, whereas all high arousing/high intensity negative emotions should evoke greater right-frontal activation. In contrast, the current experiment was designed to help tease apart the dimensions of arousal

[2] Some past research has investigated hemispheric asymmetry using beta frequency band power (Swann et al. 2009). The majority of this work has been focused on posterior asymmetry, but some has also examined frontal asymmetry (Hofman and Schutter 2012; Keune et al. 2012). We focused on the alpha band because the majority of studies examining frontal asymmetry have used the alpha band and frontal alpha asymmetry is supported by a variety of methods (e.g., lesion studies, TMS, fMRI).

and valence intensity in emotional states. This idea was predicated on past work suggesting that emotional arousal may serve as an index of motivational intensity (Bradley and Lang 2007). If arousal is more closely associated with motivational intensity than valence intensity, then observations of frontal activation associated with emotional arousal should be linked with motivational direction. Specifically, high arousing emotion states associated with approach (vs. withdrawal) motivation should evoke greater left (vs. right) frontal activation regardless of the intensity of emotional valence.

We also sought to expand past research linking the LPP and frontal alpha power asymmetry by testing whether LPPs to approach-motivated (vs. withdrawal-motivated) pictures would relate to greater frontal asymmetry. Despite much research demonstrating asymmetric frontal cortical activation in response to manipulations of emotion, some past research has failed to find the predicted frontal asymmetry results in all participants using picture stimuli (Elgavish et al. 2003; Hagemann et al. 1998; see reviews by Murphy et al. 2003; Pizzagalli et al. 2003). This inconsistency may have been caused by affective pictures not evoking sufficient emotional intensity to engage asymmetric frontal cortical activations for all individuals. Because motivation to pictures may be based on individuals' motivational responses to pictures, we investigated whether the LPP would predict greater frontal asymmetry.

We generated several hypotheses for the current experiment. First, we predicted that affective pictures would evoke larger LPP amplitudes than neutral pictures. Second, we predicted that approach-motivated affects would evoke larger LPPs in the left- (vs. right-frontal) hemisphere. Finally, because the LPP and frontal asymmetry are related to motivational processes (Gable and Poole 2012a), we predicted that midline LPPs to approach-positive and approach-negative pictures, but not withdrawal-negative pictures, should relate to greater left-frontal cortical activity.

Method

Forty-eight (36 female) right-handed introductory psychology students (mean age = 19) provided informed consent and participated in exchange for partial course credit. Sample size was determined based on past studies investigating the relationship between approach motivation and modulation of ERPs and frontal asymmetry to pictures (e.g., Bartholow et al. 2003; Gable and Harmon-Jones 2013b; MacNamara and Hajcak 2009). All methods and procedures were reviewed and approved by an internal review board. Handedness was assessed based on participant self-report of hand dominance and behavioral inspection (e.g., writing and button presses).

Procedure

Participants viewed 192 photographs taken from the Internet and the International Affective Picture System (IAPS; Lang et al. 2005). Half of the pictures were affective and half were neutral.[3] Approach-positive pictures consisted of appetitive images (e.g., delicious desserts), which have been used in previous research to evoke approach-motivated positive affect (Gable and Harmon-Jones 2008a, b, 2010, 2011; Harmon-Jones and Gable 2009). Approach-negative pictures consisted of a series of anti-American pictures (e.g., flag-burning) to evoke anger in our participants. Previous studies using similar pictures have demonstrated that such stimuli reliably evoke approach-motivate anger (Gable and Poole 2012a; Harmon-Jones et al. 2011b). Withdrawal-negative pictures were scenes of aversive objects (e.g., mutilated bodies) and have reliably evoked withdrawal-motivated negative affect (Gable and Harmon-Jones 2010; Gable and Poole 2012b).

Each affective picture was matched with a neutral picture, such that objects (e.g., buildings) were matched by shape and size, and scenes were matched for people presence, face presence, and direct gaze. Because brightness has been shown to influence affective ratings (Lakens et al. 2013), affective and neutral pictures were matched on perceived brightness. Brightness did not differ between picture types, $F(3, 18) = 1.07$, $p = .39$. All pictures were displayed in 1,024 × 768. All pictures were presented in the center of a 20-inch computer monitor and superimposed over a black background. Each trial consisted of a fixation cross (500 ms) followed by an affective or neutral picture (6,000 ms). Intertrial interval was 3 s. Pictures were presented in a semi-blocked fashion to avoid mixing affective states (Gable and Harmon-Jones 2009). Each block consisted of 64 pictures: 32 pictures of one affective picture type and 32 matching neutral pictures. Picture type was mixed within blocks, and block order was counterbalanced between participants. Because matched neutral pictures were similar across blocks, neutral pictures were combined into one index.

[3] IAPS picture numbers: neutral pictures (2038, 2102, 2190, 2191, 2200, 2210, 2214, 2215, 2381, 2385, 2396, 2397, 2440, 2441, 2493, 2495, 2499, 2514, 2516, 2595, 2850, 2870, 2880, 2890, 5471, 5510, 5531, 5533, 5535, 5740, 6150, 7000, 7002, 7004, 7006, 7010, 7020, 7034, 7035, 7038, 7041, 7043, 7052, 7053, 7056, 7058, 7059, 7080, 7090, 7100, 7160, 7161, 7170, 7175, 7179, 7182, 7185, 7187, 7211, 7217, 7233, 7235, 7242, 7247, 7248, 7249, 7500, 7547, 7550, 7640, 7830, 7950, 9070); withdrawal-negative pictures (1270, 1274, 1275, 1280, 1617, 3017, 3061, 3160, 3210, 3215, 7359, 7360, 7361, 7380, 9008, 9042, 9110, 9180, 9182, 9301, 9320, 9341, 9373, 9390, 9432, 9440, 9480, 9490, 9582, 9592, 9594, 9830); and approach-positive pictures (1441, 1463, 1710, 1750, 1920, 2040, 2070, 2071, 2080, 2091, 2150, 2165, 2340, 2345, 2550, 4608, 4650, 4652, 4660, 4676, 4680, 4687, 4689, 4694, 4695, 7283, 7330, 7340, 7390, 7402, 7410, 7430).

Following picture viewing, participants reported affective reactions to the pictures, indicating how positive (vs. negative) and arousing (vs. calming) each picture was (1 = *positive/excited*; 9 = *negative/calm*) by pressing the corresponding numbers on a computer keyboard. Arousal ratings were reverse coded so that high ratings indicate high arousal.

EEG assessment and processing

Electroencephalography, recorded with 32 tin electrodes mounted in a stretch lycra cap (Electro-Caps, Eaton, OH), was referenced to the left earlobe. A ground electrode was mounted midway between FPZ and FZ. Electrode impedances were under 5,000 Ω, and homologous sites were within 1,000 Ω of each other. Signals were amplified with Neuroscan SynAmps RT amplifier unit (El Paso, TX), low-pass filtered at 200 Hz, high-pass filtered at .05 Hz, notch filtered at 60-Hz, and digitized at 1,000 Hz. Artifacts (e.g., aberrant signals due to muscle movement or large non-blink eye movements) were removed by hand. Then, a regression-based eye movement correction was applied to remove blinks (Semlitsch et al. 1986), after which the data were again visually inspected to ensure proper correction. Because of equipment malfunction, data from site CPZ on one participant were not included in analyses.

ERP assessment

Data were epoched 100 ms before picture onset until 1,200 ms after picture onset and re-referenced using an average ears reference. Data were filtered with a low pass of 35 Hz. Aggregated waveforms for each picture type were created and baseline corrected using the pre-stimulus interval. LPP amplitude was measured as the mean EEG activity within a window of 400–1,000 ms (Hajcak et al. 2007). LPP amplitudes to affective pictures were aggregated across picture type within each block, and LPP amplitudes to neutral pictures were aggregated to form a single LPP index to neutral pictures. Because past research indicates that LPP amplitudes are most prominent at midline sites (Olofsson et al. 2008; Weinberg et al. 2012), we examined midline LPP amplitudes using an index of sites CZ, CPZ, and PZ (labeled cp-LPP). In addition, to test frontal asymmetry differences between LPP amplitudes, we made indexes of left lateral-frontal sites (F7, F5, and F3) and right lateral-frontal sites (F8, F6, and F4) for each picture type (labeled f-LPP).

Frontal asymmetry assessment

Consistent with past studies measuring state frontal cortical activation to affective pictures using alpha band power (see Coan and Allen 2004, for a review; Harmon-Jones et al. 2006; Hewig et al. 2004; Jackson et al. 2003), power spectra epochs 1.024 s in duration were extracted through a Hamming window (50 % taper of distal ends). Data were re-referenced using an average ears reference. Consecutive epochs were overlapped by 50 % to minimize data loss due to windowing. Consistent with previous research showing that high alpha power is most reflective of the inverse of cortical activity (Piazzagalli et al. 2005) and emotive processing (Gable et al. 2013; Harmon-Jones 2006; Harmon-Jones et al. 2011a; Klimesch et al. 1997; Peterson et al. 2008), power values within the alpha band (8–13 Hz) were obtained using a fast Fourier transformation and aggregated across picture type for all 6 s of picture viewing. Asymmetry indexes (log right minus log left) were computed for homologous sites (F8/F7, F6/F5). Because alpha power is inversely related to cortical activity (Lindsley and Wicke 1974), higher scores indicate greater left hemisphere activity.

Results

Affective ratings

Because pictures were presented in a blocked fashion, comparisons were made between neutral pictures and their matched affective pictures from within each block. Arousal was greater to all affective picture types than neutral pictures (see Table 1). Approach-positive pictures were more pleasant than neutral pictures [$t(46) = 13.73$, $p < .0001$, $d = 2.19$]. Approach-negative pictures [$t(46) = 24.24$, $p < .0001$, $d = 3.29$] and withdrawal-negative pictures [$t(46) = 16.07$, $p < .0001$, $d = 1.83$] were more unpleasant than neutral pictures.

Approach-positive and approach-negative pictures were similarly arousing [$t(46) = .74$, $p = .46$], but approach-positive pictures [$t(46) = 9.23$, $p < .0001$, $d = .30$] and approach-negative pictures [$t(46) = 2.05$,

Table 1 Valence and arousal means (SDs) by picture type

Rating	Picture type			
	Approach-negative	Withdrawal-negative	Approach-positive	Neutral
Valence	8.34 (.98)[a]	7.06 (1.24)[b]	2.76 (.87)[c]	4.92 (1.09)[d]
Arousal	4.57 (2.29)[a]	3.74 (1.78)[b]	4.29 (1.77)[a]	2.65 (1.37)[c]

Comparisons of valence and arousal were made between columns. Significant differences between picture types are indicated by different subscripts ($p < .05$). Higher scores indicate more negativity and arousal

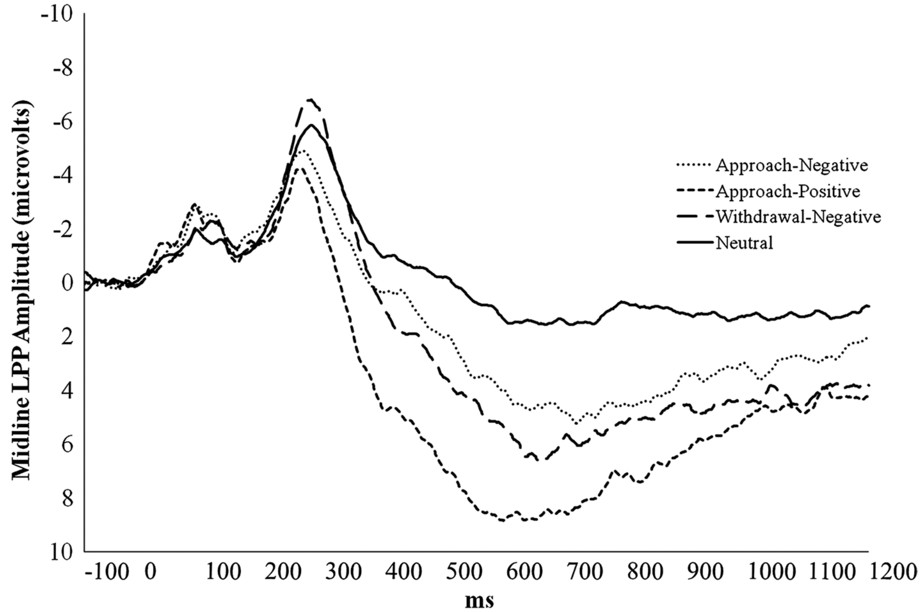


Fig. 1 ERP waveform depicting LPP amplitudes to approach-negative, withdrawal-negative, approach-positive, and neutral pictures at the midline index

$p = .05$, $d = .40$] were more arousing than withdrawal-negative pictures. Approach-positive pictures were more pleasant than withdrawal-negative [$t(46) = 22.08$, $p < .0001$, $d = 4.03$] and approach-negative pictures, $t(46) = 32.99$, $p < .0001$, $d = 6.04$. Approach-negative pictures were more unpleasant than withdrawal-negative pictures, [$t(46) = 11.94$, $p < .0001$, $d = 1.14$]. Consistent with prominent models of emotion, which propose that emotional arousal is an index of motivational intensity (Bradley and Lang 2007), these results suggest that affective pictures were high in motivational intensity. In addition, affective pictures effectively evoked the desired positive or negative state.

Midline LPP amplitudes

A 4 (picture type: approach-positive, withdrawal-negative, approach-negative, neutral) × 1 repeated-measures analysis of variance (ANOVA) revealed a significant effect of picture type, $F(3, 141) = 30.05$, $p < .001$, $\eta^2_p = .39$ (see Fig. 1). Follow-up tests using Fisher's LSD revealed approach-positive pictures evoked larger cp-LPPs than approach-negative ($p < .001$), withdrawal-negative ($p < .001$), and neutral pictures, $p < .001$. Withdrawal-negative pictures evoked marginally larger cp-LPPs than approach-negative pictures, $p = .085$. Withdrawal-negative pictures also evoked larger cp-LPPs than neutral pictures, $p < .0001$. Approach-negative pictures evoked larger cp-LPPs than neutral pictures, $p < .0001$. These results suggest that affective pictures evoked greater motivated engagement than neutral pictures. Cp-LPPs were unrelated to participants' emotive ratings of affective pictures, *r*s < .19, *p*s > .20.

Table 2 Difference score means (SDs) for lateral-frontal LPP amplitudes

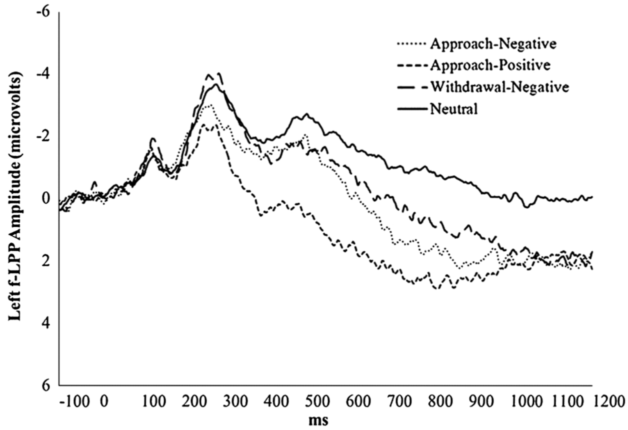
Hemisphere	Picture type		
	Approach-negative	Withdrawal-negative	Approach-positive
Left-frontal	1.73 (2.37)[a]	1.20 (3.00)[a]	3.07 (2.90)[a]
Right-frontal	−.55 (3.17)[b]	.23 (2.72)[a]	1.44 (3.18)[b]

Significant hemisphere differences for each picture type are indicated by different subscripts within each column ($p < .05$)

Frontal LPP amplitudes

To control for individual differences in f-LPP amplitudes, we created difference scores between affective and neutral pictures (Table 2). Consistent with predictions, f-LPPs to approach-negative pictures were larger in the left (vs. right) hemisphere, $t(47) = 3.76$, $p < .001$, $d = .82$ (Fig. 2). F-LPPs to approach-positive pictures were also larger in the left (vs. right) hemisphere, $t(47) = 2.39$, $p = .02$, $d = .54$. F-LPPs to withdrawal-negative pictures did not differ between the left (vs. right) hemisphere, $t(47) = 1.37$, $p = .18$. These results suggest that approach-motivated positive and negative affects enhance left-frontal (vs. right-frontal) f-LPP amplitudes. In contrast, withdrawal-motivated negative affects reduced relative left-frontal (vs. right-frontal) f-LPP amplitudes.

In addition, we sought to test whether f-LPP asymmetry was different between picture types. There was no difference between f-LPP asymmetry to approach-positive and approach-negative pictures ($p = .37$) or withdrawal-negative pictures ($p = .49$). The difference between f-LPP



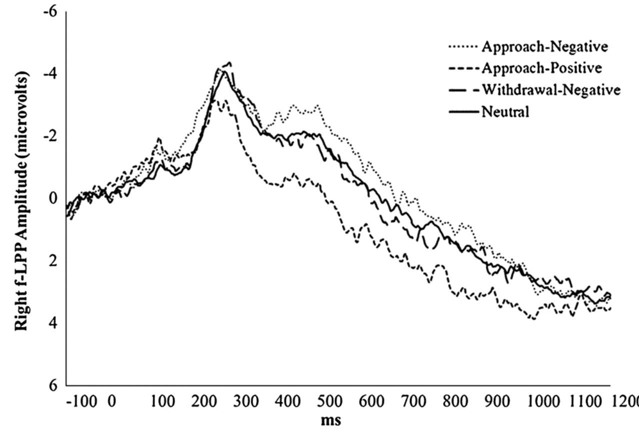


Fig. 2 ERP waveforms depicting LPP amplitudes to approach-negative, withdrawal-negative, approach-positive, and neutral pictures at the left-frontal and right-frontal indexes

asymmetry to approach-negative and withdrawal-negative pictures was also not significant, $p = .14$. F-LPP asymmetry was also unrelated to participants' emotive ratings of affective pictures, *r*s < .22, *p*s > .15.

We also sought to test whether cp-LPP amplitudes were related to f-LPP asymmetry. Cp-LPP amplitudes to each picture type were not related to f-LPP amplitudes to any picture type, *r*s < .19, *p*s > .18. LPPs at central-parietal or left and right-frontal sites were also unrelated between picture types, *r*s < .25, *p*s > .09.

Frontal asymmetry

Consistent with past research examining the influence of affective pictures on frontal asymmetry (Elgavish et al. 2003; Gable and Harmon-Jones 2008b; Hagemann et al. 1998; Harmon-Jones 2007), approach-positive pictures [$t(47) = .04$, $p = .97$], approach-negative pictures [$t(47) = .06$, $p = .95$], or withdrawal-negative pictures [$t(47) = 1.50$, $p = .14$] did not evoke differences in frontal asymmetry as compared to neutral pictures. Frontal asymmetry was unrelated to participants' emotive ratings of affective pictures, *r*s < .24, *p*s > .11.

In further analyses, we sought to examine whether individuals' differences in frontal asymmetry were related between pictures similar in valence or motivational intensity. Frontal asymmetry to approach-negative pictures was related to frontal asymmetry to approach-positive pictures ($r = .36$, $p = .01$) but not to withdrawal-negative pictures ($r = .10$, $p = .48$). Frontal asymmetry to approach-positive pictures was not related to frontal asymmetry to withdrawal-negative pictures, $r = -.02$, $p = .87$. These results suggest that approach motivational reactivity, as measured by greater left-frontal asymmetry, is related between negative and positive approach-motivated pictures.

We then investigated whether the cp-LPP would serve as an individual difference index of motivational engagement to picture and predict greater frontal asymmetry. To test whether individual differences in cp-LPP amplitude related to frontal asymmetry, we first created a difference score by subtracting relative left-frontal activity to neutral pictures from relative left-frontal activity to affective pictures. Cp-LPP amplitudes to approach-positive pictures predicted greater relative left-frontal activity to the approach-positive pictures, $r(46) = .47$, $p = .001$. In addition, cp-LPP amplitudes to approach-negative pictures predicted greater relative left-frontal activity to the approach-negative pictures, $r(46) = .36$, $p = .011$. Cp-LPP amplitudes to withdrawal-negative pictures were not related to frontal asymmetry to the withdrawal-negative pictures, $r(46) = -.08$, $p = .61$ (see Fig. 3). These results suggest that individual differences in motivational intensity as measured by cp-LPP amplitudes predicted greater state approach motivation to approach-positive and approach-negative pictures. In contrast, cp-LPP amplitudes to withdrawal-negative pictures were unrelated to frontal asymmetry.

Furthermore, we sought to test whether f-LPP asymmetry to each picture type would predict frontal asymmetry to pictures similar in valence or motivational intensity. F-LPP asymmetry to each picture type was not related to frontal alpha asymmetry to any picture type, *r*s < .19, *p*s > .20.

Discussion

In the current experiment, we tested whether approach-positive, approach-negative, and withdrawal-negative affects in the same participants would enhance frontal cortical asymmetry. Results revealed that f-LPPs to approach-positive and approach-negative pictures were larger in the

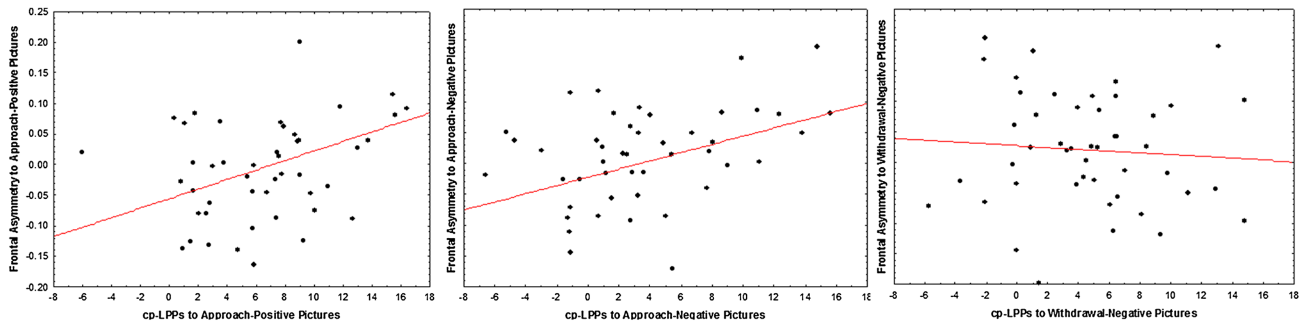


Fig. 3 Scatterplots depicting correlations between cp-LPPs and frontal asymmetry to approach-positive, approach-negative, and withdrawal-negative pictures

left-frontal hemisphere than the right-frontal hemisphere. In addition, cp-LPPs to approach-positive and approach-negative pictures were related to greater relative left-frontal activity during picture viewing. Together, these results refute models that continue to associate all positive affects with approach and all negative affects with withdrawal, and demonstrate that motivational direction, rather than affective valence or general arousal, is related to asymmetric hemisphere activation.

Results of the current experiment also support that the LPP is a neural measure related to motivational processing. Based on the current results, the lateralized frontal cortical LPP is a relatively rapid measure associated with motivational direction. Approach-motivated positive and negative pictures evoked greater left than right f-LPP amplitudes. In addition, the cp-LPP appears to be an index of motivational intensity. Cp-LPPs were larger to all affective stimuli as compared to neutral stimuli. Cp-LPPs to approach-positive and approach-negative pictures were related to greater left-frontal asymmetry. In contrast, cp-LPPs to withdrawal-negative pictures did not relate to greater left-frontal asymmetry. Together, these findings suggest that the LPP is related to state neurophysiological measures of approach motivation. However, f-LPPs in the current study did not relate to frontal asymmetry activation or cp-LPP within the same picture type. This lack of relationship may stem from previous findings that cp-LPP and f-LPP have different neural substrates (Moratti et al. 2011; Sabatinelli et al. 2013) or reflect different aspects of motivational processes.

Past research has demonstrated that withdrawal-motivated affects such as disgust and fear are associated with relatively less left-frontal activation than approach-motivated affects such as anger and desire (Harmon-Jones and Allen 1997, 1998; Sutton and Davidson 1997). Evidence of reduced frontal asymmetry and lateralized LPPs to withdrawal-negative (vs. approach-positive) pictures suggests a reduction in approach motivation and therefore enhancement in withdrawal motivation. One potential reason that left and right f-LPPs were not different to withdrawal-negative pictures could be that withdrawal-negative pictures were not as motivationally intense as the approach-motivated pictures. However, critical support for our hypotheses that approach motivational states evoke similar neurophysiological activity comes from evidence that approach-motivated affects related to greater left LPP amplitudes and left-frontal activation, whereas withdrawal-motivated affects related to relatively less left LPP amplitudes and left-frontal activation.

The current findings also help clarify the role of motivation in hemispheric activation as opposed to arousal. In studies investigating neurophysiological processes associated with positive and negative affects high in motivational intensity, one potential and almost inherent confound is arousal, that is, stimuli used to induce high approach-positive and approach-negative affects also induce high levels of self-reported arousal (Gable and Harmon-Jones 2008a, b, 2009, 2010, 2011; Gable and Poole 2012a). Thus, an alternative hypothesis could be that arousal caused the neurophysiological effects observed in response to positive or negative affects, rather than motivational direction. However, results of the current study demonstrate that affects high in arousal, but opposite in motivational direction, have a diverse influence on hemispheric activity. In addition, past research has shown that such effects are independent of physiological arousal (Gable and Harmon-Jones 2013a). Gable and Harmon-Jones (2013a) manipulated physiological arousal independent of affective motivation. Although manipulated physiological arousal enhanced heart rate, arousal did not influence LPP amplitudes, whereas manipulations of approach-motivated positive affect did enhance left-frontal LPP amplitudes. Together, this evidence provides support that motivational direction, rather than arousal, relates to hemispheric asymmetry.

Broadly, the current experiment helps disentangle the influence of motivational direction from affective valence in models examining hemispheric activation. By examining negative affects varying in motivational direction and approach-motivated affects varying in affective valence, the current findings support that frontal asymmetry appears to be driven by motivational direction, rather than affective valence. Our results contribute to a growing body of research linking positive and negative approach-motivated affects with left hemispheric activation (for review see Harmon-Jones et al. 2010).

Due to limitations of the current experiment, our results pave the way for interesting avenues of future research. For example, future research could examine the behavioral and cognitive consequences of affects varying in valence and motivational intensity by employing behavioral measures of cognitive scope. Additionally, trait motivational measures could further help examine the role of individual differences in the motivational aspect of the cp-LPP and f-LPP. Future studies may also attempt to elucidate the possible behavioral and neurophysiological correlates of withdrawal-motivated positive affect states, a condition not examined in the current experiment. In addition to much work investigating hemispheric asymmetry using alpha power, some recent work has investigated asymmetry using beta band activity (Hofman and Schutter 2012; Swann et al. 2009). It may be likely that resting beta band activity is also related to motivational direction in affective states.

References

Ahern GL, Schwartz GE (1985) Differential lateralization for positive and negative emotion in the human brain: EEG spectral analysis. Neuropsychologia 23:745–755

Balconi M, Falbo X, Conte X (2012) BIS and BAS correlates with psychophysiological and cortical response systems during aversive and appetitive emotional stimuli processing. Motiv Emot 36:218–231

Bartholow BD, Pearson MA, Gratton G, Fabiani M (2003) Effects of alcohol on person perception: a social cognitive neuroscience approach. J Personal Soc Psychol 85:627–638

Bradley MM (2009) Natural selective attention: orienting and emotion. Psychophysiology 46:1–11

Bradley MM, Lang PJ (2007) Emotion and motivation. In: Cacioppo JT, Tassinary LG, Berntson G (eds) Handbook of psychophysiology, 3rd edn. Cambridge University Press, New York, pp 581–607

Buss KA, Malmstadt Schumacher JR, Dolski I, Kalin NH, Goldsmith HH, Davidson RJ (2003) Right frontal brain activity, cortisol, and withdrawal behavior in 6-month-old infants. Behav Neurosci 117:11–20

Carver CS, Harmon-Jones E (2009) Anger is an approach-related affect: evidence and implications. Psychol Bull 135:183–204

Coan JA, Allen JJB (2004) Frontal EEG asymmetry as a moderator and mediator of emotion. Biol Psychol 67:7–49

Cook IA, O'Hara R, Uijtdehaage SHJ, Mandelkern M, Leuchter AF (1998) Assessing the accuracy of topographic EEG mapping for determining local brain function. Electroencephalogr Clin Neurophysiol 107:408–414

Cunningham WA, Espinet SD, DeYoung CG, Zelazo PD (2005) Attitudes to the right- and left: frontal ERP asymmetries associated with stimulus valence and processing goals. NeuroImage 28:827–834

Davidson RJ, Chapman JP, Chapman LJ, Henriques JB (1990a) Asymmetrical brain electrical activity discriminates between psychometrically-matched verbal and spatial cognitive tasks. Psychophysiology 27:528–543

Davidson RJ, Ekman P, Saron CD, Senulis JA, Friesen WV (1990b) Approach-withdrawal and cerebral asymmetry: emotional expression and brain physiology I. J Personal Soc Psychol 58:330–341

Depue RA, Collins PF (1999) Neuobiology of the structure of personality: dopamine, facilitation of incentive motivation, and extraversion. Behav Brain Sci 22:491–569

Elgavish E, Halpern D, Dikman Z, Allen JJB (2003) Does frontal EEG asymmetry moderate or mediate responses to the international affective picture system (IAPS)? Psychophysiology 40:s38

Ferrari V, Codispoti M, Cardinale R, Bradley MM (2008) Directed and motivated attention during processing of natural scenes. J Cogn Neurosci 20:1753–1761

Fowles DC (1987) Application of a behavioral theory of motivation to the concepts of anxiety and impulsivity. J Res Personal 21:417–435

Gable PA, Harmon-Jones E (2008a) Approach-motivated positive affect reduces breadth of attention. Psychol Sci 19:476–482

Gable PA, Harmon-Jones E (2008b) Relative left frontal activation to appetitive stimuli: considering the role of individual differences. Psychophysiology 45:275–278

Gable PA, Harmon-Jones E (2009) Postauricular reflex responses to pictures varying in valence and arousal. Psychophysiology 46:487–490

Gable PA, Harmon-Jones E (2010) Late positive potential to appetitive stimuli and local attentional bias. Emotion 10:441–446

Gable PA, Harmon-Jones E (2011) Attentional states influence early neural responses associated with motivational processes: local vs. global attentional scope and N1 amplitude to appetitive stimuli. Biol Psychol 87:303–305

Gable PA, Harmon-Jones E (2013a) Does arousal per se account for the influence of appetitive stimuli on attentional scope and the late positive potential. Psychophysiology 50:344–350

Gable PA, Harmon-Jones E (2013b) Trait behavioral approach sensitivity (BAS) relates to early (<150 ms) electrocortical responses to appetitive stimuli. Soc Cogn Affect Neurosci 8:795–798

Gable PA, Poole BD (2012a) Influence of trait behavioral inhibition and behavioral approach motivation systems on the LPP and frontal asymmetry to anger pictures. Soc Cogn Affect Neurosci. doi:10.1093/scan/nss130

Gable PA, Poole BD (2012b) Time flies when you're having approach-motivated fun: effects on motivational intensity on time perception. Psychol Sci 23:879–886

Gable PA, Poole BD, Cook MS (2013) Asymmetrical hemisphere activation enhances global-local processing. Brain Cogn 83:337–341

Gray JA (1970) The psychophysiological basis of introversion-extraversion. Behav Res Ther 8:249–266

Gray JA (1987) The psychology of fear and stress, 2nd edn. Cambridge University Press, Cambridge

Gray JA, McNaughton N (2000) The neuropsychology of anxiety. Oxford University Press, Oxford

Hagemann D, Ewald N, Becker G, Maier S, Bartussek D (1998) Frontal brain asymmetry and affective style: a conceptual replication. Psychophysiology 35:372–388

Hajcak G, Dunning JP, Foti D (2007) Neural response to emotional pictures is unaffected by concurrent task difficulty: an event-related potential study. Behav Neurosci 121:1156–1162

Hajcak G, Weinberg A, MacNamara A, Foti D (2012) ERPs and the study of emotion. In: Luck SJ, Kappenman ES (eds) Oxford handbook of ERP components. Oxford University Press, New York

Harmon-Jones E (2004) On the relationship of frontal brain activity and anger: examining the role of attitude toward anger. Cogn Emot 18:337–361

Harmon-Jones E (2006) Unilateral hand contractions cause contralateral alpha power suppression and approach motivational affective experience. Psychophysiology 43:598–603

Harmon-Jones E (2007) Trait anger predicts relative left frontal cortical activation to anger-inducing stimuli. Int J Psychophysiol 66:154–160

Harmon-Jones E, Allen JJB (1997) Behavioral activation sensitivity and resting frontal EEG asymmetry: covariation of putative indicators related to risk for mood disorders. J Abnorm Psychol 106:159–163

Harmon-Jones E, Allen JJB (1998) Anger and prefrontal brain activity: EEG asymmetry consistent with approach motivation despite negative affective valence. J Personal Soc Psychol 74:1310–1316

Harmon-Jones E, Gable PA (2009) Neural activity underlying the effect of approach-motivated positive affect on narrowed attention. Psychol Sci 20:406–409

Harmon-Jones E, Sigelman J (2001) State anger and prefrontal brain activity: evidence that insult-related relative left-prefrontal activation is associated with experienced anger and aggression. J Personal Soc Psychol 80:797–803

Harmon-Jones E, Vaughn-Scott K, Mohr S, Sigelman J, Harmon-Jones C (2004) The effect of manipulated sympathy and anger on left and right frontal cortical activity. Emotion 4:1–7

Harmon-Jones E, Lueck L, Fearn M, Harmon-Jones C (2006) The effect of personal relevance and approach-related action expectation on relative left frontal cortical activity. Psychol Sci 17:434–440

Harmon-Jones E, Harmon-Jones C, Fearn M, Sigelman JD, Johnson P (2008) Left frontal cortical activation and spreading of alternatives: tests of the action-based model of dissonance. J Personal Soc Psychol 94:1–15

Harmon-Jones E, Gable PA, Peterson CK (2010) The role of asymmetric frontal cortical activity in emotion-related phenomena: a review and update. Biol Psychol 84:451–462

Harmon-Jones E, Gable PA, Price TF (2011a) Toward an understanding of the influence of affective states on attentional tuning: comment on Friedman and Förster (2010). Psychol Bull 137:508–512

Harmon-Jones E, Harmon-Jones C, Amodio DM, Gable PA (2011b) Attitudes toward emotions: conceptualization and measurement of evaluations of specific emotions. J Personal Soc Psychol 101:1332–1350

Hewig J, Hagemann D, Seifert J, Naumann E, Bartussek D (2004) On the selective relation of frontal cortical asymmetry and anger-out versus anger-control. J Personal Soc Psychol 87:926–939

Hofman D, Schutter DJLG (2012) Asymmetrical frontal resting-state beta oscillations predict trait aggressive tendencies and behavioral inhibition. SCAN 7:850–857

Izard CE (1991) The psychology of emotions. Plenum Press, New York

Jackson DC, Mueller CJ, Dolski I, Dalton KM, Nitschke JB, Urry HL, Rosenkranz MA, Ryff CD, Singer BH, Davidson RJ (2003) Now you feel it, now you don't: frontal brain electrical asymmetry and individual differences in emotion regulation. Psychol Sci 14:612–617

Keune PM, van der Heiden L, Várkuti B, Konicar L, Veit R, Birbaumer N (2012) Prefrontal brain asymmetry and aggression in imprisoned violent offenders. Neurosci Lett 515:191–195

Klimesch W, Doppelmayr M, Pachinger T, Ripper B (1997) Brain oscillations and human memory: EEG correlates in the upper alpha and theta band. Neurosci Lett 238:9–12

Lakens D, Fockenberg DA, Lemmens KPH, Ham J, Midden CJH (2013) Brightness differences influence the evaluation of affective pictures. Cogn Emot 27:1225–1246

Lang PJ (1995) The emotion probe. Am Psychol 50:372–385

Lang PJ, Bradley MM, Cuthbert BN (2005) International affective picture system (IAPS): digitized photographs, instruction manual and affective ratings. technical report A-6. University of Florida, Gainesville, FL

Lerner JS, Keltner D (2001) Fear, anger, and risk. J Personal Soc Psychol 81:146–159

Lindsley DB, Wicke JD (1974) The electroencephalogram: autonomous electrical activity in man and animals. In: Thompson R, Patterson MN (eds) Bioelectric recording techniques. Academic Press, New York, pp 3–79

MacNamara A, Hajcak G (2009) Anxiety and spatial attention moderate the electrocortical response to aversive pictures. Neuropsychologia 47:2975–2980

Moratti S, Saugar C, Strange BA (2011) Prefrontal-occipital coupling underlies late latency human neuronal responses to emotion. J Neurosci 31:17278–17286

Murphy FC, Nimmo-Smith I, Lawrence AD (2003) Functional neuroanatomy of emotions: a meta-analysis. Cogn Affect Behav Neurosci 3:207–233

Olofsson JK, Nordin S, Sequeira H, Polich J (2008) Affective picture processing: an integrative review of ERP findings. Biol Psychol 77:247–265

Peterson CK, Shackman AJ, Harmon-Jones E (2008) The role of asymmetrical frontal cortical activity in aggression. Psychophysiology 45:86–92

Piazzagalli DA, Sherwood RJ, Henriques JB, Davidson RJ (2005) Frontal brain asymmetry and reward responsiveness: a source-localization study. Psychol Sci 16:805–813

Pizzagalli D, Shackman AJ, Davidson RJ (2003) The functional neuroimaging of human emotion: asymmetric contributions of cortical and subcortical circuitry. In: Hugdahl K, Davidson RJ (eds) The asymmetrical brain. MIT Press, Cambridge, pp 511–532

Sabatinelli D, Lang PJ, Keil A, Bradley MM (2007) Emotional perception: correlation of functional MRI and event-related potentials. Cereb Cortex 17:1085–1091

Sabatinelli D, Keil A, Frank DW, Lang PJ (2013) Emotional perception: correspondence of early and late event-related potentials with cortical and subcortical functional MRI. Biol Psychol 92:513–519

Schutter DJLG, de Weijer AD, Meuwese JDI, Morgan B, van Honk J (2008) Interrelations between motivational stance, cortical excitability, and the frontal electroencephalogram asymmetry of emotion: a transcranial magnetic stimulation study. Hum Brain Mapp 29:574–580

Semlitsch HV, Anderer P, Schuster P, Presslich O (1986) A solution for reliable and valid reduction of ocular artifacts, applied to the P300 ERP. Psychophysiology 23:695–703

Silva JR, Pizzagalli DA, Larson CL, Jackson DC, Davidson RJ (2002) Frontal brain asymmetry in restrained eaters. J Abnorm Psychol 111:676–681

Sutton SK, Davidson RJ (1997) Prefrontal brain asymmetry: a biological substrate of the behavioral approach and inhibition systems. Psychol Sci 8:204–210

Swann N, Tandon N, Canolty R, Ellmore TM, McEvoy LK, Dreyer S, DiSano M, Aron AR (2009) Intracranial EEG reveals a time- and frequency-specific role for the right inferior frontal gyrus and primary motor cortex in stopping initiated responses. J Neurosci 29:12675–12685

Terzian H, Cecotto C (1959) Determination and study of hemisphere dominance by means of intracarotid sodium amytal injection in man: II. Electroencephalographic effects. Bolletino della Societa Ztaliana Sperimentale 35:1626–1630

Tomarken AJ, Davidson RJ, Henriques JB (1990) Resting frontal brain asymmetry predicts affective responses to films. J Personal Soc Psychol 59:791–801

Tomarken AJ, Davidson RJ, Wheeler RE, Doss RC (1992) Individual differences in anterior brain asymmetry and fundamental dimensions of emotion. J Personal Soc Psychol 62:676–687

Watson D, Wiese D, Vaidya J, Tellegen A (1999) The two general activation systems of affect: structural findings, evolutionary considerations, and psycho-biological evidence. J Personal Soc Psychol 76:820–838

Weinberg A, Ferri J, Hajcak G (2012) Interactions between attention and emotion: Reflections on the late positive potential. Unpublished manuscript

Wheeler RE, Davidson RJ, Tomarken AJ (1993) Frontal brain asymmetry and emotional reactivity: a biological substrate of affective style. Psychophysiology 30:82–89