

Supervisory control system and frontal asymmetry: neurophysiological traits of emotion-based impulsivity

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Approach, avoidance and the supervisory control system are fundamental to human behavior. Much past research has examined the neurophysiological models relating trait approach and avoidance. Using measures of electroencephalographic (EEG) frontal asymmetry, trait approach has been associated with greater left-frontal activity and trait avoidance has been associated with greater right-frontal activity. However, traits related to the supervisory control system have not been previously associated with frontal asymmetry. The current study sought to test whether trait positive urgency, measuring the tendency towards rash action in response to extreme positive emotional states, would relate to frontal alpha asymmetry. One hundred twenty-six individuals completed a measure of positive urgency and resting EEG recordings. Greater positive urgency was associated with greater relative left-frontal EEG activity. Source localization revealed that this relationship appeared to originate from reduced right-frontal activity in the inferior frontal gyrus. These results clarify that the link between frontal asymmetry and positive urgency is related to reduced right-frontal activity. Reduced right-frontal activity may be a potential neurobiological trait related to the supervisory control system.

Keywords: frontal asymmetry; impulsivity; positive urgency; approach motivation

At the core of human functioning are three personality systems of approach, avoidance and supervisory control. Approach motivational responses have been theorized to be part of a behavioral approach system (BAS; Gray, 1970, 1987; Gray and McNaughton, 2000), behavioral activation system (also BAS; Fowles, 1987), behavioral facilitation system (Depue and Collins, 1999) and goal-approach system (Carver and Scheier, 2008; Elliott, 2008). In contrast, avoidance motivational responses have been theorized to be part of a withdrawal or freezing system and have been referred to as a behavioral inhibition system (BIS; Gray, 1970, 1987), fight-flight-freeze system (Gray and McNaughton, 2000) and threat avoidance system (Carver and Scheier, 2008; Elliott, 2008). Essential to the approach and avoidance system is a third supervisory control system theorized to generate effortful control, constraint, self-control (Kochanska and Knaack, 2003; Rothbart and Rueda, 2005; Nigg, 2006; Carver and Connor-Smith, 2010) and is linked to cognitive constructs of executive control and inhibitory function (Aron *et al.*, 2004, 2014; Hester and Garavan, 2009). Generally, the supervisory system is in place to regulate both the approach and avoidance systems using effortful control to override motivational impulses (Carver and Connor-Smith, 2010). This system is thought to be inversely related to trait impulsivity, because trait impulsivity is strongly related to deficits in inhibitory control, effortful control and executive functions (Logan *et al.*, 1997; Enticott *et al.*, 2006).

In the past two decades, many biological models have been based on dimensions of approach and avoidance (see Fowles, 2002; Gray, 1994; Depue and Collins, 1999; Elliott and Thrash, 2002; Caspi *et al.*, 2005; Rothbart and Hwang, 2005; Caspi and Shiner, 2006; Gable and Harmon-Jones, 2010). These models propose that approach and avoidance systems are related to distinct brain areas, and that individual differences in trait neural processes may reflect the sensitivity of each system. For much of the past century, research has demonstrated that the left and right-frontal cortical regions are asymmetrically related to approach and avoidance motivational and emotional (emotive) tendencies. Specifically, the left-frontal cortex is associated with emotive

processes related to approach, whereas the right-frontal cortex is associated with emotive processes related to withdrawal (Goldstein, 1939; Rossi and Rosadini, 1967). In humans, approach and avoidant asymmetrical activations measured by suppression of the alpha frequency band activity during resting or baseline electroencephalographic (EEG) recordings appear as stable traits (for reviews see Coan and Allen, 2004; Harmon-Jones *et al.*, 2010). Because of the strong association between motivational direction and frontal asymmetry, frontal asymmetry has been linked to trait measures of motivational direction using the BIS/BAS derived by Carver and White (1994). Greater BAS is associated with greater left-frontal activation (Harmon-Jones and Allen, 1997; Harmon-Jones and Sigelman, 2001; Coan and Allen, 2003; Harmon-Jones, 2006; Amodio *et al.*, 2008; Gable and Harmon-Jones, 2008; Harmon-Jones *et al.*, 2009, 2010; De Pascalis *et al.*, 2013), and greater BIS is associated with greater right-frontal activation (Sutton and Davidson, 1997; Balconi and Mazza, 2009; Shackman *et al.*, 2009; Balconi, 2011).

In contrast to the strong link between frontal asymmetry and approach/avoidance systems, past research has almost entirely neglected the relationship between frontal asymmetry and the supervisory control system. Some recent work has hypothesized that frontal asymmetry may be associated with traits and behaviors related to the supervisory control system (Grimshaw and Carmel, 2014). For example, greater baseline left-frontal activation is associated with trait sensation seeking (Santesso *et al.*, 2008), and right-frontal theta and delta activity relate to greater behavioral risk taking (Gianotti *et al.*, 2009). Some work has suggested that this asymmetric activity may relate to the right inferior frontal gyrus (for review see, Aron *et al.*, 2014). For example, the right inferior frontal gyrus has been linked with response inhibition on a go/no-go task (Schiller *et al.*, 2013) and inability to ignore drug-related cues in active cocaine users (Hester and Garavan, 2009). In sum, this past work suggests that the supervisory control system may be asymmetrically related to frontal-cortical activity (Aron *et al.*, 2004; Knoch *et al.*, 2006; Peterson *et al.*, 2008; Cyders *et al.*, 2014). However, to date research has not forged a connection between trait asymmetrical alpha activity and traits related to the supervisory system, such as impulsivity.

Received 14 October 2014; Revised 15 January 2015; Accepted 9 February 2015

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Research investigating the importance of trait impulsivity has begun to focus on trait urgency, or the tendency to act impulsively during intense emotional states. Along these lines, Cyders et al. (2007) developed the construct of positive urgency, or the tendency to act impulsively when experiencing positive emotions. Positive emotion-based urgency appears to play a role in a number of important domains such as drinking behavior (Cyders et al., 2009; 2010; Wray et al., 2012), drug use (Zapolski et al., 2009), risky driving behaviors (Pearson et al., 2013) and sexual aggression (Mouilso et al., 2013). Although much past work investigating positive urgency as a risk factor demonstrates that positive urgency reflects failure of the supervisory control system, the neurophysiological mechanisms associated with positive urgency are unclear. Because positive urgency appears to be a stable facet of impulsivity, it is likely related to trait neurophysiological processes such as frontal asymmetry. In addition, past work demonstrating asymmetrical inhibitory function suggests that the pre-potent reward-based responding as measured by positive urgency would require supervisory control to maintain long term goals. Frontal asymmetry may serve as a biomarker of an individual's tendency towards rash action. Revealing such relationships is part of a growing recognition of the importance of identifying neurophysiological markers associated with personality traits.

In this study we examined whether resting frontal asymmetry is related to trait positive urgency, BAS and BIS. We hypothesize that trait positive urgency will be associated with an increase in relative left (*vs* right) frontal activity. Consistent with past research linking reduced right-frontal activity and impulsive behaviors, we hypothesize that relatively greater left-frontal activity may result from a decrease in right-frontal activity.

MATERIALS AND METHODS

Participants

One hundred twenty-six (68 female, 58 male) right-handed introductory psychology students participated in exchange for course credit.

Procedure

Participants completed the study individually. First, participants were asked to complete individual difference measures of handedness, BIS/BAS and positive urgency. Following the completion of the questionnaires, EEG electrodes were applied, and resting EEG activity was assessed for 8 min. Handedness was assessed by asking participants to report which hand they use to perform 13 simple behaviors (i.e. write, use a hammer, hold a match when striking it). All participants were right-handed.

Trait positive urgency

The positive urgency measure (PUM) was developed to identify the tendency to engage in impulsive behaviors when in a positive mood (Cyders et al., 2007). Positive urgency is measured across 14 items, such as, 'I am surprised at the things I do while in a great mood'; 'When I get really happy about something, I tend to do things that can have bad consequences' (Cyders et al., 2007, p. 110). Higher PUM scores indicate greater levels of impulsive tendencies during positive moods. Positive urgency has been identified as a component of impulsivity independent from BAS (Cyders and Smith, 2007). Data from two participants were not included because they failed to complete the PUM.

Trait BIS/BAS

The BIS/BAS scales contain three subscales of BAS and one scale of BIS assessed across 20 items. BIS is assessed through seven items and relates

Table 1 Means and SDs of PUM, BIS and BAS

Scale	Mean (SD)	Cronbachs (α)
PUM	2.01 (0.71)	0.92
BIS	2.87 (0.52)	0.73
BAS	3.11 (0.35)	0.81
BAS RR	3.44 (0.42)	0.74
BAS DRIVE	2.79 (0.55)	0.73
BAS FUN	2.98 (0.54)	0.62

Note. Possible ranges for each scale are the following: for PUM, 1–5; for BIS/BAS, 1–7. Means and standard deviations (in parentheses) for PUM, BIS and BAS scales are from the current sample. PUM, positive urgency measure; BIS, behavioral inhibition system; BAS, behavioral activation system; BAS RR, behavioral activation system reward responsiveness; BAS DRIVE, behavioral activation system drive; BAS FUN, behavioral activation fun seeking.

to responses in anticipation of punishment. The following item is an example of the BIS component: 'I worry about making mistakes'. Higher BIS scores indicate greater levels of behavior inhibition. The three subscales of BAS include: BAS Reward Responsiveness, BAS Drive and BAS Fun-Seeking. BAS Reward Responsiveness is assessed through five items that measure response to the anticipation of reward. BAS Drive looks at persistent goal pursuit through four items. BAS Fun-Seeking is comprised of four items reflecting a desire for new rewards and a willingness to approach potential rewards. All BAS items from each subscale were averaged to obtain an overall index score of BAS; higher BAS scores indicate greater levels of approach motivation. We report means, standard deviations and Cronbach's alphas for PUM, BIS, BAS and BAS subscales in Table 1.

EEG assessment and processing

EEG was recorded using a stretch lycra cap with 64 mounted tin electrodes (Electro-Caps, Eaton, OH). EEG activity was referenced to an electrode placed on the left earlobe and a ground electrode was mounted midway between FPZ and FZ. Electrode impedances were under 5000 Ω and homologous sites were within 1000 Ω of each other. Signals were amplified using Neuroscan SynAmps RT amplifier unit (El Paso, TX). Signals were low-pass filtered at 100 Hz, high-pass filtered at 0.05 Hz, notched filtered at 60 Hz and digitized at 2000 Hz.

Eight minutes of resting data were acquired while participants focused their gaze in front of them; 4 min with eyes open (O) and 4 min with eyes closed (C). Two sequences were used and were alternated between participants: C-O-O-C-O-C-C-O and O-C-C-O-C-O-O-C. Artifacts (e.g. aberrant signals due to muscle movement or large non-blink eye movements) were removed manually. Following the removal of artifacts, a regression-based eye movement correction was utilized to remove blinks from the data files (Semlitsch et al., 1986). Lastly, the data were visually inspected ensuring proper correction.

Consistent with past studies measuring trait frontal-cortical activation using alpha band power (see Coan and Allen, 2004; Harmon-Jones et al., 2010 for reviews), power spectra epochs 1.024 s in duration were extracted through a Hamming window (50% taper of distal ends). Alpha power is inversely related to regional brain activity as evidenced by hemodynamic measures (Cook et al., 1998; Goldman et al., 2002; Feige et al., 2005) verbal tasks, (Davidson et al., 1990; Jauk et al., 2012), and motor tasks (Harmon-Jones, 2006; Gable et al., 2013). Data were re-referenced using a common average reference. Consecutive epochs were overlapped by 50% to minimize data loss due to windowing. We investigated the classical alpha broadband within 8–13 Hz (Shackman et al., 2010). Power values were obtained using a fast Fourier transformation and aggregated across all resting minutes. Consistent with much past work investigating frontal

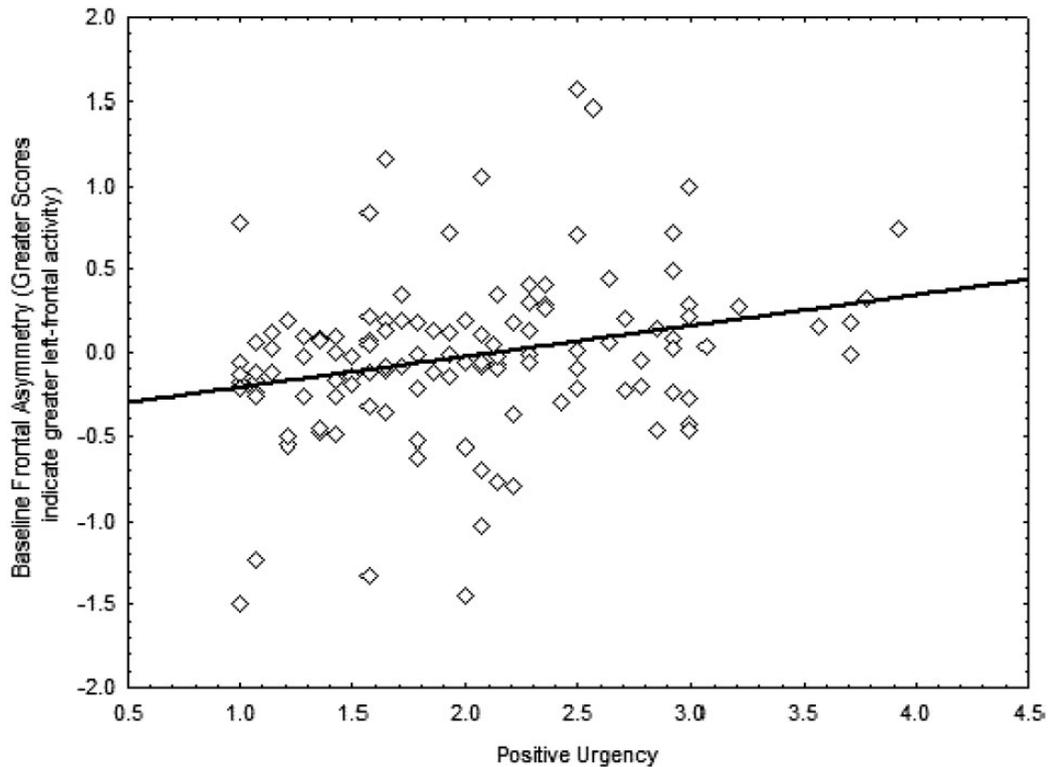


Fig. 1 Relationship between greater resting left-frontal activity and positive urgency.

asymmetry (Harmon-Jones *et al.*, 2011; Stewart *et al.*, 2011), asymmetry indexes (log right minus log left) were computed for homologous sites F6/5 and F8/7. Index scores were created by averaging the asymmetry indices. Because alpha power is inversely related to cortical activity (Lindsley and Wicke, 1974), higher scores indicate greater left hemisphere activity. These sites were aggregated to create an index of relative left-frontal activity. Data from five participants were not recorded due to equipment malfunction. One participant was excluded because their baseline activity was >3 SDs from the mean. In order to examine whether heterogeneity in trait positive urgency, BIS and BAS is associated with individual differences in resting frontal activity, we conducted individual regression analyses testing whether each self-report measure relates to the index of relative left-frontal activity.

Source Localization

We utilized standardized low-resolution brain electromagnetic tomography (sLORETA) to estimate the intracerebral electrical sources that generated the scalp-recorded alpha band frequency activity (Pascual-Marqui, 2002). sLORETA computes electric neuronal activity as current density and has been validated in comparison with fMRI, MRI and PET (Dierks *et al.*, 2000; Worrell *et al.*, 2000; Vitacco *et al.*, 2002; Mulert *et al.*, 2004; Pizzagalli *et al.*, 2005; Zumsteg *et al.*, 2006). Using the electrode positions determined by the MNI 152 scalp, the subcortical areas are partitioned in 6239 voxels at $5 \times 5 \times 5$ mm spatial resolution. We report areas of neural activity in accordance to standard anatomical labels using MNI space corrected to Talairach space.

RESULTS

Relationship between frontal activity and positive urgency

We first examined whether heterogeneity in trait positive urgency can be associated with individual differences in baseline frontal activity.

Frontal asymmetry was positively related to positive urgency, $\beta = 0.27$ [0.09, 0.44], $t(119) = 3.05$, $P = 0.003$ (see Figure 1). Individuals with greater left-frontal activity at baseline reported greater trait positive urgency.

Based on sLORETA statistics sub-program and visual inspection, current source density analyses of the relationship between PUM scores and alpha power identified the right inferior frontal gyrus (MNI coordinates: X = 50, Y = 15, Z = 0) as the origin of this relationship (See Figure 2). These results suggest that PUM scores relate to reduced right-frontal activity at the inferior frontal gyrus.

Relationship between frontal activity and BIS/BAS

Next, we examined whether BIS/BAS scores were associated with individual differences in resting frontal activity. The frontal asymmetry index was not correlated with BIS, $\beta = 0.10$ [-0.08, 0.28], $t(119) = 1.10$, $P = 0.27$. Also, frontal asymmetry was not correlated with BAS, $\beta = -0.08$ [-0.26, 0.10], $t(118) = -0.88$, $P = 0.38$. Positive urgency remained a moderate predictor of left-frontal activity when controlling for BIS, $\beta = 0.27$ [0.10, 0.45], $t(118) = 3.11$, $P = 0.002$, or BAS, $\beta = 0.26$ [0.09, 0.44], $t(117) = 2.96$, $P = 0.004$. See Table 2 for the relationships between PUM, BIS and BAS. Results suggest that BIS/BAS did not relate to frontal asymmetry in the current sample.

Our confidence intervals (CIs) are a range of plausible values for the relationship between positive urgency and left-frontal activity. Values outside the CI are relatively implausible. The lower bound estimate (lower limit) suggests that positive urgency remains a small predictor of greater left-frontal-cortical activity.

DISCUSSION

This study revealed that baseline frontal-cortical activity measured through frontal asymmetry is associated with greater trait positive

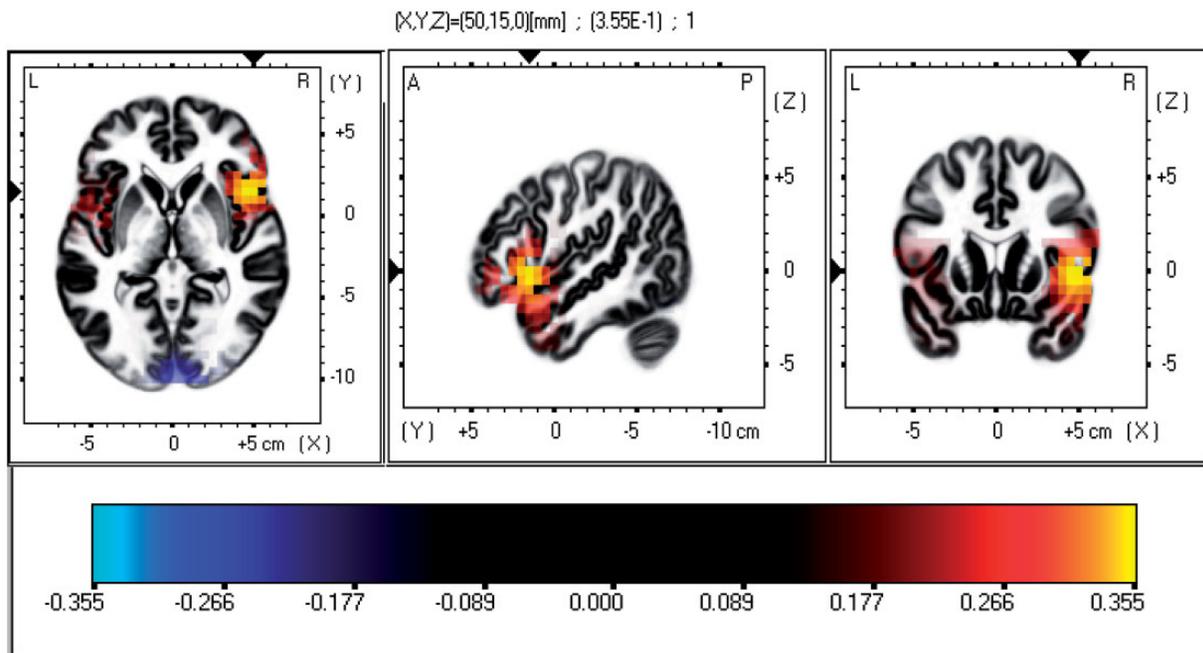


Fig. 2 Current source density analyses of the correlation between positive urgency and alpha power (less cortical activity) in the frontal cortex revealed the origin at the right inferior frontal gyrus (MNI coordinates: $X = 50$, $Y = 15$, $Z = 0$). The strength of the correlation coefficient is identified by the color scale. Red/yellow source localizations are associated with less cortical activity (greater alpha power).

Table 2 Correlations between PUM and BIS, BAS and BAS subscales

Scale	Pearsons r	P-value
BIS	-0.14	0.15
BAS	-0.12	0.21
BAS RR	-0.31	0.00*
BAS DRIVE	-0.08	0.42
BAS FUN	0.11	0.24

PUM, positive urgency measure; BIS, behavioral inhibition System; BAS, behavioral activation system; BAS RR, behavioral activation system reward responsiveness; BAS DRIVE, behavioral activation system drive; BAS FUN, behavioral activation fun seeking.

urgency. Consistent with predictions, greater relative left-frontal activity related to greater trait impulsivity. Source localization of this relationship revealed its origin as reduced activity in the right inferior frontal gyrus. These results suggest that the relationship between greater relative left-frontal activity and positive urgency stem from relatively greater left-frontal activity because of less right-frontal activity in the inferior frontal gyrus. Reduced right-frontal cortical activity seems to be associated with reduced functioning of the supervisory control system. Greater relative left-frontal asymmetry has predominantly been associated with approach temperament and behaviors. These new findings suggest that greater relative left-frontal asymmetry associated with the supervisory control system is driven by reduced right-frontal activation.

Past research suggests that reduced right-frontal activity through temporary or permanent lesions results in greater approach-related behaviors such as mania or aggression (Sackeim et al., 1982; d'Alfonso et al., 2000). Other work suggests that right-frontal activity relates to the supervisory control system, as evidenced by enhanced impulsivity (Knoch et al., 2006; Aron et al., 2014). The current findings

provide new insight into the link between personality traits and neurophysiological markers. Previous research has neglected to research the connection between asymmetric cortical activity specific to the alpha band (inverse of cortical activity) and trait individual differences in impulsivity. This is the first instance of research exploring the relationship between positive urgency and baseline cortical activity.

Results from this study suggest that reduced right-frontal cortical activity may be a neurophysiological marker of an individual's propensity towards rash action under intense positive emotional states. Positive urgency is a unique personality construct that predicts a wide range of risky behaviors. The current results suggest that positive urgency is related to reduce right-frontal activity. Baseline cortical asymmetry may play a role in promoting risky behaviors. Better understanding the neurophysiological correlates of positive urgency may contribute to our understanding of how urgency contributes to substance use and pathologies associated with impulsivity. For example, the neural correlates associated with positive urgency may shed light on pathological and addictive behaviors. Future research should investigate the potentially mediational role of frontal asymmetry in disorders and behaviors associated with positive urgency.

The current results did not find that trait behavioral approach sensitivity related to baseline frontal asymmetry. However, much past research demonstrates that greater left-frontal activation evoked by approach-motivated emotional states is related to individual differences in approach motivation (Harmon-Jones et al., 2010; Gable and Poole, 2012, 2014). Perhaps the link between approach/avoidance systems and frontal asymmetry may be largely driven by situational context, such as emotional/motivation states. The relationship between individual differences in frontal asymmetry and approach/avoidance systems may be more pronounced in the context of emotional responses (Coan et al., 2006). However, because the current research found a robust association between positive urgency and baseline frontal activity, the link between baseline frontal asymmetry and trait impulsivity may be less influenced by situational context.

Of note in the current findings is that positive urgency and greater relative left-frontal cortical activity have been associated with positive affect. However, it is unlikely that the current results are dependent on positive mood. Past work examining greater relative left-frontal activity has linked greater left-frontal activity with negative affects such as anger (Poole and Gable, 2014), suggesting that it is approach motivation, rather than positive affect that evokes relatively greater left-frontal activity. However, it is unlikely that the association between greater left-frontal asymmetry and positive urgency is due to enhanced trait approach motivation. In the current findings, the relationship between relative left-frontal cortical activity and positive urgency was not diminished when controlling for the variance in behavioral approach. Examination of the psychometric properties of PUM and BAS reveals that positive urgency represents a distinct factor from those represented by the subscales of BAS (Cyders et al., 2007). Indeed, the current findings support this distinction; overall, positive urgency was unrelated to the BAS scales. Moreover, positive urgency, but not BAS scales, related to resting frontal asymmetry. Future research is needed to examine the neural correlates of the supervisory control system governing approach and avoidance motivational states.

Investigating neurophysiological measures associated with traits related to impulsivity are key to better understanding the supervisory control system mediating the approach and avoidance systems. The current results help to clarify that the link between trait positive urgency and greater left-frontal activity is driven by reduced right-frontal activity. Because much past work has associated frontal asymmetry with approach and avoidant systems, the current results suggest that deficits in the supervisory control system may be related to neural substrates associated with these motivational systems.

This is the first study to link the trait neurophysiological marker of resting alpha asymmetry with trait impulsivity, as measured by positive urgency. These results suggest a potential underlying neurobiological mechanism for the development and maintenance of trait positive urgency. Emotion-based rash action associated with relatively greater left-frontal activity may be a means through which individuals have increased reactive approach-related tendencies and affect. These results are in line with a growing recognition of the importance of identifying neural or neurophysiological markers of personality traits related to core systems of human behavior (Nusslock et al., 2012; Cyders et al., 2014). Such markers can increase understanding of the physiology of traits and the underlying mechanisms of these systems.

CONFLICT OF INTEREST

None declared.

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