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Frontal asymmetry and alcohol cue reactivity: Influence of core personality systems

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Abstract

Greater left frontal activation appears to be a measure of appetitive reactivity for desired stimuli, such as alcohol cues. However, inconsistencies in past research examining frontal asymmetry to appetitive stimuli suggest that individual differences strongly influence frontal asymmetry to appetitive stimuli. Because core personality systems of approach, avoidance, and supervisory control play a fundamental role in directing alcohol behavior, the current study sought to determine which core system would influence asymmetric frontal activation to alcohol cues. Results revealed that greater trait impulsivity (reduced functioning of the supervisory control system) is related to greater relative left frontal activation in response to alcohol cues. Approach motivation and avoidance motivation were unrelated to greater relative left frontal activation in response to alcohol cues. These results suggest that decreased activation of the supervisory control system (increased trait impulsivity) is responsible for appetitive reactivity to alcohol cues.

Descriptors: Hemispheric differences/laterality, Individual differences, Alcohol/alcoholism

Much research has identified activation of the frontal cortex as a measure of appetitive alcohol reactivity (George et al., 2001; Tapert, Brown, Baratta, & Brown, 2004; Tapert et al., 2003; Wrase et al., 2002). Greater frontal cortical activation is associated with desire for alcoholic substances and alcohol consumption (George et al., 2001; Goldstein & Volkow, 2002). Functional magnetic resonance imaging (fMRI) research has identified activity in the orbitofrontal cortex as a neural substrate related to alcohol cue reactivity (George et al., 2001; Tapert et al., 2003; Wrase et al., 2002). Additionally, altering the excitability of neurons located in the left and right dorsolateral prefrontal cortex using transcranial direct current stimulation administration effectively diminishes alcohol cravings (Boggio et al., 2007). Importantly, the frontal cortex demonstrates asymmetrical functioning of the right and left hemispheres. Appetitive cue reactivity, or reactive desire toward substance-related cues, has been associated with greater left frontal activation across several different domains, such as cocaine cravings (van de Laar, Licht, Franken, & Hendriks, 2004), nicotine cravings (McClernon, Hiott, Huettel, & Rose, 2005), internet use cravings (Han et al., 2011), and appetitive responses to alcohol cues (Myrick et al., 2004). Cue reactivity is generally described as responses evoked from substance-related stimuli associated with appetitive or consumptive behavior (Carter & Tiffany, 1999).

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Appetitive cue reactivity is associated with greater activation of the left frontal cortex. However, appetitive cues do not always evoke greater left frontal activation (Elgavish, Halpern, Dikman, & Allen, 2003; Hagemann, Ewald, Becker, Maier, & Bartussek, 1998). Work directly investigating this failure to evoke greater left frontal activation to appetitive cues has found that individual differences strongly influence frontal asymmetry to appetitive stimuli (Asmaro et al., 2012; Gable & Harmon-Jones, 2008, 2012; Gable & Poole, 2014; Harmon-Jones, Lueck, Fearn, & Harmon-Jones, 2006; Prause, Staley, & Roberts, 2014; Wacker, Mueller, Pizzagalli, Hennig, & Stemmler, 2013). These results suggest that greater left frontal activation in response to alcohol cues may be driven by individual differences (Fleming & Bartholow, 2014) and, more specifically, core personality systems (Gordon et al., 2006; Papachristou, Nederkoorn, Havermans, van der Horst, & Janse, 2012; Zisserson & Palfai, 2007).

Core Personality Systems

Three systems are thought to lie at the core of human behavior: the approach motivation system, the avoidance motivation system, and the supervisory control system. The approach motivation system is theorized as the “go” system responsible for behavioral approach actions as well as goal-directed behaviors (Carver & Scheier, 2008; Depue & Collins, 1999; Elliot, 2008; Gray, 1970, 1987; Gray & McNaughton, 2000). In contrast, the avoidance motivation system is theorized as the “withdraw” system responsible for avoidance behaviors that occur in response to threat and nonrewarding situations (Carver & Scheier, 2008; Elliot, 2008; Gray, 1970, 1987). Carver and White (1994) developed the Behavioral Inhibition

System/Behavioral Activation System scales (BIS/BAS) to measure these systems.

The supervisory control system moderates the actions of the approach and avoidance systems (Carver & Connor-Smith, 2010; Kochanska & Knaack, 2003; Nigg, 2006; Rothbart & Rueda, 2005). This system exists as a regulatory system and functions by employing executive control to restrict impulses produced by the approach and avoidance systems. Biological models of human behavior identify the supervisory control system as distinct from the approach and avoidance systems (Carver & Connor-Smith, 2010; Elliot, 2008; Nigg, 2006). The supervisory control system is associated with inhibitory control, constraint, effortful control, and has an inverse relationship with trait impulsivity (Carver & Connor-Smith, 2010; Enticott, Ogloff, & Bradshaw, 2006; Kochanska & Knaack, 2003; Logan, Schachar, & Tannock, 1997; Nigg, 2006; Rothbart & Reuda, 2005). Failure of the supervisory control system evidenced by elevated trait impulsivity reduces forethought and may leave individuals more vulnerable to desired impulses.

Personality Systems and Alcohol Cue Reactivity

Because each of these systems plays a fundamental role in human behavior, evidence suggests that each one of them may play a role in alcohol cue reactivity. An enhanced approach system may drive alcohol cue reactivity in that individuals high in approach are more sensitive to rewards and more motivated by alcohol cues (Hicks, Friedman, Gable, & Davis, 2012; Zisserson & Palfai, 2007). Alcohol is associated with positive mood states and high energy situations generally associated with approach motivation (Cyders & Smith, 2008). The association between positive situations and alcohol can enhance approach motivation toward alcohol resulting in elevated cravings and reactivity (Cox & Klinger, 1988). Individual differences in reward seeking are related to increased cravings for alcohol (Verheul, van der Brink, & Geerlings, 1999). This past work suggests that reactivity toward alcohol cues may be associated with enhanced activation of the approach system.

Heightened, or overactive avoidance system may also relate to alcohol cue reactivity. For example, individuals with depression and anxiety are thought to have an enhanced avoidance system (relative to the approach system). Such individuals demonstrate increased alcohol reactivity and consumption (Cooney, Litt, Morse, Bauer, & Gaupp, 1997; Gordon et al., 2006; Grant & Harford, 1995) and have a higher prevalence for alcohol consumption (Canan & Ataoglu, 2008; Carpenter & Hasin, 1998; Gordon et al., 2006; Kushner, Thuras, Abrams, Brekke, & Stritar, 2001; Witkiewitz & Bowen, 2010). High avoidance motivation is associated with increased sensitivity to threats in the environment and greater negative affect. Avoidance of these aversive states may motivate individuals to consume alcohol (Canan & Ataoglu, 2008; Cooper, Russell, Skinner, & Windle, 1992; Kushner et al., 2001). Although individuals may be motivated to approach alcohol to relieve such states, it seems possible that these behaviors may stem from an overactive avoidance system.

Finally, alcohol cue reactivity may be associated with reduced functioning of the supervisory control system. Individuals high in trait impulsivity experience more inhibitory failure in the presence of alcohol cues, resulting in greater reactivity toward alcoholic substances and subsequent consumption (Joos et al., 2013; Perry & Carroll, 2008). Greater trait impulsivity is associated with increased alcohol craving (Crews & Boettiger, 2009). Additionally, individuals high in disinhibition tend to experience increased cravings for alcohol in the presence of alcohol cues (Verheul et al., 1999). Strengthening the supervisory control system through effortful training reduces alcohol craving in the presence of alcohol cues (Field & Cox, 2008; Garland, Gaylord, Boettiger, & Howard, 2010; Leeman, Bogart, Fucito, & Boettiger, 2014). This past work suggests that a deficient supervisory control system may drive alcohol cue reactivity.

Frontal Asymmetry and Core Personality

Frontal activation has been asymmetrically related to the behavioral approach systems and behavioral avoidance system (Broca, 1861; Gazzaniga, 1985; Sperry, Gazzaniga, & Bogen, 1969; Toga & Thompson, 2003). Greater relative activation of the right frontal cortex is associated with the avoidance system (Aron, Robbins, & Poldrack, 2004; Elliot, 2008; Sutton & Davidson, 1997). In contrast, greater relative activation of the left frontal cortex is associated with the approach system (Coan & Allen, 2003; Goldstein, 1939; Harmon-Jones, 2003; Harmon-Jones & Gable, 2009; Harmon-Jones, Gable, & Peterson, 2010; Rossi & Rosadini, 1967; Sutton & Davidson, 1997).

Recently, past work has linked the supervisory control system with frontal asymmetry (Aron, Robbins, & Poldrack, 2014; Grimshaw & Carmel, 2014). Trait sensation seeking, a facet of impulsivity, has been linked to greater right frontal alpha cortical activity at baseline (Santesso et al., 2008). Greater behavioral risk taking has been linked to right frontal theta and delta activation (Gianotti et al., 2009). Additionally, Gable, Mechin, Hicks, and Adams (2015) found that positive urgency, a measure of trait impulsivity, related to greater relative left frontal EEG activity. Specifically, reduced functioning of the right inferior frontal gyrus was responsible for the association with positive urgency and increased left frontal asymmetry. Results of this study suggest that greater relative left frontal activity may reflect the neural underpinnings of the supervisory control system.

Core personality systems drive alcohol cue reactivity and relate to frontal asymmetry. It seems likely that frontal activation to alcohol cues could stem from one of the following: increased activation of the approach system, increased activation of the avoidance system, or a reduced functioning of the supervisory control system. The current study sought to investigate which core personality system drives greater relative left frontal activation to alcohol cues. Specifically, we examined the impact of trait impulsivity, trait approach motivation, and trait avoidance motivation on frontal asymmetry to alcohol and neutral pictures. We hypothesized that core personality traits would relate to greater left frontal activation to alcohol pictures, but not neutral pictures.

Method

Forty-two participants (29 females, 10 males, three did not report gender) completed the study in return for partial course credit. The average age of the sample was 18.76 years ($SD = 5.36$). EEG data from seven participants were not analyzed due to equipment failure during recording. All data were examined for potential outliers (> 3 *SD* from the mean). One outlier was identified for their EEG asymmetry score and one outlier was identified for their alcohol use. These individuals were removed from analyses including these variables.

Procedure

Participants completed the UPPS-P Behavioral Impulsivity Scale (Cyders et al., 2007), the BIS/BAS scales (Carver & White, 1994), and general demographics including age, gender, and questions about their current drinking habits. After completing the demographic questions as well as the measures of impulsivity and approach/avoidance motivation, participants viewed 32 neutral pictures (rocks) and 32 alcohol pictures (alcoholic beverages such as beer, wine, and liquor) presented in random as opposed to block order. Each picture was displayed for 9 s and preceded by a 500-ms fixation cross. Neutral and alcohol pictures were matched for size, color, and complexity across condition to reduce the potential of perceptual confounds. EEG activity was recorded during picture presentation as a measure of cue reactivity. Lastly, experimenters thoroughly debriefed participants and granted participation credits. The current study was approved by the Institutional Review Board ethics committee, and all participants were informed of their rights as participants before beginning the study.

Demographics

Participants reported their sex (1 = female, 2 = male). Participants also reported handedness by indicating whether they use their left, right, or either hand for 13 different behaviors (e.g., drawing; Chapman & Chapman, 1987). All participants reported being right-handed.

UPPS-P Behavioral Impulsivity Scale

The UPPS-P Behavioral Impulsivity Scale is a 59-item scale with five subscales measuring trait impulsivity. Each question is rated on a 4-point Likert scale (1 = *strongly disagree*; 4 = *strongly agree*). The first subscale, negative urgency, encompasses 12 items (e.g., "In the heat of an argument, I will often say things that I later regret"). Negative urgency refers to the tendency to act rashly when in a distressed state. The second subscale, lack of premeditation, consists of 11 items that gauge an individual's inability to consider the consequences of actions (e.g., "I am not one of those people who blurt out things without thinking"; item reverse scored). The third subscale, lack of perseverance, consists of 10 items and measures an inability to persist in completing tasks or committing to obligations (e.g., "I generally like to see things through to the end"; item reverse scored). The fourth subscale, sensation seeking, is 12 items and measures an individual's propensity for stimulation and excitement (e.g., "I generally seek new and exciting experiences and sensations"). Finally, the fifth subscale, positive urgency, is comprised of 14 items and measures the tendency to act rashly when experiencing high positive affect (e.g., "When I am in a great mood, I tend to get into situations that could cause me problems"). Means, standard deviations, and reliability scores for the UPPS-P and subscales can be found in Table 1. Consistent with past research, the items comprising the subscales were combined in a total UPPS-P score to measure trait impulsivity (Cirilli, de Timary, Lefevre, & Missal, 2011; Kipper, Green, & Prorak, 2010; Klonsky, May, & Glenn, 2013). See Table 1 for means, standard deviations, and reliability scores for the UPPS-P scales and all trait measures.

Trait BIS/BAS

The BIS/BAS questionnaire contains one scale of BIS (behavioral inhibition) and three subscales of BAS (behavioral activation). The BIS scale component relates to the anticipation of punishment and is a measure of the avoidance motivation system. The BIS scale encompasses seven items (e.g., "I worry about making mistakes").

Table 1. *Descriptive Statistics and Reliabilities of Individual Difference Measures for the Current Sample*

Measure	Mean	*SD*	Cronbach's alpha
BAS total	2.97	0.38	0.81
BAS reward responsiveness	3.28	0.31	0.44
BAS drive	2.67	0.52	0.76
BAS fun	2.87	0.61	0.81
BIS	2.91	0.66	0.89
UPPS-P total	2.87	0.39	0.93
Negative urgency	2.87	0.54	0.84
Positive urgency	3.23	0.46	0.92
Lack of premeditation	2.93	0.47	0.89
Lack of perseverance	3.12	0.43	0.84
Sensation seeking	2.26	0.55	0.87

Note. Mean refers to mean score on each scale across participants.

The three BAS scales include BAS reward responsiveness, BAS drive, and BAS fun seeking. BAS reward responsiveness looks at responses to the anticipation of reward across five items. BAS drive measures an individual's persistent pursuit of goals across four items. BAS fun seeking measures an individual's willingness to approach new stimuli with the potential of reward across four items. The entire BIS/BAS scale is 20 items (Carver & White, 1994). BAS total is calculated by taking the average of the BAS subscale items.

Drinking Habits

Two questions measured past month drinking habits. Past month drinking was measured by asking participants, "During the past month, how many times have you had at least one drink of alcohol?" (referred to as "past month drinking episodes"). The typical amount consumed during each episode of drinking was measured by asking participants, "During the past month on the days you drank, on average, how many drinks did you have?" (labeled "past month drinks per episode"). Alcohol use was quantified using a product of drinking episodes and drinks per episode. One participant did not report past month drinking episodes and another did not report drinks per episode. Table 2 includes descriptive statistics concerning reported drinking habits. Participants ranged in drinking habits from lifetime abstainers to participants reporting recent binge drinking episodes. The current sample included abstainers and light drinkers in order to assess the neurophysiological reactions to alcohol cue reactivity in a range of young adults.

EEG

EEG activity was recorded using 64 electrodes embedded in a stretch Lycra cap, placed according to the 10-20 system using known anatomical landmarks (Jasper, 1958). Data were referenced to the left earlobe with a ground electrode mounted between FPZ and FZ sites (Electro-Caps, Eaton, OH). Electrode impedances were kept under 5,000 Ω for all sites and within 1,000 Ω for homologous electrode pairs. Signals from the electrodes were amplified

Table 2. *Descriptive Statistics for Reported Drinking Behaviors*

Measure	Mean	*SD*	Min	Max
Past month drinking episodes	5.45	5.66	0	20
Past month drinks per episode	2.45	2.21	0	8
Alcohol use	19.56	25.43	0	100

Note. Alcohol use is the product of past month drinking episodes and past month drinks per episode.

using a Neuroscan SynAmps RT amplifier unit (El Paso, TX), low-pass filtered at 100 Hz, high-pass filtered at 0.05 Hz, notch filtered at 60-Hz, and digitized at 2,000 Hz. Artifacts were removed from the data by hand. A regression-based eye movement correction was used to remove blinks, and visual inspection of the data was performed to insure proper correction before the data were used for analyses (Semlitsch, Anderer, Schuster, & Presslich, 1986).

Consistent with previous research, frontal asymmetry was measured using alpha band power (Coan & Allen, 2003; Harmon-Jones et al., 2010, for reviews) within the traditional alpha broad-band range of 8–13 Hz using a fast Fourier transform (Shackman, McMenamin, Maxwell, Greischar, & Davidson, 2010). Cortical alpha activity was averaged across the 9 s of picture presentation for each picture type. Power spectra epochs 1.024 s in duration were extracted through a Hamming window (alcohol trials $M = 397.61$ epochs, min = 144; neutral trials $M = 389.09$, min = 95), and data were rereferenced using a common average reference. Asymmetry scores were created for frontal homologous sites (F3/F4, F5/F6; log right minus log left; Gable & Harmon-Jones, 2008) to measure cue reactivity. Asymmetry scores were aggregated to create an index of frontal asymmetry (Cronbach's $\alpha = .61$). To investigate whether the observed effects of trait impulsivity are specific to the frontal region, asymmetry scores were created for posterior homologous sites (P3/P4, P5/P6; log right minus log left) and aggregated to create an index of posterior asymmetry. Because alpha power is inversely related to cortical activity, higher index scores indicate greater left than right hemispheric activity (Lindsley & Wicke, 1974) and greater appetitive cue reactivity.

Results

Trait Impulsivity, Trait Approach, and Trait Avoidance

To examine the relation between frontal EEG asymmetry and personality traits, we ran a series of regression analyses predicting asymmetry during alcohol pictures from asymmetry during neutral pictures and UPPS-P total, BAS total, or BIS. The regression tests investigating our three a priori hypotheses were conducted using a Bonferroni adjusted alpha of .0167 per test (.05/3). In order to adjust for neural activity to pictures in general, neural activity to neutral pictures was included in the analyses predicting neural activity to alcohol pictures (Gable & Harmon-Jones, 2013). Trait impulsivity (UPPS-P total) significantly related to greater left frontal activation to alcohol pictures, ß = .30, $t(31) = 2.99$, $p = .01$, 95% CIs [0.03, 0.15], adjusting for left frontal activation to neutral pictures. Trait impulsivity did not relate to greater left frontal activation to neutral pictures, ß = −.19, $t(31) = -1.60$, $p = .12$, 95% CIs [−0.12, 0.02], adjusting for left frontal activation to alcohol pictures. Additionally, there was a significant interaction between trait impulsivity and picture type, $F(1,32) = 5.95$, $p = .02$, $\eta_p^2 = .16$ (see Figure 1).[1] Adjusting for greater left frontal activation to neutral pictures, trait impulsivity explains a significant portion of variance as evidenced by partial correlation, $r = .47$, $p = .01$. An independent samples t test found no significant difference between left frontal activation to neutral pictures and left frontal activation to alcohol pictures, $t(66) = -0.07$, $p = .94$.

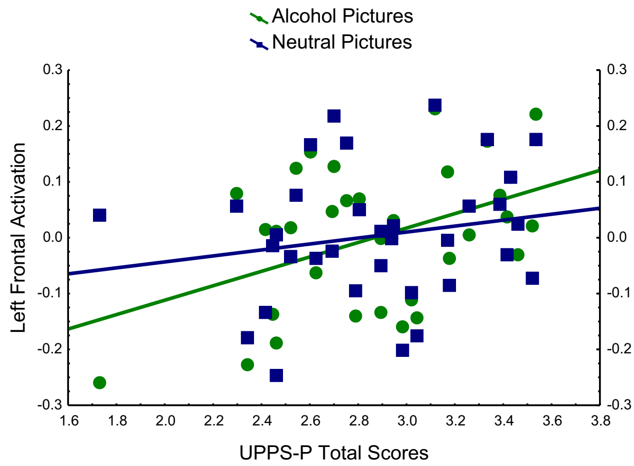

Figure 1. Regression interaction of UPPS-P total scores and picture condition on left frontal activation. Lines depict simple slopes for each picture type.

Trait approach motivation (BAS total) did not relate to greater left frontal activation to alcohol pictures, ß = .03, $t(31) = 0.23$, $p = .82$, 95% CIs [-0.07, 0.08], adjusting for left frontal activation to neutral pictures. BAS also did not relate to greater left frontal activation to neutral stimuli, ß = .02, $t(31) = 0.22$, $p = .83$, 95% CIs [−0.06, 0.08], adjusting for left frontal activation to alcohol pictures. Trait behavioral avoidance (BIS) did not relate to greater left frontal activation to alcohol pictures, ß = .11, $t(30) = 1.03$, $p = .31$, 95% CIs [-0.02, 0.06], adjusting for left frontal activation to neutral pictures. BIS also did not relate to greater left frontal activation to neutral stimuli, ß = −.05, $t(30) = -0.48$, $p = .63$, 95% CIs [−0.05, 0.03], adjusting for left frontal activation to alcohol pictures. Multiple regression analyses were conducted to test the relationship between the subscales of BAS and the UPPS-P as predictors of left frontal activation to alcohol and neutral pictures. Table 3 reports the beta values of these analyses. Participant gender did not moderate any of the observed findings, $ps > .18$.

These results suggest that trait impulsivity (UPPS-P total), not trait approach (BAS total) or trait avoidance (BIS), is responsible for driving left frontal activation associated with alcohol cue reactivity (i.e., greater left frontal cortical activation in response to alcohol stimuli). Specifically, it appears that decreased activation of the supervisory control system (increased trait impulsivity) is responsible for alcohol cue reactivity.

Analyses of the posterior index produced nonsignificant results. Specifically, UPPS-P total is not a significant predictor of asymmetric posterior activation to alcohol pictures, ß = −0.11, $t(32) = -1.26$, $p = .22$, 95% CIs [−0.13, 0.03], adjusting for asymmetric posterior activation to neutral pictures. The interaction between trait impulsivity and picture type is also nonsignificant at posterior sites, $F(1,33) = .75$, $p = .39$, $\eta_p^2 = .02$. Finally the partial correlation associated with trait impulsivity is also nonsignificant at posterior sites, $r = -.22$, $p = .22$. The observed relationship between frontal asymmetry and trait impulsivity appears to be specific to the frontal region.

1. One participant appeared to be an influential data point in this analysis (see Figure 1). Although this participant was within three *SD*s of the mean, we sought to examine analyses without this participant. UPPS-P total did not significantly predict greater left frontal activation to alcohol pictures, ß = .11, $t(30) = 1.22$, $p = .23$, 95% CIs [−0.02, 0.09], adjusting for left frontal activation to neutral pictures. The interaction between trait impulsivity and picture type was also nonsignificant, $F(1,31) = .49$, $p = .49$, $\eta_p^2 = .02$. The partial correlation associated with trait impulsivity also becomes nonsignificant, $r = .22$, $p = .23$. Of note, removing a participant from a sample this size can have a profound influence on results. The decrease in slope and increase in p values suggest this was a particularly influential data point.

Table 3. *Multiple Regression Analyses*

Personality measure	Left frontal activity to alcohol pictures	Left frontal activity to neutral pictures
BAS reward responsiveness	.14	−.12
BAS drive	.01	.11
BAS fun	−.05	−.04
Negative urgency	.24*	−.13
Positive urgency	.01	−.02
Lack of premeditation	.24*	−.11
Lack of perseverance	.05	−.01
Sensation seeking	.16	−.06

Note. Beta values are reported. In order to adjust for neural activity to pictures in general, neural activity to alcohol and neutral pictures were simultaneously entered.
*$p < .05$.

Relationship with Past Drinking

To determine if drinking behavior impacts the relationship between trait impulsivity and left frontal activation, past drinking was included as a variable in the regression analysis. Trait impulsivity remained significantly related to greater left frontal cortical activation when adjusting for alcohol use, ß = .43, $t(29) = 2.19$, $p = .04$, 95% CIs [0.01, 0.26]. Additionally, trait impulsivity remained non-significantly related to greater left frontal cortical activation in response to neutral pictures when adjusting for alcohol use, ß = .36, $t(29) = 1.77$, $p = .09$, 95% CIs [−0.02, 0.25].

Discussion

The current study suggests that, in a nonclinical sample, deficits in the supervisory control system relate to frontal asymmetry to alcohol cues. Reduced functioning of the supervisory control system (greater trait impulsivity) related to greater left frontal activation toward alcohol cues. Trait impulsivity remained significantly related to left frontal activation toward alcohol cues when adjusting for drinking behaviors and frontal activation to neutral pictures. In contrast, results did not reveal a relationship between trait approach or trait avoidance and greater left frontal activation to alcohol cues. These results suggest that the supervisory control system, but not the behavioral approach or behavioral avoidance systems, moderates frontal asymmetry to alcohol cues. Additionally, these results may contribute to the current understanding of alcohol use by highlighting the importance of including trait impulsivity in future theoretical models of alcohol cue reactivity.

Inhibitory functions are responsible for regulating immediate affective responses to stimuli and rely heavily on the executive function of the prefrontal cortex. Because positive and negative affective states strongly influence impulsive behavior, affective states may moderate alcohol cue reactivity driven by the supervisory control system (Cyders et al., 2007; Joos et al., 2013). A weakened supervisory control system (increased trait impulsivity) may enhance the impact of affective reactions on alcohol cue reactivity. Impulsive individuals may be less able to call upon executive control when confronted with desirable stimuli, leading to increased reactivity (Doran, Spring, & McChargue, 2007). Individuals who demonstrate low supervisory control may experience greater relative left frontal asymmetry when confronted with alcohol-related stimuli. This neural pattern may then lead to heightened craving and increased likelihood of alcohol use.

Research on craving has shown that alcohol cue reactivity is predictive of alcohol consumption and relapse for recovering alcoholics (Flannery et al., 2001). Understanding that the reduced functioning of the supervisory control system is a mechanism behind alcohol cue reactivity can help identify those who may be susceptible to the risky outcomes associated with alcohol cue reactivity. Those high in trait impulsivity may be especially susceptible to craving elicited by alcohol cues. Increasing control efficacy and reducing impulsive tendencies may be effective in reducing neural indices of alcohol cue reactivity.

Activity of the supervisory control system and behavioral activation systems may influence different components of substance use. Trait impulsivity may relate to rash action without forethought in the presence of substance-related stimuli, while BAS relates to a purposeful reward-sensitive drive to obtain stimuli (Dawe & Loxton, 2004). BAS may impact cue reactivity systems measured through self-report and subjectivity, but may not impact frontal asymmetry as it relates to alcohol cue reactivity. For example, some past research has identified a relationship between BAS and self-reported desire to consume alcohol following alcohol cue exposure (Franken, 2002; Zisserson & Palfai, 2007). Additionally, previous research has also found that greater BAS is related to virtual alcohol myopia (i.e., attentional narrowing that occurs in response to alcohol-related cues; Gable, Mechin, & Neal, 2015).

Results of the current study did not find a relationship between trait BAS and frontal asymmetry in response to alcohol cues. Both BAS and impulsivity may relate to consumption and craving, while only impulsivity relates to greater left frontal activity to alcohol cues. Substance use likely engages both purposeful goal-directed planning (BAS) as well as rash action (impulsivity). Fleming and Bartholow (2014) suggest a dual process model of substance use: an approach bias and an inhibitory control bias. Alcohol cues elicit approach motivation that must be regulated through inhibitory control. Results of the current study suggest that frontal activation to alcohol cues appears to be driven by deficits in inhibitory control. However, because the observed relationship between BAS and left frontal activation was null, the current study is limited in the conclusions that can be drawn from this relationship. The current sample may have a limited ability to detect small effects, or the nature of the passive picture viewing task may have limited activation of the behavioral approach system.

The current study identified negative urgency and lack of premeditation as specific components relating to the relationship between trait impulsivity and greater left frontal activation to alcohol cues. Some theorists have proposed that (lack of) premeditation and negative urgency are integral to impulsivity-based substance use (Gullo, Loxton, & Dawe, 2014). Indeed, Gullo and colleagues (2014) conclude that "only (lack of) premeditation and negative urgency are consistently associated with substance use" (p. 1550). Negative but not positive urgency or BAS was found to be related to greater left frontal activation. Because past research has found that positive urgency and BAS are related to left frontal activity and activation (Gable, Mechin, Hicks, & Adams, 2015; Gable & Poole, 2014; Neal & Gable, 2016; Poole & Gable, 2014), the observed null relationship between positive urgency, BAS and left frontal activation to alcohol cues may have been due to the task and setting. The current task was a passive picture viewing paradigm in a solitary room. Individuals high in positive urgency and BAS may have been less reactive than individuals high in negative urgency because they were passively viewing images of alcohol cues by themselves in a laboratory setting. Future research could investigate the influence of positive urgency and BAS on alcohol cue reactivity in more social settings.

The relationship between trait impulsivity and greater left frontal activation to alcohol cues remained when adjusting for recent drinking behavior. One reason for this could be that the link between impulsivity and left frontal activation may not be entirely dependent on previous drinking experience. In our college-age sample, beliefs about alcohol may have been enough to impact cue reactivity. For example, enhanced social status, enhanced social bonding, greater perceived attraction, and sexual encounters are all associated with alcohol and may influence greater left frontal activation to alcohol cues (Fromme, Stroot, & Kaplan, 1993; Kuntsche, Knibbe, Gmel, & Engels, 2005). Such associations could be learned through media exposure, advertisements, and observation, occurring independently of alcohol consumption. For some individuals, past drinking experience might not be necessary to have an appetitive response to alcohol cues. Other research suggests that some neural responses to alcohol cues may not relate to drinking behavior (Bartholow, Lust, & Tragesser, 2010). In conjunction with the current findings, these results suggest that neural responses to alcohol cues may be regulated by individual differences in the supervisory control system.

One particular limitation of the current study is the sample. Studies examining frontal asymmetry and personality traits typically have samples ranging from small (20) to large (240) sample sizes (median = 46; Wacker, Mira-Lynn, Gerhard, 2010). The current sample is close to the median size in this range, but there is limited power to detect potentially important moderators of this effect (e.g., alcohol use). In addition, the current sample had slightly more female participants. However, consistent with the current analyses of gender differences, previous research suggests that gender does not impact appetitive responses to alcohol cues (Hicks et al., 2012; Ramirez, Monti, & Colwill, 2015). Also, the current study did not assess measures of substance use other than alcohol use or psychopathology. Both are potential individual differences that may influence alcohol cue reactivity.

In sum, reduced functioning of the supervisory control system, measured by increased trait impulsivity, appears to be responsible for greater left frontal-cortical activation associated with alcohol cue reactivity. These results are part of a growing body of literature demonstrating impulsivity is related to greater state and trait left frontal asymmetry (Gable et al., 2015; Santesso et al., 2008). Enhanced alcohol cue reactivity precipitated by failure of the supervisory control system may relate to deficits in attentional regulation and lead to greater approach-motivated drinking behavior. In addition, the current research contributes to a growing body of literature that aims to identify the neurophysiological correlates and markers of individual differences in personality systems (Cyders et al., 2014; Gable et al., 2015; Hicks, Fields, Davis, & Gable, 2015; Nusslock et al., 2012).

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