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EEG Asymmetry and BIS/BAS among Healthy Adolescents

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Abstract

Asymmetry in frontal alpha activation (FAA) has been associated with specific behavior patterns. Greater activation in the left frontal cortex is related to “approach” motivation, while greater activation in the right cortex is associated with “withdrawal” motivation. Moreover, resting FAA is stable over time among adults. This stability has not been demonstrated among adolescents, and the correspondence between resting FAA and personality has been inconsistently observed. The present study examined stability of FAA and the association between resting FAA and behavioral activation among adolescents. At baseline and 4 months, 99 adolescents completed a resting electroencephalogram (EEG) and a pencil-and-paper measure of personality (BIS/BAS). FAA showed good stability over time (Intra-class correlation coefficient = .65, $p < .001$), but there was no correlation between FAA and personality. Results are interpreted in light of a capability model of FAA; namely, that asymmetry may emerge under conditions of stimulation and recede during resting.

Keywords

electroencephalogram; behavioral activation; personality

As reported by De Pascalis et al. (10), “a main question in psychophysiology research concerns how individual differences in hemispheric asymmetry are manifested in motivation and personality (p. 198)”. Implicit in this statement is a dispositional model of frontal affective style. As described by Davidson (8), the dispositional model posits that individuals may be characterized according to a tendency to respond to stimuli with an approach motivation (manifested as relatively greater activity in the left frontal cortex) or a withdrawal motivation (manifested as relatively greater activity in the right frontal cortex). The specific aspects of personality that have been linked to the asymmetry in frontal cortical activation were described by Gray (13) as part of his “reinforcement sensitivity theory”, which postulates that individuals differ in their responsiveness to cues of impending reward and/or

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punishment. These individual differences are expressed as varying levels of motivation or drive. Evidence from studies using measurements of frontal alpha asymmetry (FAA) suggest that increased activity in the left frontal cortical region of the brain reflects activation of approach motivation and activity in the right frontal cortex indicates activation of withdrawal motivation (9, 18, 25). Based on these theories and findings, a number of studies have examined resting asymmetry in the frontal cortex as a predictor of motivations and affective response to stimuli [e.g., (15, 24)].

A considerable amount of research has investigated the robustness of the reinforcement sensitivity theory, often employing measures of asymmetry in brain activity (using electroencephalography; EEG) as an independent variable to predict self-reported or observed motivational tendencies. Cortical asymmetry has been shown to reflect a stable latent trait (14) and to be associated with affective response to an emotion-eliciting stimulus (7, 24) and with measures of personality (16). A study among adult women found that mood responses to emotion-eliciting films were significantly associated with resting frontal EEG asymmetry (27). Motivational tendencies have been assessed using a variety of tools, including the BIS/BAS questionnaire developed by Carver and White (3). This paper-and-pencil self-report survey provides a measure of the individual's usual tendency to avoid punishing stimuli (sensitivity of the Behavior Inhibition System; BIS) and/or to approach rewarding stimuli (sensitivity of the Behavioral Activation System; BAS). Studies of the relationship between EEG asymmetry and BIS/BAS are overwhelmingly cross-sectional, with some reporting a significant association between scores on the BIS/BAS and resting EEG asymmetry and others failing to find evidence of this relationship. A meta-analysis of studies examining the correlation between FAA and BAS found that "this association is considerably weaker and more inconsistent than generally assumed (p. 167)" (30).

The BIS and BAS constructs are generally viewed as aspects of personality, and therefore stable traits (2, 6). The recent evidence failing to support the FAA-BAS relationship (30), therefore, calls into question the assumption that trait-based patterns of cortical asymmetry drive the BAS. An alternative possibility is a "capability model" [cf. (32)] of frontal EEG asymmetry and personality. According to this model, a true measure of resting EEG asymmetry (i.e., devoid of any emotion-eliciting stimuli) would be unlikely to yield useful information about affective tendencies. Rather, individual differences in affective tendencies will emerge as a function of the interaction between the innate capabilities of the individual and the situational context (5). The capability model is bolstered by a recent study in which male college students' EEG asymmetry was correlated with their BAS scores only when the EEG was administered by an attractive female experimenter (31). The authors of this study speculate that the association emerged in a situation where approach motivation was highly salient, but did not emerge without that contextual stimulus. Two additional possibilities are null hypotheses; namely, that there is no relationship between FAA and motivational tendencies.

Studies demonstrating stability of EEG asymmetry over time (26, 29), support the contention that this measure represents a characteristic trait, although it is assumed that there is also a state component to EEG asymmetry (4). Research has shown evidence for test-retest reliability of EEG asymmetry over relatively short periods of time in healthy adults

(28) and socially anxious adults (22), and over relatively longer periods of time in healthy preschool and elementary school aged children (20, 29); however, research into the temporal stability of EEG asymmetry during adolescence is lacking. In a recent pilot study of 10 adolescents (9 female, 1 male), initial support for reliability of EEG asymmetry did emerge (33). Our study improves upon these pilot data by incorporating a larger sample of boys and girls that is ethnically diverse and by examining the stability over a longer time period (i.e., 5 months rather than 1 month).

In the present study, we test the hypothesis that EEG asymmetry represents a stable disposition that is related to motivational tendencies among younger adolescents.

Methods

Participants

This study was comprised of an ethnically diverse sample of 99 adolescents in 6th grade at a public middle school in Southern California (51% male; 52% Latino). All participants were recruited through school as part of a larger longitudinal physical activity intervention study. Procedures relevant to the current study are described here while recruitment and other methods used in the larger study are described elsewhere (23). Participants who were right-handed and who completed two electroencephalogram (EEG) recordings approximately four months apart were included in this study. A board-certified clinical neurophysiologist reviewed each EEG to screen for drowsiness and clinical abnormalities. The original sample included 144 adolescents but 42 were excluded owing to insufficient useable EEG data at either the Time One or the Time Two assessment. Reasons for obtaining insufficient data included hair styles not conducive to obtaining quality EEG (N = 10), study withdrawal between assessments (N = 4) or data quality issues with EEG recordings (e.g., excessive drowsiness or muscle artifact, N = 28). In addition, individuals with asymmetry values that were determined to be outliers (i.e., greater than 3 standard deviations from the mean, N = 3) were excluded from analyses. A final sample of 99 participants included 49 males and 50 females aged 10-12 years. The time between EEG recordings ranged from 16-27 weeks (M = 22.2, SD = 2.6).

Procedures

After providing written assent and written parental consent for the study, study participants completed the BIS/BAS and were brought into a classroom that had been converted into a research laboratory on the school grounds to undergo a resting EEG assessment. The BIS/BAS assessment and EEG were repeated again approximately 4 months later under identical conditions.

EEG Data Acquisition. The EEG was acquired using a microEEG (BioSignal Group Corp.) and a flexible electrode cap (Electro-Cap International, Inc) containing all standard International 10-20 system electrodes. The microEEG is a miniature, wireless, battery powered EEG device designed for clinical use in emergency departments. The same design features address the challenges of performing EEG in a public school setting, i.e. limited time for data acquisition, relatively high electrode-scalp impedances, absence of electrical shielding, and limited space to use and store equipment. EEG data were recorded at a sampling rate of 250 Hz and all electrode impedances were under 45 kΩ, an acceptable range for the microEEG device (12, 21). EEG recording sessions took place in a classroom that was turned into a clinical laboratory for the purposes of the larger study. For eyes-open condition, instructions were to sit comfortably and to blink naturally. For eyes-closed condition, instructions were to sit comfortably with eyes closed and to think about something interesting to help stay awake. EEG data were recorded for 16 minutes containing four 240 s intervals alternating between eyes-open and eyes-closed, beginning with eyes-open (i.e., EO1, EC1, EO2, EC2).

EEG Data Reduction. Within each 240 s interval of EO or EC, 120 seconds of EEG were selected for data analysis. All intervals of drowsiness and relatively high amplitude muscle artifact were excluded, as were >1 s intervals of eye blink or muscle artifact of any amplitude[1]. We selected for analysis, whenever possible, a single, continuous 120 s EEG segment within each EO and EC interval. When this was not possible, multiple segments of artifact-free awake EEG were extracted to obtain 120 s of data. Analyses were restricted to participants with a minimum of 240 usable seconds of EEG data. The average segment length did not differ between Time One and Time Two after removing artifacts.

The Fourier power spectrum analysis of the alpha band (8 - 13 Hz) was performed on each 120 s of EEG data, with electrodes of interest referenced to an average reference (electrodes F3, F4, F7, F8, C3, C4, T3, T4, T5, T6, P3, P4, Fz, Cz, Pz equally weighted)[2], low pass filter set at 70 Hz, and a time constant of 0.16 s. The 60Hz notch filter was not used. Fourier transform parameters included a sampling rate of 250 Hz, Hamming window with 50% overlap, and 2,048 points per window for a window duration of 8.192 seconds and a frequency resolution of 0.24 Hz. When an individual EEG segment within an EO or EC interval was < 8.192 seconds the points per window was necessarily reduced to the highest allowable. Results of the Fourier transform were log transformed. The difference between the log transformed alpha power values from one right hemisphere electrode and the corresponding electrode on the left was calculated to compute EEG asymmetry (e.g., ln (F4) – ln (F3)). Cerebral alpha activity is generally considered to reflect a “resting state” and is therefore inversely proportional to cognitively substantive synaptic activity. Positive EEG asymmetry scores indicate greater brain activation in the left hemisphere compared to the right hemisphere; conversely, negative EEG asymmetry scores indicate greater activation in the right hemisphere of the brain compared to the left. Asymmetry scores were computed for mid-frontal (F3, F4), parietal (P3, P4) and occipital (O1, O2) electrode pairs.

Data Analysis

All data were screened for normality and outliers. As is standard with EEG asymmetry data, a logarithmic transformation was used to correct for skewed distributions. In addition,

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[2]To address possible concern about the inclusion in our analyses of low-amplitude artifact less than 1 second in duration, we compared frontal alpha power asymmetry derived from 10 randomly-selected EEGs within our dataset with and without all artifact (even artifact less than 1 second in duration) excluded. Correlations were extremely high (.91 for F3F4, .94 for C3C4 and .90 for P3P4).

[2]Data also were analyzed using a Cz reference, with results no different from those found with the average reference, so only those findings related to the average reference are reported here.

participants with EEG asymmetry values that were more than 3 standard deviations from the mean were removed from analyses (N = 3). Stability of within-individual affective responses was evaluated with Intra-Class Correlation Coefficients (ICC's). ICCs were classified according to Fleiss' (11) standards for poor (< 0.40), good (0.4 < 0.75), and excellent (≥ 0.75) agreement. As a second test of stability, FAA was dichotomized into groups reflecting greater left-sided activation or greater right-sided activation at each time point [those with no asymmetry at time one were omitted from the analysis (N = 18)], and Chi-Square analysis was utilized to test the correspondence between the two dichotomous variables. To test for a correlation between FAA and BIS/BAS, EEG asymmetry scores were aggregated (i.e., a mean was computed) across the two assessment periods and BIS and BAS scores were similarly aggregated. Person's correlations were examined between the aggregated scores.

Measures

BIS/BAS. Approach (BAS) and withdrawal (BIS) motivations were measured with the 20-item BIS/BAS Scale (3), which has demonstrated validity and reliability among adults, convergent and discriminant validity in relation to other measures of personality among college students, and retains measurement and construct validity when used with adolescents (6). The 7-item BIS subscale assesses apprehension over the possibility of negative events and reaction to these events. The 13 BAS items assess drive for obtaining rewards, reward responsiveness, and fun-seeking.

Respondents use a 5-point response scale from 1 (strongly disagree) to 5 (strongly agree) to score items such as ‘‘criticism or scolding hurts me quite a bit’’ (BIS) and ‘‘when I go after something, I don't hold anything back’’ (BAS). In the present sample, the BAS scale had good internal consistency (Cronbach's alpha = .86), and the BIS scale had acceptable internal consistency (Cronbach's alpha = .63). Some investigators have argued that averaging BIS/BAS scores over time increases the trait specificity of the measure(17). Accordingly, we also computed a mean score for each subscale across the two time periods.

Average Alpha Asymmetry. The alpha asymmetry values for the four individual segments of EEG data (EO1, EC1, EO2, EC2) at three regions (F3/F4, P3/P4, O1/O2) were examined to determine the level of internal consistency across segments. Cronbach's alphas indicated a high degree of consistency (Cronbach's alphas = 0.78, 0.83. and 0.84 at the first EEG assessment; Cronbach's alphas = 0.79, 0.85, and 0.87 at the second EEG assessment). Based on these statistics, a mean alpha asymmetry value was computed and used for all subsequent analyses.

Results

Descriptive Statistics

Table One presents descriptive characteristics for the study participants at baseline. Comparison of means from the two assessment periods revealed no significant changes over time in either BIS/BAS or EEG. Scores on the BIS/BAS were moderately stable over time (p's< .001; see Figure 1), with test-retest correlations of .42 (BIS) and .41 (BAS). The FAA values were very small compared to the log transformed alpha power values, and clustered very close to zero. Figure 2 illustrates the individual scores on resting FAA at time 1 and time 2.

Intra-class correlation coefficients were computed for the EEG asymmetry values at each region. Asymmetry in the frontal region was quite stable over time [ICC(CI) = 0.65 (0.49-0.76), $p < .001$], as was the asymmetry in the parietal region [ICC(CI) = 0.80 (0.71-0.86), $p < .001$]. Asymmetry in the occipital region was considerably less stable over time [ICC(CI) = 0.29 (−0.04-0.513, $p<.05$). Chi-Square analysis of the dichotomized FAA values at time one and time two indicated a significant association between laterality at time one and laterality at time two (Chi-Square = 27.54, $p < .001$). Seventy-nine percent of the adolescents manifested the same laterality at time 2 as they had at time 1.

Association between BIS/BAS and EEG asymmetry

Table 2 shows the correlations of the EEG asymmetry values (aggregated across Time One and Time Two) with the BIS/BAS scores aggregated across both time periods. The FAA did not correlate with BIS or BAS. Asymmetry in the parietal region was likewise unrelated to BIS and BAS, but there was a small positive correlation between Occipital asymmetry and BIS. This association suggests that greater activity in the left Occipital region was related to higher scores on the BIS (greater inhibitory activation). Figure 3 illustrates the absence of correspondence between EEG asymmetry in the mid-frontal cortex and BAS.

Analysis by Gender Matching

All analyses were run separately for participants who were matched to the EEG technician for gender at both time points (N =54) and those who were mismatched with the EEG technician for gender at both time points (N = 62). There were no differences between the groups (data not shown).

Discussion

To extend the research into the relationship between FAA and behavioral motivation, this study examined the stability of resting EEG asymmetry over time and the association between behavioral activation and resting EEG asymmetry among younger adolescents. Resting EEG asymmetry in the frontal cortex exhibited considerable stability across time. The vast majority (79%) of the adolescents exhibited the same laterality at Time Two as they had at Time One. The magnitude of the ICC was comparable to that found in a pilot study of 10 adolescents (33), which yielded an ICC of .57 for FAA. There was no correlation, however, between behavioral motivation (BIS/BAS) and FAA. The findings do not support, therefore, the hypothesis that resting FAA is an indicator of an underlying affective style that correlates with the strength of the Behavioral Activation System.

The absence of a correlational association between BAS and resting FAA found in this study is consistent with the findings of the majority of studies using similar methodology and included in a meta-analysis conducted in 2010 (30). A couple of studies reported in this prior review did report significant correlations between BAS and FAA, so it is instructive to examine the specific methods of these studies. A study with a sample that was predominantly female (1) reported a significant association between FAA and BAS. It is interesting to note that, in addition to the possible impact of participant gender, study participants were informed prior to the initiation of the EEG recording that following a resting EEG assessment the EEG recording would continue during a computer task. It is possible that the participants may have experienced some anticipatory motivational activation that makes this EEG less than a true “resting” assessment. A second study in which the association between FAA and BAS was documented (16) featured only female participants with high social anxiety. It is possible that these participants, given their known predilection for experiencing social anxiety, may have experienced the experimental setting as a stimulus that would activate underlying capacities for asymmetrical cortical activity. Thus, our finding that FAA was not associated with BAS may indicate that we were successful in obtaining a true resting EEG, and that the situation was not conducive to eliciting underlying differences in affective style.

A more recent study also reported a significant association between BAS and FAA. De Pascalis et al. (10) found the relationship in a study of resting FAA and BAS scores among 51 female Italian undergraduate students. Scatterplots of the associations suggest that some individual subjects in this study manifested considerable asymmetry. Given the evidence presented by Wacker et al. (30) demonstrating that a BAS-asymmetry link emerged among males only when the experimenter was an attractive female, it seems appropriate to suggest that female undergraduate students undergoing a resting EEG assessment by male experimenters would similarly evince an approach motivation likely to uncover the EEG-BAS association. In personal communication, we confirmed that the gender of the experimenter in the De Pascalis et al. study was in fact male, which is consistent with this hypothesis. The present study was not designed to examine the impact on the relationship of EEG to BIS/BAS of concordance in gender between the participant and the researcher. We did not expect that the same dynamics would be in play for this study, in which participants were so much younger than researchers (i.e., average of 10 years compared to average of 25 years), compared to the studies that included young adults as both participants and researchers. Nevertheless, we ran all analyses separately for participants who were matched for gender at both time points and those who were mismatched for gender at both time points and found no differences between the groups.

Our findings are also consistent with the results of a recent review of the evidence related to the association between FAA and post-traumatic stress disorder (PTSD) (19). In this review, the authors examined the evidence for differences in resting FAA (referred to in this paper as “trait FA”) between persons with and without PTSD and also the evidence for an association between resting FAA and severity of PTSD symptoms. The overwhelming preponderance of the evidence showed no association between resting FAA and PSTD. In contrast, when the authors reviewed studies investigating the association of frontal alpha asymmetry during a stimulus task (referred to as “state FA”), PTSD patients displayed significantly stronger right-sided activation in response to trauma-related stimuli. Thus the evidence seems to suggest that the capacity model may be a more productive avenue for future research investigating the role of frontal alpha asymmetry in behavior.

Finally, there is a possibility that the BIS/BAS measure employed in this study may have been insufficiently reliable in this study sample. It has been suggested recently that the

BIS/BAS instrument used in this study may not be optimally reliable among a culturally diverse sample (11), that removing certain items may increase the validity of the scales (21), and that scores on the BIS/BAS may increase with age (23). In the present study, scores were only moderately stable over time, suggesting either that the instrument was not very reliable in this sample or that participants' affective styles were still developing.

There are certain limitations to this study that should be taken into account. For reasons connected to the larger study of which these data are a part, adolescents who were members of team sports and/or involved in competitive athletics were excluded from participating. It is unknown how this criterion may have impacted the findings, but it should be noted that the results may not be generalizable to student-athletes. Secondly, although the sample was ethnically diverse, the number of participants of African-American descent who provided data for this study was lower than it could have been owing to the difficulty in obtaining EEG recordings from some of these adolescents, whose hair style precluded the procedure. Results, therefore, may not be relevant to African-American adolescents. It is also noted that although this study sample is larger than many studies in the literature, it is still not large enough to detect small correlations (i.e., below .30). Finally, our EEG data did not exclude low-amplitude artifact of less than 1 second in duration. As noted in a footnote to the methods, we compared the data from 10 cases after removing all artifact with the data used in our analyses, and found a very high correlation (close to 1), so we do not believe that including these brief low-amplitude artifacts had an impact on our findings. Future research might extend our findings by using a revised assessment tool to measure BIS/BAS and by obtaining EEG data while exposing participants to an emotion-eliciting stimulus.

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Highlights

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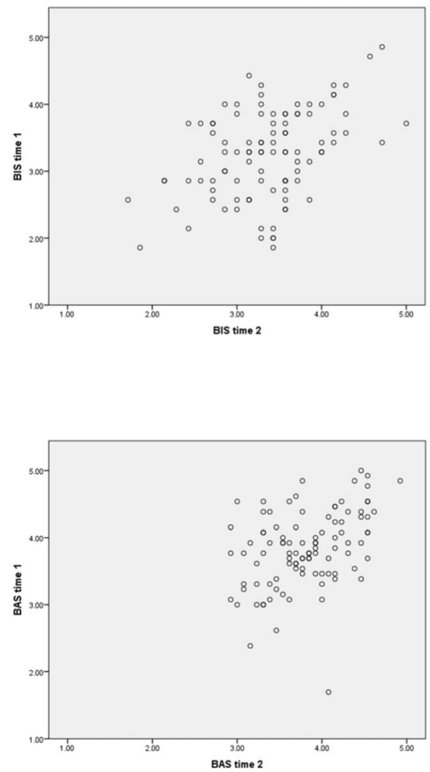

Figure 1.

Scatterplots of the test-retest correlations of BIS and BAS scores.

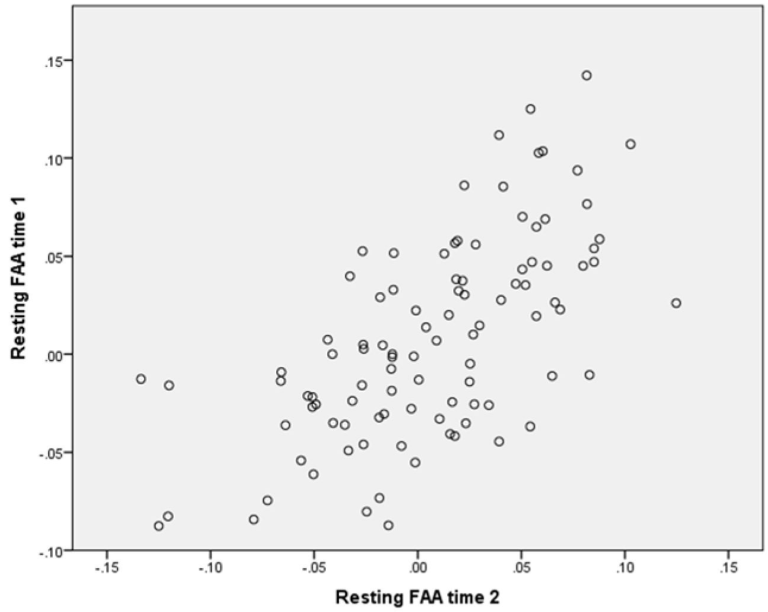

Figure 2.
Scatterplot of the test-retest correlation of FAA.

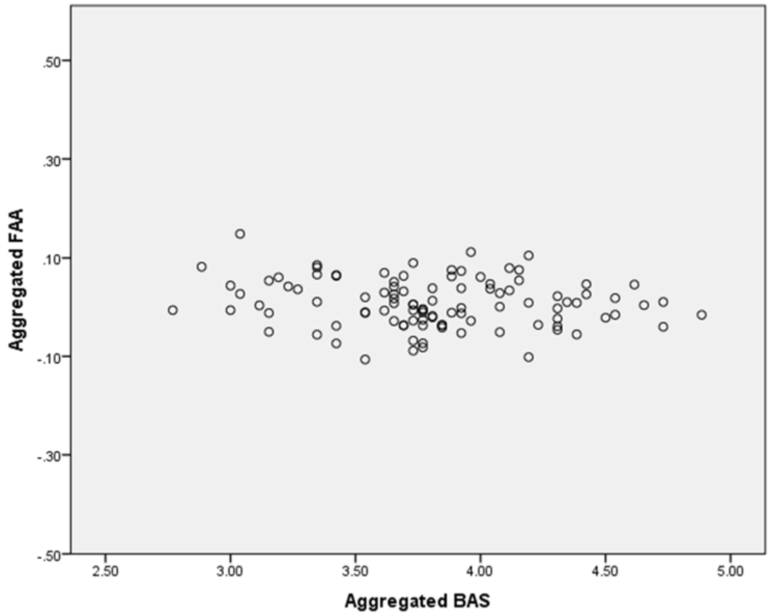

Figure 3.
Graph of the correlation between aggregated FAA and aggregated BAS.

Table 1

Participant characteristics (N = 99).

	Time One	Time Two
Variable	**M (SD)**	**M (SD)**
BAS	3.84 (0.57)	3.81 (0.46)
BIS	3.25 (0.65)	3.35 (0.61)
Alpha power F3[1]	1.88 (0.87)	1.81 (0.53)
Alpha power F4[1]	1.87 (0.87)	1.80 (0.53)
Asymmetry F3/F4[2]	0.00 (0.05)	0.00 (0.05)
Alpha power P3[1]	2.19 (0.85)	2.17 (0.56)
Alpha power P4[1]	2.25 (0.83)	2.19 (0.52)
Asymmetry P3/P4[2]	−0.05 (0.13)	−0.01 (0.18)
Alpha Power O1[1]	2.51 (0.77)	2.54 (0.64)
Alpha Power O2[1]	2.49 (0.76)	2.52 (0.64)
Asymmetry O1/O2[2]	0.01 (0.12)	0.02 (0.13)

[1]Values log transformed with logarithmic transformation

[2]The difference between the log transformed alpha values from one right hemisphere electrode and the corresponding electors on the left.

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Table 2

Correlations between aggregated BIS/BAS and aggregated EEG Asymmetry (N = 99)

Region	BAS	BIS
Mid-frontal	−.14	.01
Parietal	.14	−.17
Occipital	.00	.22*

Note: BAS= Behavioral activation system; BIS = Behavioral inhibition system.

Scores were aggregated across the two assessment periods (Time One and Time Two) for both the EEG Frontal Alpha Asymmetry and the BIS and BAS scores.

$p < .05$