Neurophysiological Markers of Multiple Facets of Impulsivity

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Abstract

Human behavior is influenced by three core personality systems: approach, avoidance, and supervisory control. The supervisory control system is inversely related to impulsivity. Although past research has related some aspects of impulsivity to frontal hemispheric asymmetry, impulsivity as a multi-faceted construct has not been studied in relation with frontal asymmetry. In addition, past work has potentially confounded impulsivity with approach-motivation. In the current study, greater relative left frontal activity was related to multiple facets of impulsivity: negative urgency, lack of premeditation, lack of perseverance, and positive urgency. Regressing both positive and negative urgency on frontal asymmetry revealed that approach-related positive urgency related to greater left frontal activity, but withdrawal-related negative urgency marginally related to greater right frontal activity. These results suggest that impulsivity, independent of affective valence, relates to greater left frontal activity. When controlling for trait approach motivation, the relationship between impulsivity and left frontal activity is unchanged.

Neurophysiological Markers of Emotion-Based Impulsivity

Human personality consists of three core systems: approach, avoidance, and supervisory control. The approach system encompasses behavioral activation and approach of goals, while the avoidance system involves behavioral inhibition, withdrawal, and escaping threat (Gray, 1970; Carver & Scheier, 2008). The supervisory control system manages impulses produced by both the approach and avoidance systems. The supervisory control system exercise effortful control over motivational impulses (Carver & Connor-Smith, 2010) and has been linked to executive control and inhibition (Aron, Robbins, & Poldrack, 2014; Hester & Garavan, 2009). Impulsivity is an inverse measure of the supervisory control system. Impulsivity is related to deficits in control and inhibition (Enticott, Ogloff, & Bradshaw, 2006; Logan, Schachar, & Tannock, 1997) and encompasses deficits in approach behaviors such as persistence and planning (Churchill & Jessop, 2010). Clarifying the relationship between these three personality systems helps shed light on the biological basis for human behavior. The approach and avoidance system are often associated with distinct hemispheres of the brain, but the supervisory control system may also be related to lateralized brain activity.

Much psychophysiological work has focused on the neural correlates of the approach and avoidance systems. Greater left frontal asymmetry relates to the approach system, while greater right frontal asymmetry relates to the avoidance system (Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997; Coan & Allen, 2003; Schutter et al., 2008; Hietanen et al., 2008; Poole, & Gable, 2014; for reviews see Harmon-Jones, Gable, & Peterson, 2010; Rutherford & Lindell, 2011). In this manuscript, “asymmetry” is used to describe baseline or resting levels of activity, and “activation” to describe state-related activity (Coan & Allen, 2004). Asymmetric hemispheric activation has been found to relate to both trait (Sutton & Davidson, 1997) and

situational approach and avoidance motivation (Poole & Gable, 2014; Gable & Harmon-Jones, 2008; Coan, Allen, & Harmon-Jones, 2001). While the past work regarding state behavioral approach and avoidance has consistently related to asymmetrical activation, trait approach and avoidance has been inconsistent, even among large samples (Wacker, Chavanon, & Stemmler, 2010). Hemispheric asymmetry may instead reflect the functioning of the supervisory control system as it governs urges of approach and avoidance.

Recent evidence suggests that greater relative left frontal asymmetry may be associated with impulsive traits (Grimshaw & Carmel, 2014). Greater relative left frontal (or diminished right frontal) asymmetry has been associated with trait sensation seeking (Santesso et al., 2008), positive urgency (Gable, Mechin, Hicks, & Adams, 2015), and response inhibition (Schiller, Gianotti, Nash, & Knoch, 2013). Greater relative right frontal activity has been associated with less risk-taking (Gianotti et al., 2009). However, each of these constructs has been investigated independently from other facets of impulsivity and may have been confounded with approach motivation. For example, positive emotion-based urgency and sensation seeking are conceptually related to the behavioral approach system. In the current study, we sought to examine whether multiple facets of impulsivity, independent of approach motivation, related to greater left frontal asymmetry.

The UPPS-P Impulsive Behavior Scale assesses five impulsivity traits that reflect distinct facets of impulsivity. The lack of premeditation and lack of perseverance scales reflect aspects of impulsivity related to conscientiousness (Gullo, Loxton, & Dawe, 2014). Sensation seeking assesses openness to new and exciting experiences, but is less related to the other subscales (Simons et al., 2010). Positive urgency and negative urgency refer to the tendency for rash behavior in positive and negative emotional states, respectively (Cyders & Smith, 2007).

Because positive approach-motivated affect and negative withdrawal-motivated affect have been linked to left and right frontal asymmetry, respectively (Davidson, 1984), we sought to determine whether emotion-based impulsivity has distinct neural substrates from nonemotion-based impulsivity. We predict that all facets of impulsivity will relate to greater relative left frontal asymmetry.

Methods

One hundred and fifty three introductory psychology students participated for course credit. Two participants were excluded for failing to complete individual difference measures, and one was excluded for excessive artifacts in EEG data. Data from one hundred and fifty participants (88 female, 7 declined to respond) were included.

Procedure

Participants came into the lab and completed measures of handedness, BIS/BAS, and the UPPS-P. Then, EEG electrodes were applied and 8 minutes of resting baseline activity was recorded.

Measures

Handedness was assessed using a 13-item checklist asking participants which hand they use to perform certain tasks. Right-handedness was defined as performing no more than one item with their left hand. All participants reported being right-handed.

The BIS/BAS Scales (Carver & White, 1994) assess trait levels of behavioral approach and inhibition. BIS measures punishment sensitivity, while BAS total is the average of three BAS subscales measuring responsiveness and pursuit of rewards.

The UPPS-P Behavioral Impulsivity scale (Cyders & Smith, 2007) consists of fifty-nine items capturing five facets of impulsivity: Negative Urgency, lack of Premeditation, lack of Perseverance, Sensation Seeking, and Positive Urgency.

EEG Assessment and Processing

Electroencephalography was recorded from 64 tin electrodes mounted in a stretch lycra cap (Electro-Caps, Eaton, OH) based on the 10-20 system with a ground electrode between FPZ and FZ. EEG activity was referenced to the left earlobe. All electrode impedances were under 5 kΩ and homologous sites were within 1 kΩ of one another. A Neuroscan SynAmps RT amplifier unit (El Paso, TX) was used. Data were low pass filtered at 100 Hz, high-pass filtered at 0.05 Hz, notch filtered at 60 Hz, and digitized at 500 Hz. Data were visually inspected and hand-corrected to eliminate artifacts. A regression-based eyeblink correction was applied (Semlitsch, et al., 1986), and data were visually inspected a second time to ensure proper correction.

Epochs 1.024 s in duration were extracted through a Hamming window and referenced using a common average reference. Consecutive epochs overlapped by 50%. Power spectra were calculated using a fast Fourier transform. Power values across the traditional Alpha band (8-13 Hz) were averaged across epochs (Coan & Allen, 2004; Harmon-Jones & Allen, 1997). Asymmetry scores at homologous sites (F4/F3, F6/F5, F8/F7) were calculated by subtracting log left from log right alpha activity. Scores were averaged together to create an index of frontal asymmetry. An average of 844.88 (*SD* = 138.11) usable epochs were analyzed for each participant. Because alpha activity is inversely related to cortical activation (Laufs et al., 2003), higher scores indicated greater relative left frontal activity.

Source Localization

Following past methods (Gable et al., 2014), we used standardized low-resolution brain electromagnetic tomography (sLORETA; Pascual-Marqui, 2002) software to investigate a potential intracerebral electrical source of alpha band frequency activity.

Results

All subscales of the UPPS-P except sensation seeking were positively correlated with one another (see Table 1). Sensation seeking was negatively related to other UPPS-P subscales. Greater positive urgency, negative urgency, lack of premeditation and lack of perseverance all predicted greater relative left frontal asymmetry (see Figure 1). Sensation seeking predicted greater relative right frontal asymmetry (see Table 2). No relationships were found between BIS, BAS Total, or BAS subscales and frontal asymmetry rs < |.10|, ps > .23

Table 1. Correlations between the UPPS-P and BIS/BAS scales.

	1	2	3	4	5	6	7
1. Lack of Premeditation	---						
2. Lack of Perseverance	.73*	---					
3. Sensation Seeking	-.29*	-.47*	---				
4. Positive Urgency	.70*	.74*	-.30*	---			
5. Negative Urgency	.54*	.54*	-.17*	.71*	---		
6. BAS	-.15	-.07	-.15	-.25*	-.09	---	
7. BIS	.11	-.05	.18*	-.10	-.07	.09	---

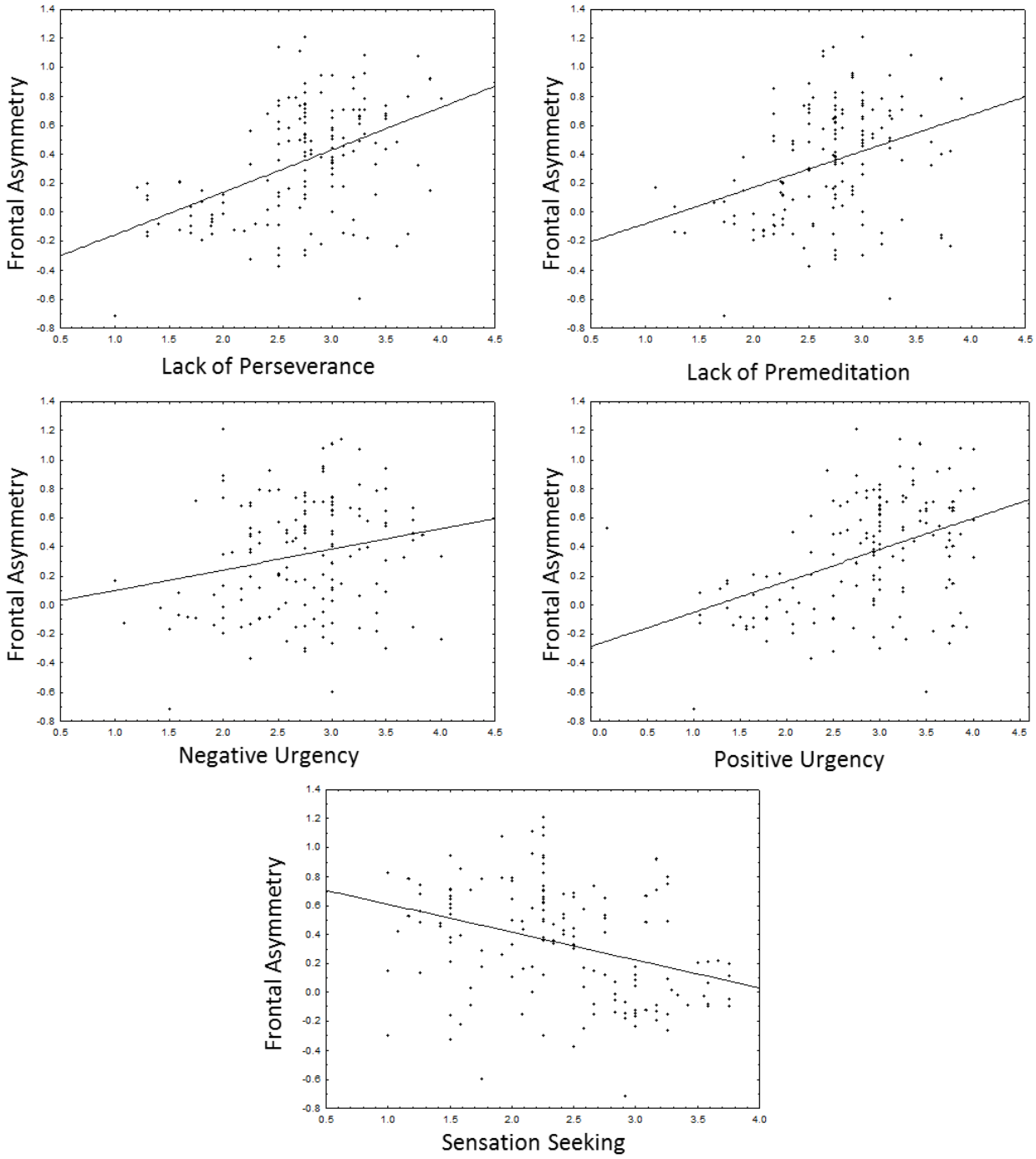
* $p < .05$

Table 2. Bi-variate Regression analyses between relative left frontal asymmetry, BIS/BAS, and the UPPS-P.

	ß	*t*	*p*

Lack of Premeditation	.34	4.43	.0001
Lack of Perseverance	.47	6.45	.0001
Sensation Seeking	-.34	-4.45	.0001
Positive Urgency	.42	5.75	.0001
Negative Urgency	.21	2.60	.01
BIS	-.05	-1.04	.30
BAS	-.11	-1.13	.26

Figure 1. Relationships between frontal asymmetry and UPPS-P subscales. Greater scores on frontal asymmetry indicate greater relative left frontal activity.



To assess the impact of emotional valence on impulsivity, negative urgency and positive urgency were included as simultaneous predictors of frontal asymmetry. When controlling for urgency, positive urgency became more strongly related to greater left frontal asymmetry, *ß* = .56, $p < .0001$. In contrast, negative urgency became marginally related to greater right frontal

asymmetry, *ß* = -.19, *p* = .07. Data met the assumption of collinearity (Tolerance = .496, VIF = 2.016), indicating that multicollinearity was not a concern.

To ensure that approach motivation is not responsible for the relationship between left frontal asymmetry and impulsivity, multiple regression analyses were conducted controlling for BAS with each UPPS-P subscale. Relationships between UPPS-P scales and left frontal asymmetry remained; BAS did not explain a significant amount of variance in any analyses (*p*s > .35).

Based on sLORETA statistics sub-program, current source density analyses of the origin of the relationship between Positive Urgency, Perseverance, and Premeditation scores and alpha power localized to the right anterior Cingulate Gyrus and Medial Frontal Gyrus (MNI coordinates: X=5, Y = 15, Z = 35). Negative Urgency scores localized to the right Precentral Gyrus and Medial Frontal Gyrus (X = 35, Y = 10, Z = 40).

Discussion

Positive urgency, negative urgency, lack of premeditation and lack of perseverance related to greater left frontal asymmetry. When the common variance of urgency was controlled when regressing positive and negative urgency, positive urgency became more strongly associated with greater left frontal asymmetry, but negative urgency became marginally related to greater right frontal asymmetry. The relationship between emotion-based facets of impulsivity and frontal asymmetry does not appear to be due to the valence of the affective state, but instead seems to be due to the underlying construct of urgency. Controlling for trait approach motivation (BAS) did not alter the relationship between left frontal asymmetry and impulsivity. These findings address the potential confound of approach motivation and positive affect in previous research examining the relationship between positive urgency and frontal asymmetry (Gable et

al., 2015). Together, these results suggest that greater left (reduced right) frontal asymmetry may be a neurophysiological marker of diminished functioning of the supervisory control system.[1]

The majority of past work linking greater left frontal asymmetry to personality variables has examined traits related to approach or avoidant emotion and motivation. The current study links greater left frontal asymmetry to the supervisory control system, a core personality system theorized to regulate emotional/motivational processes by operating independent of approach and avoidance systems. Past work has demonstrated a relationship between greater left frontal activity and the approach system (Harmon-Jones & Allen, 1997; Harmon-Jones, Gable, & Peterson, 2010). In conjunction with this past work, it appears that greater left frontal asymmetry may be an overlapping neural signature of both approach motivation and the supervisory control system. The two systems work in conjunction to orchestrate functional behavior and greater relative left frontal activity may be underlying both of these systems.

Previous work has localized the relationship between positive urgency and frontal asymmetry to diminished activity in the right inferior frontal gyrus (Gable et al., 2014). The current study did not directly replicate this result. In the current sample, positive urgency, premeditation, and perseverance localized to the right cingulate gyrus. Past work investigating response inhibition, a process closely tied to impulsivity, has found activation in the cingulate gyrus during Go/No-Go tasks (Garavan et al., 2002; Horn et al., 2003). Activation of the limbic network may reflect the motivational components of impulsivity. It is likely that multiple brain regions associated with impulsive processes contribute to the relationship between resting asymmetrical activation and trait impulsivity.

Together with past work, this study suggests that greater left frontal activity in impulsive individuals seems to be driven by reduced activation of the right frontal cortex. Structural studies

have revealed that reduced volume of the right prefrontal cortex is associated with poor impulse control (Boes et al., 2009). Disruption of functioning of the right prefrontal cortex leads to riskier decision-making (Knoch et al., 2006). Trait impulsivity is related to diminished right frontal activity (Gable et al., 2015). Overall, reduced right prefrontal cortical activity appears to play a role in failure of the supervisory control system.

Understanding the neural mechanisms associated with the supervisory control system contributes to a growing interest in relating personality traits to stable neurophysiological markers. Frontal asymmetry may be one neural mechanism underlying the supervisory control system. The current study demonstrates that the relationship between left frontal activity and impulsivity is not due to approach motivation or emotive processes, but instead may be reflect functioning of the supervisory control system.

Footnotes

1. Sensation seeking related to greater right frontal activity and inversely with the other UPPS-P scales. Researchers have noted that the UPPS-P sensation seeking scale is least related to the other scales, and may reflect a construct distinct from impulsivity and self-control (Simons et al., 2010). Others have failed to find differences in sensation seeking between control and drug-using populations, leading to its exclusion when measuring impulsivity (Moreno-Lopez et al., 2012; Simons et al., 2010). Research linking sensation seeking and left frontal activity used the Zuckerman Sensation Seeking Scale (SSS; Zuckerman, 1994; Santesso et al., 2008). The SSS assesses boredom susceptibility and disinhibition, similar to the lack of perseverance and urgency scales on the UPPS-P.

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