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Individual differences in motivation and impulsivity link resting frontal alpha asymmetry and motor beta activation

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ABSTRACT

Previous research has linked neural correlates with motivational traits and measures of impulsivity. However, few previous studies have investigated whether individual differences in motivation and impulsivity moderate the relationship between these disparate neural activity patterns. In a sample of 118 young adults, we used Electroencephalography (EEG) to examine whether behavioral activation and inhibition systems (BIS/BAS) and impulsivity facets (negative urgency, lack of perseverance), moderate the relationship between beta power and resting frontal alpha asymmetry. Regression analyses revealed a novel relationship between lesser beta power and greater left frontal alpha asymmetry (LFA). Moderation analyses suggest this relationship may strengthen as BIS/BAS levels increase, and trait impulsivity levels decrease from the mean. These results are among the first revealing a relationship between two widely investigated neural activity patterns of motivation and provide some indication individual differences moderate this relationship. The limitations of these findings and need for future research are discussed.

1. Introduction

Complex patterns of activity in the human brain produce the unique range of cognitions, emotions, and behaviors that constitute individual experiences (Davison et al., 2016). Personality traits have long been associated with differences in region-specific activity patterns between individuals. Yet, little to no research has examined whether individual differences in personality may moderate the relationship between seemingly distinct neural activity patterns. Revealing these relationships would not only add to the growing understanding of neural activity patterns but could also offer a new means of understanding and assessing how individual personality factors impact neural functioning.

Much of behavior relies on one's physical ability to act. Therefore, it is important to examine cortical motor-action preparation when studying motivationally driven behaviors or traits. Motor and pre-motor areas of the cortex become more active during motor-actions and when merely thinking or imagining movement (McFarland, Miner, Vaughan, & Wolpaw, 2000). Beta band activity (13–30 Hz), or beta power, measured by electroencephalography (EEG) over the motor and pre-motor cortex is thought to reflect motor-action preparation (Doyle et al., 2005; Gable, Threadgill, & Adams, 2016; Meadows, Gable, Lohse, & Miller, 2016). Prior investigations have linked contemplating motor-movement with reduced beta power over these regions (Babiloni et al., 2016; McFarland et al., 2000; Pfurtscheller, Neuper, Brunner, & da Silva, 2005; Sanes & Donoghue, 1993). Further, motor and pre-motor cortex activity is enhanced when movement is reward-motivated and requires quick responses (Gable et al., 2016; Neuper & Pfurtscheller, 2001) and Meyniel and Pessiglione (2014) found beta power was diminished when reward levels were increased, suggesting motor-preparation increased for a motivated goal.

In addition to reflecting motor preparation, decreases in beta power during motor planning are thought to reflect a shift to a more prepared state for action execution (Grent-'t-Jong, Oostenveld, Jensen, Medendorp, & Praamstra, 2014; Heinrichs-Graham & Wilson, 2016; Tzagarakis, Ince, Leuthold, & Pellizzer, 2010; Tzagarkis, Thompson, Rogers, & Pellizzer, 2019). Research also shows that trait sensitivity to rewards relates to more efficient motor-preparation (Beck et al., 2006; Chein, Albert, O'Brien, Uckert, & Steinberg, 2011; Threadgill & Gable, 2018). This is supported by studies showing that reduced beta power can lead to enhanced preparation for action, typically measured by faster reaction times (RTs; Doyle et al., 2005; Gable et al., 2016; van Wijk, Daffertshofer, Roach, & Praamstra, 2009).

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In addition to the evidence linking changes in beta power in response to motor planning or motor movement, previous studies have linked resting beta power to individual differences in personality. For example, Threadgill and Gable (2018) found that greater impulsivity is positively associated with resting beta power, suggesting that individuals reporting greater impulsivity display neural activity related to a lack of planned movement. These same authors report that greater trait approach-motivation is related to reduced resting beta power, suggesting that individuals with greater trait motivation show enhanced motor-action preparation at rest. These results are consistent with several prior investigations suggesting beta power may be a marker of impulsivity (De Pascalis, Cirillo, & Vecchio, 2020) and individual differences in approach/avoidance traits associated with more planful action (De Pascalis, Vecchio, & Cirillo, 2020; Pavlenko, Chernyi, & Goubkina, 2010; Schutter, de Weijer, Meuwese, Morgan, & van Honk, 2008; Vecchio & De Pascalis, 2020).

Past research has also linked individual differences associated with motivation and impulsive behavior to asymmetric frontal cortical activation, as measured by the alpha band frequency (8–12 Hz; Allen & Reznik, 2015; Davidson, 1992; Coan & Allen, 2003, 2004; Harmon-Jones, Gable, & Peterson, 2010). Specifically, studies have investigated the relation of frontal cortical asymmetry and the core motivational systems of approach, avoidance, and control that underlie behaviors and personality traits related to motivational intensity (Aron, Robbins, & Poldrack, 2014; Aron, Robbins, & Poldrack, 2004; Harmon-Jones & Gable, 2018; Neal & Gable, 2017; Rutherford & Lindell, 2011).

Research using EEG suggests alpha asymmetry accounts for approximately 25 % of the variance in behavioral inhibition system (BIS) and behavioral activation system (BAS) traits (Sutton & Davidson, 1997). Further, greater activity in left frontal cortical areas, relative to right frontal cortical areas, is associated with greater approach-motivated affective responses (Gable & Poole, 2014; Harmon-Jones et al., 2010; Kelley, Hortensius, Schutter, & Harmon-Jones, 2017; Mechin, Gable, & Hicks, 2016; Tomarken, Davidson, Wheeler, & Doss, 1992), impulsive actions, and sensation-seeking personality traits (Gable, Mechin, Hicks, & Adams, 2015; Grimshaw & Carmel, 2014; Neal & Gable, 2016, 2019; Santesso et al., 2008), and manic symptoms in bipolar disorder (Harmon-Jones & Allen, 1997, 2010; Harmon-Jones et al., 2002; Kano, Nakamura, Matsuoka, Iida, & Nakajima, 1992).

Although greater left frontal activation is consistently related to approach-motivated behavior, the link between right frontal activation seems to be more complex and perhaps twofold. Some studies suggest greater right frontal activation, relative to left frontal activation, is related to withdrawal-motivated actions or negative affective states low in motivational intensity, such as depressive symptoms (Gotlib, Ranganath, & Rosenfield, 1998; Harmon-Jones, 2003; Harmon-Jones et al., 2010; Schaffer, Davidson, & Saron, 1983; Schutter et al., 2008; Tomarken et al., 1992). More recent studies, however, have linked right frontal cortical activity to being more closely responsible for a supervisory motivational control system, whereby greater relative right frontal activity is related to motivational control or inhibition of approach-motivated and withdrawal-motivated systems (Aron et al., 2014; Gable et al., 2018; Lacey, Neal, & Gable, 2020; Neal & Gable, 2017, 2019). This view is also supported by lesion studies suggesting right frontal activity is largely responsible for maintaining self-control. Individuals who have experienced lesions in the right frontal cortex have diminished inhibition capabilities (Aron, Fletcher, Bullmore, Sahakian, & Robbins, 2003) and partake in riskier decisions during gambling tasks (Clark, Manes, Antoun, Sahakian, & Robbins, 2003; Tranel, Bechara, & Denburg, 2002). When the reverse is examined by applying transcranial direct current stimulations (tDCS) to stimulate the right frontal cortex, participants show enhanced response inhibition capabilities (Kelley & Schmeichel, 2016; Stramaccia et al., 2015) and less risk-taking in gambling tasks (Fecteau et al., 2007).

In sum, previous research suggests that frontal alpha asymmetry and beta power over the motor cortex have overlapping associations with impulsivity and motivational states. Despite this evidence, little to no work has explored whether beta power and frontal alpha asymmetry are directly related or moderated by impulsive and motivational personality traits. Uncovering direct or indirect links between these neural correlates of motivation may offer a new means of understanding and assessing the impact of individual differences on neural activity and related sequelae.

1.1. *Current study*

In this study we investigate whether resting beta power over the motor cortex is directly related to left frontal alpha asymmetry. Additionally, we investigate whether individual differences in impulsivity or motivational traits (BIS, BAS) moderate the relationship between beta power over the motor cortex and frontal alpha asymmetry. The BAS instrument includes three subscales: Reward Responsiveness, Drive and Fun Seeking and recent investigations have provided psychometric justification for summing subscale scores to examine BAS total score (Kelley et al., 2019). As mentioned previously, both beta power and frontal alpha asymmetry have been associated with motivation to obtain rewards in previous studies. Yet, little to no work has investigated whether motivation or impulsivity are linked to these distinct neural activity patterns. Consistent with previous evidence, we hypothesized greater approach motivation and impulsivity would be associated with relatively left frontal alpha asymmetry. Secondly, we hypothesized beta power would be positively associated with impulsivity, and negatively associated with behavioral approach motivation. Lastly, we hypothesized trait motivation and impulsivity would moderate the relationship between beta power and frontal alpha asymmetry. Given the dearth of similar investigations in the literature, we made no a priori predictions regarding the direction or magnitude of potential moderation effects (i.e., whether the relationship between beta power and frontal alpha asymmetry would be strengthened by high or low levels of personality traits).

Clarifying the role of these neural activity patterns and the potential moderating effects of motivation and impulsivity has several important implications. Primarily, to the best of our knowledge, finding a link between beta power and frontal alpha asymmetry would be the first link between these two distinct neural correlates of motivation. Similarly, examining the potential moderating effects of impulsive or motivational personality traits on these neural correlates of motivation may begin to elucidate the extent to which individual differences influence neural activity relating to motivation.

2. Method

2.1. *Procedure*

Participants ($n = 118$) were recruited and participated for partial course credit. Handedness was assessed using a 13-item list asking about handedness when performing day-to-day tasks (Gable & Poole, 2014; Neal & Gable, 2017). These include things like drawing, writing, using scissors, etc. A participant was classified as right-handed if they performed no more than one of the items on the list with their left hand. To avoid any potential cortical activity differences due to handedness, participants who were left-handed were not included in analyses.

After completing basic demographics (e.g., age, gender), participants completed the 20-item Behavioral Inhibition System and Behavioral Approach System (BIS/BAS) Behavior Scale (Carver & White, 1994). All items are on a 4-point Likert scale ranging from *strongly agree* to *strongly disagree*. Higher scores on the BIS scale reflect greater apprehensive anticipation (e.g., "*I worry about making mistakes*"). Previous research has reported acceptable internal consistency for the BIS scale (Ross, Benning, Patrick, Thompson, & Thompson, 2009). Higher BAS total scores indicate greater sensitivity to reward signals, goal pursuit and engagement in planned motor actions (Carver & Scheier, 2008; Fowles, 1980; Gray, 1970, 1987, 1994; Gray & McNaughton, 2000; Threadgill & Gable, 2018). The three subscales comprising the BAS total score have shown acceptable internal consistency (Carver & White, 1994; Ross et al., 2009; Voigt et al., 2009), as well as factorial, convergent, and discriminant validity (Jorm et al., 1999; Kasch, Rottenberg, Arnow, & Gotlib, 2002; Sutton & Davidson, 1997).

Participants then completed the UPPS-P Impulsive Behavior Scale (UPPS-P; Lynam, Smith, Whiteside, & Cyders, 2006). Based on the results of previous exploratory and confirmatory factor analyses, this instrument assesses five distinct aspects of impulsivity; sensation seeking, lack of premeditation, lack of perseverance, negative urgency, and positive urgency (Cyders & Smith, 2007; Cyders, Littlefield, Coffey, & Karyadi, 2014; Whiteside & Lynam, 2001). Previous studies suggest these aspects are differentially related to varying negative outcomes of impulsivity. For example, negative and positive urgency are most highly related to problematic alcohol use, negative urgency and lack of premeditation are most highly related to alcohol dependence, and lack of perseverance is related to drinking quantity (Coskunpinar, Dir, & Cyders, 2013; Herschberger, Um, & Cyders, 2017). Thus, the UPPSP-P provides an index of overall impulsivity, as well as clinically useful sub-facets which may display differential associations with resting beta power and relative frontal alpha asymmetry. A breadth of research has demonstrated the construct validity (Smith et al., 2007) and test-retest reliability (Billieux et al., 2012) of the UPPS-P. Further, this measure has demonstrated a robust and consistent factor structure across cultures (Billieux et al., 2012; Cyders & Smith, 2007; D'Orta et al., 2015; Verdejo-Garcia, Lozano, Moya, Alcazar, & Perez-Garcia, 2010). In the current study, we focus on negative urgency and lack of perseverance to assess differing aspects of impulsivity (Neal & Gable, 2016). Specifically, negative urgency refers to the tendency for individuals to engage in rash behaviors while in negative emotional states (Cyders & Smith, 2007), whereas lack of perseverance is considered more cognitively based, reflecting impulsivity related to conscientiousness (Gullo, Loxton, & Dawe, 2014).

After completing demographics, BIS/BAS, and UPPS-P measures, EEG electrodes were applied to the scalp. Participants then completed eight minutes of baseline resting EEG recording. Participants kept their eyes open in half of the baseline recordings and closed in the other half. The eyes open/closed instructions changed every minute and were counterbalanced between the first half and second half of the baseline recording.

2.2. *Electroencephalography (EEG) assessment*

Electroencephalography (EEG) activity was recorded using 59 tin electrodes in a stretch-lycra cap (Electro-Cap, Eaton, OH). The ground sensor was placed midway between FZ and FPZ. Recorded data were referenced to the left earlobe. Electrode impedances were kept under 5 kΩ (with homologous sites within 1 kΩ of one another). Recordings were amplified with NeuroScan SynAmps RT amplifier units with AC gains of 2010 (El Paso, TX) using a low pass filter at 100 Hz, high-pass filter at 0.05 Hz, notch filter at 60 Hz, and digitized at 500 Hz. A filter slope was set at 12 dB per octave. Initially, data were semi-automatically hand inspected for artifacts. Data were then transformed with an ICA-based ocular artifact rejection function within the Brain Vision Analyzer software (electrode FP1 served as the VEOG channel; BrainProducts, 2013). This ICA function finds an ocular artifact template in channel FP1, and then finds ICA-derived components that account for the user specified (50 %) amount of variance in the template matched portion from FP1. The component is then removed from the raw EEG signal and reconstructed for further processing.

The duration of all epochs for alpha frequency analyses were 1,024 ms. Consecutive epochs overlapped by 50 %, and were extracted using a Hamming window. Data were re-referenced offline using an average ears reference (Amodio, Master, Yee, & Taylor, 2008; Sutton & Davidson, 1997). Power spectra were calculated using a Fast Fourier Transform (FFT) and power values for the alpha band (8−13 Hz) were averaged across all epochs. An asymmetry score was calculated by subtracting logarithmically transformed left from right for all homologous sites. These homologous sites were F8-F7, F6-F5, and F4-F3 (Coan & Allen, 2003; Jacobs & Snyder, 1996). A mean score was created to combine all right and left hemispheric sites. Past research shows frontal alpha asymmetry is inversely related to cortical activation (Davidson, 1988; Laufs et al., 2003), so greater scores reflect greater relative left frontal activity and lower scores reflect greater relative right frontal activity.

During the same resting period, power spectra (using FFT) for the beta band (13−30 Hz) were also averaged across all epochs. These epochs were averaged across the regions of the head at sites over the motor areas of the cortex: C1, C2, C3, C4, C5, C6, CP1, CP2, CP3, CP4, CP5, CP6 (Gable et al., 2016; Rüther, Brown, Klepp, & Bellebaum, 2014).

2.3. *Overview of analyses*

We began by conducting bivariate correlations between beta power, frontal alpha asymmetry, BIS/BAS, and UPPS-P scales. Subsequent linear regression analyses were conducted to further examine the relationship between beta power and frontal alpha asymmetry. Age and sex were entered as covariates given previous evidence linking these variables with frontal alpha asymmetry (Kovalev, Kruggel, & Von Cramon, 2003; Smit, Posthuma, Boomsma, & De Geus, 2007).

To determine whether personality characteristics moderate the relationship between beta power and frontal alpha asymmetry, we conducted regression analyses using SPSS macro PROCESS (Hayes, 2017; Model 1). This macro was designed specifically for testing complex regression models and has been used widely in previous research (Hayes & Rockwood, 2017). We conducted individual analyses with BIS and BAS entered as unique predictors. Subsequently, we conducted individual regression analyses to determine if two commonly used measures of impulsivity moderate the relationship between beta power and frontal alpha asymmetry. Age and gender were entered into these models as covariates.

The SPSS syntax generated by PROCESS was used to visualize the effects of motivational traits and impulsivity on the relationship between beta power and frontal asymmetry. To gain a more comprehensive understanding of the hypothesized relationships, we used the Johnson-Neyman technique to probe interactions in addition to traditional standard deviation level comparisons. All analyses were conducted using SPSS version 26.0 (IBM Corp, 2019).

3. Results

Bivariate correlations are shown in Table 1. Surprisingly, reduced beta power over the motor cortex was related to greater left frontal alpha asymmetry. Contrary to our hypotheses, neither of these variables were associated with trait motivation or impulsivity despite an abundance of previous research linking these constructs (Gable, Neal, & Threadgill,

Table 1
Bivariate Correlations Between Physiology, Motivational States and Personality Characteristics.

Variable	1	2	3	4	5	6
1. Beta Power	-					
2. Frontal Alpha Asymmetry	-.29**	-				
3. BAS	-.10	.04	-			
4. BIS	.09	.01	-.01	-		
5. Lack of Perseverance	.03	.09	-.13	.01	-	
6. Negative Urgency	.04	.07	.19*	.30**	.32**	-

* $p < .05$.
** $p < .01$.

2017; Balconi, 2011; Gable et al., 2015; Harmon-Jones et al., 2010; Shackman, McMenamin, Maxwell, Greischar, & Davidson, 2009).

The results of initial linear regression analyses examining the relationship between beta power and frontal alpha asymmetry after adjusting for age and gender are shown in Table 2.

Results revealed that lesser beta power is directly related to greater left frontal alpha asymmetry after adjusting for relevant demographic variables. As mentioned above, no previous research has directly linked these variables, hence, we did not hypothesize a direct relationship. Follow-up regression analyses further adjusting for parental education, family income and subjective social status only slightly strengthened the relationship between beta power and frontal alpha asymmetry ($\Delta\beta =$ .04, $p < .001$). This would suggest that the relationship between beta power and frontal alpha asymmetry may be moderated by trait motivation or impulsivity.

The results of regression analyses exploring whether BAS moderated the relationship between beta power and frontal alpha asymmetry after adjusting for age and sex revealed these variables accounted for a significant amount of variance, $R^2 = .16$, F(5,112) = 4.18, $p = .002$ and the visualization produced by PROCESS appeared to indicate a cross-over interaction (Fig. 1).

However, contrary to our hypotheses the interaction of BAS and beta power was not significant (B = -0.34, $p = .152$) suggesting the absence of a moderation effect. Additionally, the significance level of the interaction term did not cross the default threshold ($p < .10$) for probing conditional effects in PROCESS. Hence, contrary to our hypotheses we did not find evidence BAS moderates the relationship between beta power and relative frontal alpha asymmetry. Surprisingly, moderation analyses examining whether BIS moderates the relationship between beta power and frontal alpha asymmetry after adjusting for relevant demographic variables revealed a similar pattern of results (Fig. 2).

Specifically, these variables accounted for a significant amount of variance, $R^2 = .14$, F(5,112) = 3.77, $p = .003$, and the visualization produced by PROCESS appeared to indicate the presence of an interaction. However, the interaction term was not significant suggesting the absence of the hypothesized moderation effect.

Regression analyses exploring the potential moderating effects of negative urgency and lack of perseverance on the relationship between beta power and frontal alpha asymmetry revealed a similar pattern of results. Specifically, both the negative urgency ($R^2 = .16$, F(5,112) = 4.33, $p = .001$) and lack of perseverance ($R^2 = .15$, F(5,112) = 3.92, $p = .003$) models accounted for a significant proportion of variance. However, neither interaction term reached statistical significance. Further, visual inspection of these relationships provides no indication of a cross-over interaction between negative urgency (Fig. 3) or lack of perseverance (Fig. 4) at the beta power levels observed in our sample.

Hence, we found evidence contrary to the hypothesized relationships between impulsivity and neural activity patterns. Although these results are contrary to our hypotheses, the percentage of explained variance and the appearance of cross-over interactions in models examining BAS and BIS may suggest these motivational traits and impulsivity mediate the relationship between beta power and frontal alpha asymmetry. Thus, we conducted subsequent exploratory regression analyses to determine whether motivational traits and impulsivity *mediate* the relationship between beta power and frontal alpha asymmetry. The results of these analyses revealed the relationship between beta power and frontal asymmetry was not better explained by mediating effects of motivational traits or impulsivity. Alternatively, we may not have found evidence for a statistically significant moderation effect due to a seemingly unrelated confounding variable we are unable to adjust for here (Vecchio & De Pascalis, 2020). For example, in a sample of female college students, De Pascalis, Sommer, & Scacchia, 2018) recently revealed significant associations found between FFFS and greater left frontal alpha asymmetry, and BIS and greater right frontal alpha asymmetry. These associations remained significant in the sub-sample with a same-sex experimenter but were attenuated in the sub-sample with an opposite-sex experimenter. Hence, although we are unable to interpret conditional moderation effects with certainty, probing the effects of motivational traits and impulsivity may contribute substantially to future research which can adjust for similar confounds. Thus, we repeated the initial moderation analyses without the default significance threshold to explore conditional effects. The results of exploratory analyses examining BAS are shown in Table 3.

Table 2
Results of Linear Regression Analyses Examining the Relationship Between Beta Power and Frontal Alpha Asymmetry Adjusting for Age and Gender.

		95 % CI			
Variable	*B*	*LL*	*UL*	*SE B*	β
Age	0.02	−0.01	0.04	0.01	0.12
Gender	0.10	0	0.20	0.05	0.18
Beta Power	−0.20	−0.32	−0.08	0.06	−0.30***

Note. CI = confidence interval, LL = lower limit, UL = upper limit.
*** $p < .001$.

Results revealed that lesser beta power may be related to greater left frontal alpha asymmetry for individuals reporting mean or higher levels of BAS when probed at standard deviation levels of BAS. More precise examination using the Johnson-Neyman technique suggests the relationship between beta power and frontal alpha asymmetry may be moderated by BAS levels ≥2.7869, corresponding to 83.05 % of our sample. Similar exploratory analyses examining BIS are shown in Table 4.

When probed at standard deviation levels, these analyses suggest beta power may be related to relatively greater left frontal alpha asymmetry when individuals reported average or greater BIS levels and this relationship may strengthen as BIS levels increase from mean levels (B= -.25) to two standard deviations above the mean (B= -.34) in our sample. Examination using the Johnson-Neyman technique suggests the relationship between beta power and frontal alpha asymmetry may be moderated by BIS levels ≥2.5845, corresponding to 72.88 % of our sample. The results of exploratory analyses investigating the potential effect of negative urgency are shown in Table 5, and the results of similar regression analyses exploring the effect of lack of perseverance are shown in Table 6. Interestingly, both widely used measures of impulsivity display a similar pattern; when impulsivity levels are average or below average in our sample, beta power may be related to greater left frontal alpha asymmetry.

Specifically, the relationship between beta power and left frontal alpha asymmetry may strengthen as reports of negative urgency decrease from average (B= -.27) to two standard deviations below the mean in our sample (B= -.40). Similarly, the relationship between beta power and left frontal alpha asymmetry may strengthen as reports of lack of perseverance decrease from average (B= -.27) to two standard deviations below the mean in our sample (B= -.38). However, the use of the Johnson-Neyman technique suggests two moderation values for impulsivity. Specifically, examining the conditional effects in this manner suggest negative urgency may strengthen the relationship between beta power and frontal alpha asymmetry at values between 1.39–2.79, corresponding to 81.36 % of the sample. Similarly, examining the effect of lack of perseverance using the Johnson-Neyman method suggests the relationship between beta power and frontal alpha asymmetry may be moderated by lack of perseverance levels between 1.32–2.38, corresponding to 74.58 % of our sample.

4. Discussion

Previous evidence has consistently linked both frontal alpha asymmetry and beta power to motivation (Gable et al., 2016; Neuper & Pfurtscheller, 2001). Despite these overlapping associations, little previous work has investigated the potential associations between frontal alpha asymmetry and beta power. Given the relative dearth of research

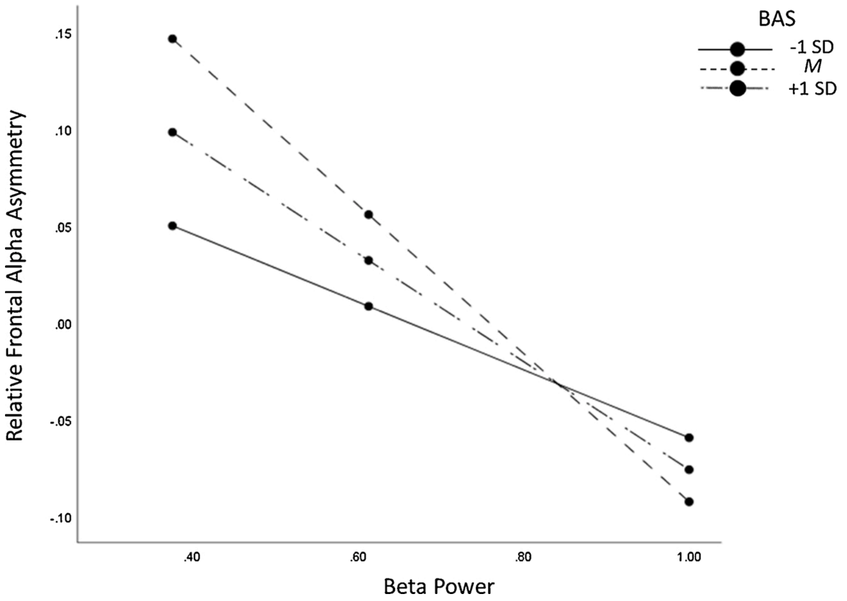

Fig. 1. Association Between Beta Power and Frontal Alpha Asymmetry at Standard Deviation Levels of BAS.

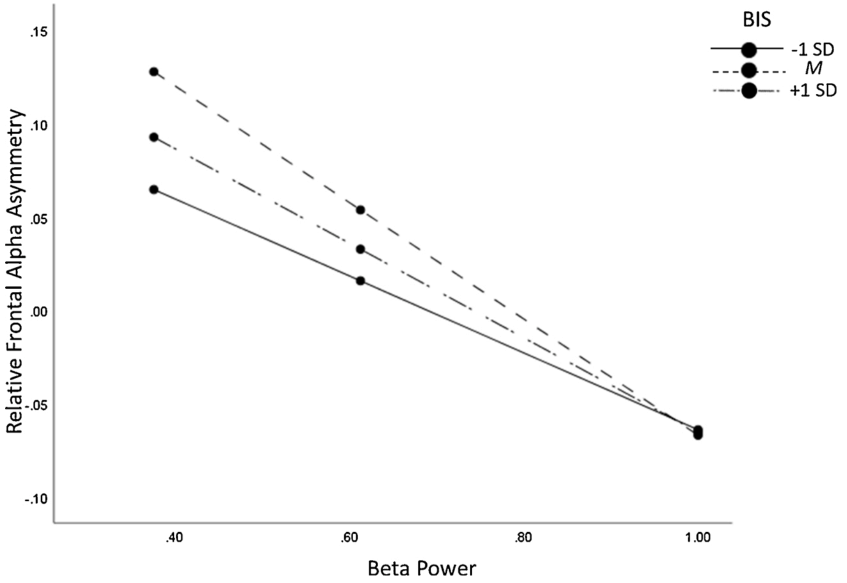

Fig. 2. Association Between Beta Power and Frontal Alpha Asymmetry at Standard Deviation Levels of BIS.

in this area, it is possible these widely used measures of neural activity are directly associated or moderated by individual differences in motivation and impulsivity.

In the current study, we explored whether resting beta power, a neural activity pattern associated with readiness to act (Doyle et al., 2005; Gable et al., 2016; van Wijk et al., 2009), is related to frontal alpha asymmetry directly. Further, we explored whether this relationship was influenced by trait motivation and impulsivity. Initial linear regression analyses controlling for age and gender revealed that reduced beta power was associated with relatively greater left frontal alpha asymmetry. This relationship remained significant after further adjusting for paternal education, family income and subjective social status. Hence, we conducted subsequent linear regression analyses examining potential moderating effects of trait motivation and impulsivity. Contrary to our hypotheses, we found no evidence trait motivation and impulsivity consistently moderate the relationship between beta power and frontal alpha asymmetry. However, the visualization of these relationships provided some evidence for potential interaction effects at specific levels of trait motivation and impulsivity. Thus, we conducted exploratory analyses to probe these relationships further.

Exploratory analyses revealed a surprising and consistent pattern of results. Lesser beta power was associated with left frontal alpha asymmetry after controlling for age and gender for individuals reporting greater trait motivation, in both directions (i.e., higher BAS and higher BIS scores). Further, this relationship becomes stronger as trait motivation increases, with effect sizes increasing from mean levels of trait motivation to one and two standard deviations above the mean for trait motivation. Interestingly, reduced beta power was related to greater left frontal alpha asymmetry after controlling for age and gender for individuals reporting less negative urgency and lack of perseverance. In contrast to the potential moderating effect found for trait motivation, the relationship between beta power and frontal alpha asymmetry may become stronger as negative urgency and lack of perseverance levels decrease.

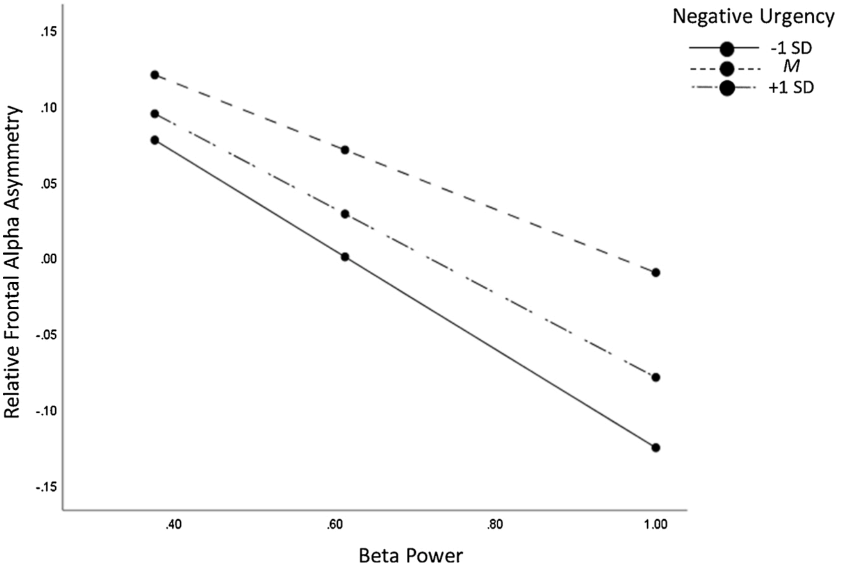

Fig. 3. Association Between Beta Power and Frontal Alpha Asymmetry at Standard Deviation Levels of Negative Urgency.

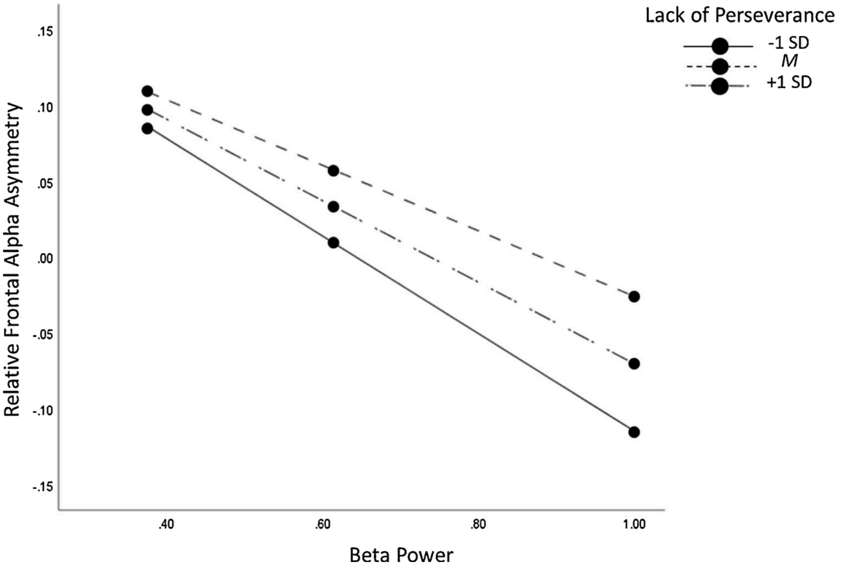

Fig. 4. Association Between Beta Power and Frontal Alpha Asymmetry at Standard Deviation Levels of Lack of Perseverance.

Table 3

Results of Regression Analyses Examining Whether BAS Moderates the Relationship Between Beta Power and Relative Frontal Alpha Asymmetry.

Predictor	*B*	*SE B*	*t*	95 % CI	
				LL	*UL*
Beta Power	0.76	0.71	1.06	−0.65	2.17
BAS	0.28	0.19	1.48	−0.10	0.67
Beta Power X BAS	−0.34	0.23	−1.44	−0.80	0.13
Age	0.02	0.02	1.36	−0.01	0.05
Gender	0.10	0.06	1.61	−0.02	0.22
Conditional effects	*B*	*SE*	*t*	*LL*	*UL*
16 %	−0.18	0.09	−1.86	−0.36	0.01
50 %	−0.28***	0.07	−3.87	−0.42	−0.14
84 %	−0.38***	0.11	−3.51	−0.60	−0.17

Note. 16 % = -1SD level of BAS, 50 % = Mean level of BAS, 84 % = +1 SD level of BAS, CI = confidence interval, LL = lower limit, UL = upper limit.
*$p < .05$. **$p < .01$. ***$p < .001$.

Table 4

Results of Regression Analyses Examining Whether BIS Moderates the Relationship Between Beta Power and Relative Frontal Alpha Asymmetry.

Predictor	*B*	*SE B*	*t*	95 % CI	
				LL	*UL*
Beta Power	−0.01	0.45	−0.02	−0.90	0.88
BIS	0.08	0.11	0.72	−0.14	0.30
Beta Power X BIS	−0.08	0.14	−0.59	−0.36	0.19
Age	0.02	0.02	1.43	−0.01	0.05
Gender	0.10	0.06	1.58	−0.02	0.22
Conditional effects	*B*	*SE*	*t*	*LL*	*UL*
16 %	−0.21	0.13	−1.61	−0.46	0.05
50 %	−0.25***	0.08	−3.30	−0.41	−0.10
84 %	−0.31**	0.10	−3.02	−0.52	−0.11

Note. 16 % = -1SD level of BIS, 50 % = Mean level of BIS, 84 % = +1 SD level of BIS. CI = confidence interval, LLCI = lower limit, UL = upper limit.
*$p < .05$. **$p < .01$. ***$p < .001$.

Table 5

Results of Regression Analyses Examining Whether Negative Urgency Moderates the Relationship Between Beta Power and Relative Frontal Alpha Asymmetry.

Predictor	*B*	*SE B*	*t*	95 % CI	
				LL	*UL*
Beta Power	−0.61	0.47	−1.28	−1.54	0.33
Negative Urgency	0	0.14	−0.01	−0.28	0.28
Beta Power X Negative Urgency	0.14	0.20	0.72	−0.25	0.53
Age	0.02	0.02	1.46	−0.01	0.05
Gender	0.10	0.06	1.67	−0.02	0.22
Conditional Effects	*B*	*SE*	*t*	*LL*	*UL*
16 %	−0.32**	0.10	−3.15	−0.53	−0.12
50 %	−0.28***	0.07	−3.87	−0.42	−0.14
84 %	−0.21	0.11	−1.84	−0.43	0.02

Note. 16 % = -1SD level of negative urgency, 50 % = Mean level of negative urgency, 84 % = +1 SD level of negative urgency, CI = confidence interval, LLCI = lower limit, UL = upper limit.
*$p < .05$. **$p < .01$. ***$p < .001$.

Table 6

Results of Regression Analyses Examining Whether Lack of Perseverance Moderates the Relationship Between Beta Power and Relative Frontal Alpha Asymmetry.

Predictor	*B*	*SE B*	*t*	95 % CI	
				LL	*UL*
Beta Power	−0.53	0.48	−1.10	−1.49	0.42
Lack of Perseverance	−0.02	0.16	−0.13	−0.34	0.30
Beta Power X Lack of Perseverance	0.13	0.24	0.56	−0.34	0.60
Age	0.02	0.02	1.37	−0.01	0.05
Gender	0.09	0.06	1.58	−0.02	0.21
Conditional Effects	*B*	*SE*	*t*	*LL*	*UL*
16 %	−0.32**	0.12	−2.63	−0.56	−0.08
50 %	−0.70***	0.07	−3.74	−0.41	−0.13
84 %	−0.22	0.11	−1.88	−0.44	0.01

Note. 16 % = -1SD level of lack of perseverance, 50 % = Mean level of lack of perseverance, 84 % = +1 SD level of lack of perseverance, CI = confidence interval, LLCI = lower limit, UL = upper limit.
*$p < .05$. **$p < .01$. ***$p < .001$.

Collectively, these results offer some initial evidence that individuals reporting higher motivational states, in either direction, as well as less impulsivity, may show a stronger relationship between beta power and relatively greater left frontal alpha asymmetry. One explanation for these results may be that the association between beta power and frontal alpha asymmetry is driven by motivated, planful action.

Specifically, we found that the relationship between beta power and left frontal alpha asymmetry may be stronger when individuals reported less impulsivity and greater approach or avoidance motivation, characteristics consistent with planful behavior. An alternative explanation for the relationships found here may be that greater motivation control may enhance motor-action planning, which is associated with beta power over the motor cortex. Hence, the results found here may be due to an underlying relationship between motivational control and frontal alpha asymmetry, fostering lesser beta power via planned actions.

Importantly, the differing patterns found between motivational states and impulsivity suggest that the results of this study are not due simply to these variables' associations with motivational direction. As described above, previous research has suggested that greater BIS is related to greater relative right frontal alpha asymmetry (Balconi, 2011; Shackman et al., 2009) and greater impulsivity is related to greater left frontal alpha asymmetry (Gable et al., 2015). Revealing consistent associations in this study which differ from previous findings may suggest individual differences in personality moderate the relationship between these neural oscillations. Hence, these novel results may offer a new framework for examining and understanding the links between individual differences in personality and seemingly disparate patterns of neural activity.

4.1. Limitations

We cannot make any causal claims based on the results of this study namely because we examined the potential associations between resting beta power and resting frontal alpha asymmetry. Additional research investigating potential moderating effects of individual differences on task-dependent beta power and frontal alpha asymmetry is still needed for a more thorough and reliable understanding of these effects.

To the best of our knowledge, there are no previous studies linking beta power and frontal alpha asymmetry. These results appear to be robust and are not likely to be influenced by demographic factors of the participant. Although exploratory analyses suggest motivational traits and impulsivity may moderate the relationship between beta power and frontal alpha asymmetry, we cannot make confident conclusions regarding these results. Specifically, although these results suggest potential conditional effects for average or higher levels of trait motivation, and average or lower levels of impulsivity, we did not reveal strong evidence for a consistent moderation effect (i.e., statistically significant interaction term).

This is the first investigation of individual differences moderating the relationship between beta power and relative frontal alpha asymmetry. Hence, future work is needed to replicate the direct relationship between resting beta power and relative frontal alpha asymmetry found here. Future research is also needed to further explore the potential moderating effects of motivation and impulsivity. Post-hoc power analyses using G*Power (Version 3.1.9.7; Faul, Erdfelder, Lang, & Buchner, 2007; Faul, Erdfelder, Buchner, & Lang, 2009) suggest we had high degrees of power (1-β) to detect the medium sized interaction effects (Cohen, 1988) described here. Specifically, we had excellent power (.996) to detect a potential interaction effect of BAS and resting beta (calculated $f^2 = 0.186$, $\alpha = 0.05$, $n = 118$, n tested predictors = 1, total n predictors = 5). Similar analyses revealed excellent power to detect potential interaction effects of BIS and resting beta power (power = 0.992, calculated $f^2 = 0.168$), negative urgency and resting beta power (power = 0.997, calculated $f^2 = 0.193$), and lack of perseverance and resting beta power (power = 0.995, calculated $f^2 = 0.175$). Therefore, although little previous evidence is available to suggest the replicability of the current study, it appears unlikely the results described here are spurious. Hence, future research is also needed to identify potential confounding factors, particularly those which may interact with trait motivation and impulsivity levels.

Additionally, given the novel nature of both the direct and moderating effects described here, there are multiple avenues available for future replication. Our results may be replicated by revealing consistent main effects between beta power and frontal alpha asymmetry. Also, future replications may reveal consistent indirect effects with greater motivation and less impulsivity strengthening the relationship between beta power and relative frontal alpha asymmetry. Notably, the methods used here probe the moderating effects of motivation and impulsivity to suggest when a relationship between beta power and relative frontal alpha asymmetry should *not* exist. Thus, our results could be partially replicated by revealing no association between beta power and relative frontal alpha asymmetry for individuals low in trait motivation or high in impulsivity.

Lastly, our college sample limits the generalizability of our results to other samples. Specifically, previous evidence suggests age impacts frontal alpha asymmetry (Kovalev et al., 2003), thus, it is possible the results of this study may not be found outside of young adults. Additionally, the mean level of parental income and education reported in our sample was between $125,000 and $200,000, as well as between an associate's and bachelor's degree for both mothers and fathers. Although the accuracy of parental income reports are questionable, when taken alongside reports of parental education, it is likely our participants predominantly come from economically and educationally privileged backgrounds. Thus, we cannot be certain that our results would generalize to community samples in which these characteristics are often less common.

5. Conclusions

The results of this study revealed a direct relationship between beta power over the motor cortex and greater left frontal alpha asymmetry after controlling for age and gender. Further adjusting for demographic variables did not reduce the strength of this association. To the best of our knowledge, this study is one of, if not the first revealing a direct relationship between these two seemingly disparate neural activity patterns. Subsequent exploratory analyses suggest greater motivation, both approach and avoidance, and lower impulsivity may strengthen the relationship between beta power and greater left frontal alpha asymmetry. Hence, one explanation may be that greater trait motivation or low impulsivity (i.e., higher BIS/BAS, lower impulsivity) links beta power and greater left frontal alpha asymmetry.

Declaration of Competing Interest

The authors report no declarations of interest.

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