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Frontal EEG asymmetry and the behavioral activation and inhibition systems

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Abstract

Two studies have examined whether there exists a relationship between resting frontal alpha asymmetry and the Behavioral Inhibition and Activation Scales (C. S. Carver & T. L. White, 1994), which are based on Gray's Behavioral Inhibition and Behavioral Activation Systems. Findings suggest that greater relative left frontal activity characterizes individuals higher in self-reported behavioral activation sensitivity (E. Harmon-Jones & J. J. B. Allen, 1997; S. K. Sutton & R. J. Davidson, 1997), and, in one instance, lower behavioral inhibition sensitivity (S. K. Sutton & R. J. Davidson, 1997). In the present study, relatively greater left frontal activity correlated positively with behavioral activation scores. No significant relationship between resting frontal alpha asymmetry and the behavioral inhibition score emerged. These data suggest that relatively greater left frontal activity is indeed an index of approach oriented, appetitive motivational tendencies, whereas the relationship between relative right frontal activity and the behavioral inhibition system is likely to be complex and not accounted for by behavioral withdrawal alone.

Trait frontal alpha electroencephalographic (EEG) asymmetry, often conceptualized as an index of approach and withdrawal tendencies, has been examined in two recent studies as a potential correlate of self-report measures thought to tap Gray's (1972, 1987, 1990) Behavioral Activation and Inhibition systems (BAS and BIS, respectively; Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997). Although these studies agree that there is a relationship between frontal EEG asymmetry and the BAS, findings for the BIS have been inconsistent. In this article, relationships between frontal EEG alpha asymmetry, the BIS, and the BAS are investigated in a third independent sample.

Frontal EEG Alpha Asymmetry, Approach, and Withdrawal

A sizable literature supports the approach/withdrawal model of frontal EEG alpha asymmetry, motivation, and emotion (Davidson, 1993, 1998; for review, see Coan & Allen, in press). According to this model, patterns of frontal brain activity (with activity inferred as the inverse of alpha power) correspond to motivational propensities to approach versus withdraw. Specifically, relatively greater left frontal activity corresponds with an increased trait tendency to approach or respond more intensely to affectively positive stimuli, whereas relatively greater right frontal activity (or, possibly, less left activity; cf. Coan, Allen, & Harmon-Jones, 2001) corresponds with an increased trait tendency to withdraw or respond more intensely to affectively negative stimuli (Tomarken, Davidson, & Henriques, 1990; Wheeler, Davidson, & Tomarken, 1993). These trait-like relationships are mirrored by a correspondence between changes in frontal EEG asymmetry and state changes in emotion and motivational tendency (Coan et al., 2001; Davidson, Ekman, Saron, Senulis, & Friesen, 1990; Ekman & Davidson, 1993; Ekman, Davidson, & Friesen, 1990).

In addition to its relationships with trait motivational or affective styles (see Davidson, 1998) and discrete emotional states, trait frontal EEG asymmetry may indicate an increased risk for affective disorders, including depression (Allen, Iacono, Depue, & Arbisi, 1993; Henriques & Davidson, 1991, but see also Reid, Duke, & Allen, 1998) and anxiety (Davidson, Marshall, Tomarken, & Henriques, 2000; Heller & Nitscke, 1998; Wiedemann et al., 1999).

The Behavioral Inhibition and Activation Systems

In describing the behavioral approach and inhibition systems, Gray (1972, 1987, 1990) has argued that individuals who have a high trait capacity for behavioral activation are thought to be motivated to actively seek out both positive and negative reinforcement (Gray, 1994). Further, high levels of trait BAS sensitivity in humans have been associated with greater general positive affectivity (Gable, Reis, & Elliot, 2000) and, interestingly, a greater likelihood of aggressive behavior (Wingrove & Bond, 1998).

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In contrast, the BIS is thought to be sensitive to signals of punishment and nonreward, as well as to novel stimuli and innate fear stimuli (Gray, 1994). The BIS, when active, is thought to lead to behavioral inhibition, an increment in physiological arousal, and an increase in focused attention (Gray, 1994). In humans, the BIS has been associated with a greater likelihood of general negative affectivity (Gable et al., 2000) and a decreased likelihood of aggressive behavior (Wingrove & Bond, 1998).

Human studies of the BAS and the BIS have utilized the BIS/BAS scales (Carver & White, 1994). In addition to general BIS and BAS assessments, these scales are thought to measure three proposed subtypes of the BAS, namely, a "reward responsiveness" system, a "drive" system, and a "fun seeking" hedonistic system. These subtypes were introduced by Carver and White as part of their BAS scale, and were not specified previously.

A number of investigators have noted the similarity of the BIS and BAS to the basic motivational constructs of approach and withdrawal (Carver, 1996; Fowles, 1988; Gray, 1994; Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997). In general, an emerging consensus in the literature suggests that the approach system, the BAS, and perhaps other related constructs, such as the behavioral engagement system (Depue, Krauss, & Spoont, 1987) and the behavioral facilitation system (Depue & Iacono, 1989), overlap conceptually and share substantial variance. Whether this is true of the withdrawal and BIS constructs is not as clear (Harmon-Jones & Allen, 1997), though at least some authors have argued explicitly that they are highly related and possibly identical (Carver, 1996; Sutton & Davidson, 1997).

In the two investigations most germane to this report, Harmon-Jones and Allen (1997) and Sutton and Davidson (1997) each examined the relationship between frontal EEG alpha asymmetry and these constructs.[1] In particular, the BAS should, like approach tendencies, correspond to relatively greater trait left frontal brain activity. Further, the BIS—to the extent that it resembles the construct of withdrawal—should correspond with relatively greater right frontal brain activity. On the first point, these two studies agree. On the second point, there is some empirical disagreement. Although Sutton and Davidson found the predicted relationship between frontal brain activity and the BIS, Harmon-Jones and Allen did not. This led Harmon-Jones and Allen to question the extent to which the withdrawal and BIS constructs overlap, and to point out that the relationship between these systems is not as obvious, especially when one considers that the withdrawal system could conceivably overlap at times with other systems proposed by Gray (1987), such as the fight/flight system (FFS) and even the BAS (Harmon-Jones & Allen, 1997). Thus the variety of behaviors involving withdrawal from a stimulus may include, for example, withdrawal tendencies involved in unconditioned escape behavior (FFS), avoidance of conditioned punishment or nonreward (BIS), or avoidance behaviors primarily motivated by the positively reinforcing properties of safety cues (BAS; cf. Fowles, 1987; Harmon-Jones & Allen, 1997).

[1] In another attempt to study the relationship between BIS, BAS, and frontal EEG asymmetry, Hagemann et al. (1999) used measures of extroversion and neuroticism to assess the relationship between EEG asymmetry and BIS/BAS strength. Hagemann et al., following from the postulations of Gray (1994), attempted to measure BIS/BAS strength using the German version of the revised Eysenck Personality Questionnaire (EPQ-R; Eysenck & Eysenck, 1975), reasoning that labile extroverts should be high in BAS strength whereas labile introverts should be high in BIS strength. Citing Harmon-Jones and Allen (1997) and Sutton and Davidson (1997), they reasoned further that labile extroverts should show greater left frontal activation than stable extroverts, and that labile introverts should show greater right frontal activation than stable introverts. They found no such relationships, prompting them to speculate that the findings of Harmon-Jones and Allen and Sutton and Davidson may be specific to the operationalization of the BIS and BAS constructs in the BIS and BAS scales, also noting that Gray's model of how BIS and BAS are manifest in extroversion and neuroticism may be wrong. Obviously, the relationships between frontal EEG asymmetry, extroversion, neuroticism, BIS, and BAS warrant further study.

The Present Study

An independent sample was used to assess the replicability of the findings of both Harmon-Jones and Allen (1997) and of Sutton and Davidson (1997). Because of the clear theoretical similarities, and because of the precedents set in past research, it was first hypothesized that higher self-reported BAS scores would again correspond with relatively greater left frontal activity. In contrast, it was hypothesized that the relationship between frontal EEG asymmetry and BIS scores would be weaker or nonexistent by virtue of the theoretical dissimilarities between the constructs of the BIS and behavioral withdrawal. This second hypothesis derives from the assumption that behavioral inhibition, in the sense that Gray (1987) or Carver and White (1994) envision it, may only partially overlap with the withdrawal system described by Davidson (1993, 1998).

Method

Participants

Thirty-six introductory psychology students (age 17–24 years) served as participants (10 male, 26 female). All participants were strongly right handed (scoring over 35 on the 39 point scale; Chapman & Chapman, 1987). Due to missing data in resting EEG files and/or questionnaires, 4 participants were not used for these analyses, resulting in a final sample of 32 participants.

Procedure

A detailed description of the procedures involved in this study is provided in Coan et al. (2001). After arriving, participants were informed of the laboratory tasks, which included a baseline resting assessment (reported here) and, subsequently, a state manipulation component (reported in Coan et al., 2001, and not reported here). After providing informed consent, participants completed questionnaires—including the BIS/BAS Scales (Carver & White, 1994)—while electrodes were affixed to their face and scalp. Resting EEG was recorded while participants sat quietly in a sound-attenuated room for an 8-min resting period, consisting of a counterbalanced sequence of minute-long eyes-open and eyes-closed segments.

BIS and BAS Scales

Internal consistency reliability estimates were obtained for the BIS and BAS scales, yielding reliabilities commensurate with those reported by Carver and White (1994) and Harmon-Jones and Allen (1997). Specifically, the BIS scale yielded an internal-consistency reliability estimate of .75 and a mean score of 20.65 ($SD = 2.84$). BAS subscales yielded reliability estimates of .58 ($M = 17.25$, $SD = 1.46$), .72 ($M = 12.59$, $SD = 2.08$) and .72 ($M = 11.41$, $SD = 1.81$) for the BASR (reward responsiveness), BASF (fun seeking), and BASD (drive) subscales respectively. The BAS subscales all correlated highly with each other and with a total BAS score, the minimum correlation being .51, p (two-tailed) < .001. Given the extensive overlap of these subscales, and the fact that the subscales will necessarily be less reliable than the total scale, subsequent BAS-related analyses were limited to the total BAS score, itself yielding an internal-consistency reliability estimate of .83 and a mean score of 40.83 ($SD = 4.46$). The BIS scale and the general BAS scale were not significantly correlated, $r = .22$; p (two-tailed) = .23.

Assessment of EEG and EOG

Tin electrodes in a stretch-lycra cap were used to record EEG at sites FP1, FP2 F3, F4, F7, F8, Fz, FTC1, FTC2, C3, C4, T3, T4, TCP1, TCP2, T5, T6, P3, P4, Pz, O1, O2, Oz, A1, and A2. All sites were referenced online to Cz, and rereferenced off-line using different reference schemes, as recommended by Reid et al. (1998), who noted that data from different references schemes do not necessarily correlate highly. In addition to the online vertex (Cz) reference, a computer-linked mastoids reference and an average reference were derived off-line. The average reference involves subtracting from each site the average activity of all scalp sites, whereas the computer-linked mastoids reference involves subtracting from each site the arithmetic average of the two mastoid leads. The ground lead was on the midline just anterior to Fz. Electrode impedances were reduced to less than 5 KΩ. All sites were amplified by a factor of 20,000 with AC differential amplifiers (bandpass 0.1 and 300 Hz), and digitized continuously at 2048 Hz.Three electrodes, one on the nasion and two others at approximately 20% of the nasion–inion distance directly below FP1 and FP2, were used to monitor eye movements (amplification = 5 K, bandpass = 0.1 to 300 Hz).

Data Reduction and Analysis

Prior to artifact screening, data files were filtered with a finite impulse response zero phase shift 161-point digital 60-Hz notch filter. The file was visually screened for gross movement artifacts and for clipped signals; time periods containing such artifacts were removed from further analyses. Epochs with eyeblinks were rejected automatically, when ocular signals exceeded $\pm 100\ \mu$V. Each 1-min segment of data was epoched into 119 2-s epochs that overlapped by 1.5 s to compensate for the loss of data due to the imposition of a Hamming window prior to spectral analysis. The average percentage of rejected epochs per subject was 27%, ranging from 1.4% to 60%. Data were rereferenced off-line to an average montage and to computer-linked mastoids. Data from the online Cz reference and both off-line reference schemes were analyzed separately. A fast Fourier transform (FFT), using a Hamming window that tapered data at the distal 10% of each 2-s epoch, transformed data to power spectra, and the average power spectrum for each 1-min period was obtained. Total power within the alpha frequency band (8–13 Hz) was extracted, and these values were averaged across minutes, weighted according to the number of artifact-free epochs in each minute. Average alpha power values at each site were then log transformed using the natural log. A measure of EEG hemispheric asymmetry (right hemisphere compared to left hemisphere) was then derived (ln[right] – ln[left]) for each of the regions of interest. Because cortical alpha power is inversely related to cortical activity (Davidson, 1988), lower scores on this metric indicate relatively less left frontal activity. Internal consistency reliability estimates (Cronbach's alpha) were obtained for the alpha asymmetry score at each region. As detailed in Figure 1, 8 min of resting EEG activity yielded internal consistency reliability estimates ranging from .64 to .96, depending on scalp region and reference scheme, with a median reliability coefficient of .91, a mean of .87, and a standard deviation of .09.

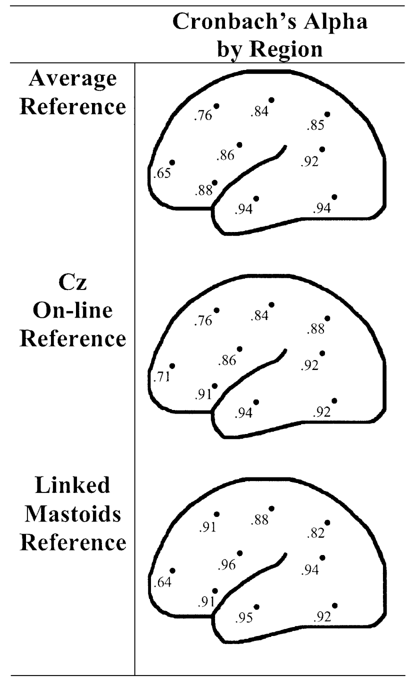

Figure 1. Internal consistency reliability estimates for cortical alpha power asymmetry, by reference scheme.

Results

The Use of Multiple Reference Schemes

Descriptive results reported here are replicated across three different reference montages. Although rational arguments have been levied in favor of one or another reference scheme (e.g., Hagemann, Naumann, & Thayer, 2001; Reid et al., 1998), it remains a somewhat empirical question which reference scheme has the greatest predictive validity with respect to motivational and emotional constructs. Particularly problematic, on both theoretical and empirical grounds, is the Cz reference. It has been argued that the Cz reference may under- or overestimate activity at the target site (Hagemann et al., 2001), and empirical investigations of the correspondence between reference schemes have found Cz to be the least related to other reference schemes (e.g., Hagemann et al., 2001; Reid et al., 1998). Nevertheless, much of the literature has reported results with the Cz reference scheme. Although it is conceivable that significant results using the Cz reference to date derive, in part, not only from a relationship of constructs with frontal asymmetry, but also with sources of variance unique to the Cz reference (e.g. overall alpha power), it may also be that this reference scheme simply introduces more error variance in terms of asymmetry, and therefore is less robust for demonstrating empirical relationships with motivation and emotion. An evaluation of Cz to date suggests the latter, although differentiating these possibilities is possible only by reporting results with multiple reference schemes. The Cz reference is thus included here in all descriptive analyses.

In contrast, all inferential analyses include both the average and linked mastoid reference schemes. This is because these two reference schemes can more readily be conceptualized as contributing unique sources of error variance to any given analysis, providing the researcher with semi-independent measures of EEG activity without introducing sufficient unique error to attenuate potential effects. Generally, results that are statistically independent of reference scheme should be considered the most generalizable, being less likely to reflect only the reference-specific "method" variance (cf. Campbell & Fiske, 1959).

Correlations between BIS, BAS, and EEG Asymmetry

BIS. Two-tailed Pearson product-moment correlations were first computed between resting frontal EEG asymmetry and the BIS scale (see Figure 2). Relationships were mostly nonsignificant, the exception being a significant correlation between the BIS scale and asymmetry in the central region when using the Cz-online reference scheme, $r = .48$, $p < .01$. However, and as discussed above, the appearance of an isolated relationship in only one reference scheme is not considered robust, and could reflect factors unique to that reference, especially in the case of Cz, where large changes in the reference site can mask or create asymmetries and which has been shown to be particularly uncorrelated to other reference schemes (cf. Hagemann et al., 2001; Reid et al., 1998). Other than this isolated effect and a general pattern of correlations under the Cz reference scheme that deviated from the other two schemes, no statistically significant relationships between resting asymmetry and the BIS scale were identified.

BAS. Results for the BAS scale, by contrast, suggest diffuse relationships with asymmetries primarily over the frontal cortex, but also in the central region (C4-C3). These relationships were significant with the average and linked mastoid reference schemes, but not with the Cz-Online reference (see Figure 2). Specifically, analyses using the linked mastoids reference indicate a statistical trend in the temporal-central-parietal region, $r = .34$, $p < .10$, and significant relationships in the frontal pole, $r = .36$, $p < .05$, midfrontal, $r = .44$, $p < .01$, lateral-frontal, $r = .48$, $p < .01$, frontal-temporal-central, $r = .42$, $p < .01$, and central, $r = .49$, $p < .01$, regions. With the average reference scheme, statistical trends were apparent in the frontal pole, $r = .30$, $p < .10$, and midfrontal, $r = .31$, $p < .10$ regions, and significant correlations were obtained between the BAS and asymmetry scores in the frontal-temporal-central, $r = .40$, $p < .05$, and central, $r = .39$, $p < .05$, regions.

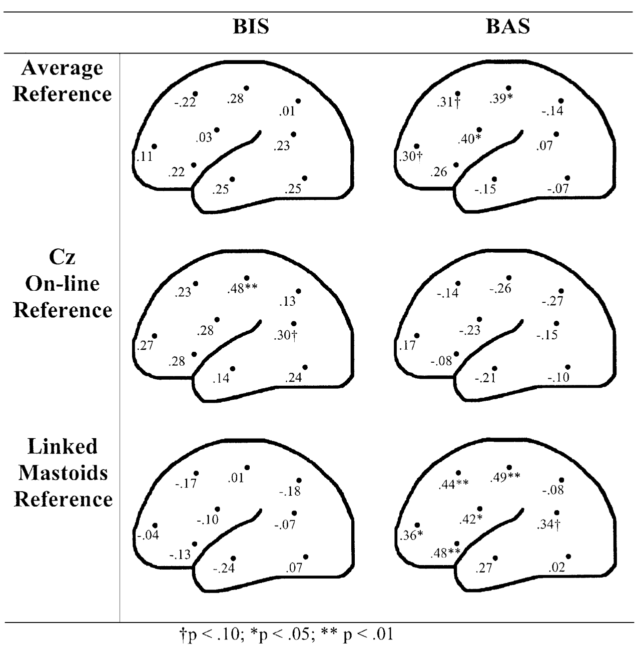

Figure 2. Correlations between cortical alpha power asymmetry and BIS and BAS scores by reference scheme. Positive correlations indicate relatively greater left cortical activity is associated with more of the trait.

General Model of Cortical Asymmetry, BIS, BAS, and Reference Scheme

Because the number of correlations reported in the previous analysis threatens to inflate the Type I error rate, they are best thought of as descriptive. Therefore, a hierarchical general linear model was calculated representing the multiple sources of variance contributing to the relationship between cortical asymmetry, BIS, and BAS scores. This model included both categorical and continuous predictors. Moreover, this model was specifically designed to assess whether frontal EEG asymmetry was significantly more strongly related to BAS than to BIS scores.

For this analysis, BIS and BAS scores were first concatenated into a single criterion variable called *BISBAS score*, which was treated as a single within-subject, repeated measure. To then contrast the BIS and BAS scales within a single model, a contrast-coded variable, *BISBAS contrast*, was created per the recommendations of Aiken and West (1991). The interaction between this contrast variable and asymmetry scores in predicting BIS and the BAS scores could then be assessed. Further, asymmetry scores from specific regions were entered as continuous variables for each level of BISBAS contrast. These regions included F4-F3, F8-F7, FTC2-FTC1, C4-C3, T4-T3, T6-T5, TCP2-TCP1, and P4-P3. The frontopolar regions (FP2-FP1) were excluded due to their lower internal consistency estimates. Additionally, reference scheme (average versus linked mastoid)—itself a potentially important source of variance—was also included as a contrast-coded repeated measure, with EEG asymmetries, and BISBAS scores repeated for each level of reference scheme.

To summarize, a hierarchical general linear model designed to test the differential prediction of BIS and BAS on the basis of asymmetry scores was conducted. This concatenated BISBAS score was predicted by (a) BISBAS contrast, (b) reference scheme, and (c) alpha asymmetry at a variety of regions across the scalp. Additionally, interactions between each region and reference scheme, and each region and BISBAS contrast, were entered. The specific interactions of interest were those between BISBAS contrast and region, which would indicate that asymmetry in some regions, but not others, differentially predicted BIS versus BAS scores. Interactions with reference scheme were entered into the model in order to determine whether relationships between asymmetry and BISBAS scores were dependent upon reference scheme. Thus, with this single model, all of the major and minor questions of this report, including the specific effects of reference scheme, were tested simultaneously.

Table 1 lists the significant effects of this model. The overall model was significant and indicated that the total variance in BIS and BAS scores was more than adequately accounted for,

Table 1. *Significant Effects of General Linear Model Designed to Test the Differential Prediction of BIS and BAS on the Basis of Asymmetry Scores*

Source	*Df*	*F*	*P*	η^2
BISBAS contrast	1,94	1120.64	< 0.000	0.92
F8-F7	1,94	8.08	0.01	0.08
C4-C3	1,94	8.62	0.01	0.08
T6-T5	1,94	5.71	0.05	0.06
BISBAS Contrast × F8-F7	1,94	6.60	0.05	0.07
BISBAS Contrast × F4-F3	1,94	5.40	0.05	0.05

Note: The model was specified using both BIS and BAS scores as a single DV, using a contrast-coded variable, *BISBAS contrast*, as one predictor (cf. Aiken & West, 1991; see text for explication). Other predictors included continuous asymmetry scores at F4-F3, F8-F7, FTC2-FTC1, C4-C3, T4-T3, T6-T5, TCP2-TCP1, and P4-P3. All interactions between Region, BISBAS Contrast, and Reference were entered into the model. $N = 32$; adjusted R squared = .90.

$F(33,94) = 35.45$; $p < .000$; adjusted $R^2 = .90$. The largest specific effect was of BISBAS contrast, $F(1,94) = 1120.64$, $p < .000$, $\eta^2 = .92$, which is entirely expected as the BIS and BAS scales have different ranges and, therefore, necessarily different means. Other main effects on BISBAS score were attributed to F8-F7, $F(1,94) = 8.08$, $p < .01$, $\eta^2 = .08$; C4-C3, $F(1,94) = 8.62$, $p < .01$, $\eta^2 = .08$; and T6-T5, $F(1,94) = 5.71$, $p < .05$, $\eta^2 = .06$. Such main effects are difficult to interpret, as they represent relationships between asymmetry at these regions and higher (or lower) scores across both BIS and BAS scales simultaneously. In contrast, interactions between each region and BISBAS score were of particular interest and are readily interpretable. Only the interaction between frontal regions and BISBAS score were significant. These included the midfrontal region (F4-F3), $F(1,94) = 5.40$, $p < .05$, $\eta^2 = .05$, and the lateral-frontal region (F8-F7), $F(1,94) = 6.60$, $p < .05$, $\eta^2 = .07$.

To decompose these interaction effects, a regression was computed separately for each frontal region, using EEG asymmetry to predict BIS and BAS separately (cf. Aiken & West, 1991). In each case, reference scheme was entered as a repeated measure to assess the dependence upon reference scheme of any particular relationship. No main effects of reference scheme were identified, nor were any interaction effects of reference scheme by region. Results indicated that EEG asymmetry predicted BAS scores in both the midfrontal, $F(1,60) = 8.15$, $p < .01$, $\eta^2 = .12$; and lateral-frontal, $F(1,60) = 9.99$, $p < .01$, $\eta^2 = .14$, regions. Figures 3 and 4 represent regression lines graphically contrasting relationships between frontal asymmetry and both BIS and BAS. Interestingly, although not statistically significant, a statistical trend—in the opposite direction—was apparent in the relationship between BIS scores and EEG asymmetry in the midfrontal region, $F(1,60) = 2.52$, $p = .12$, $\eta^2 = .04$, but not the lateral-frontal region, $F(1,60) = .03$, $p = .87$, $\eta^2 = .00$. Of particular note is that this midfrontal trend is in the same direction as that reported by Sutton and Davidson (1997), with relatively greater right midfrontal activity showing a tendency to correspond to higher BIS scores. It is interesting to note that the effect size for the

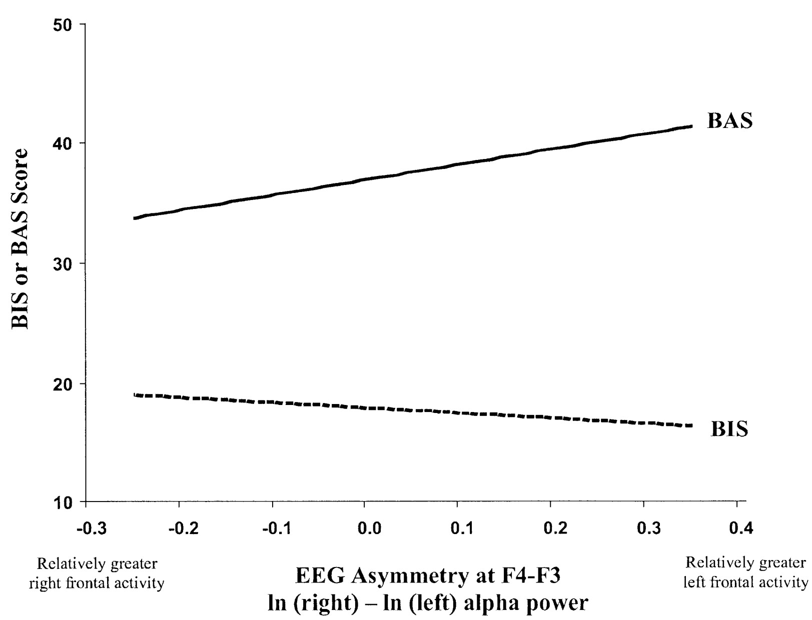

Figure 3. Regression lines for EEG asymmetry in the midfrontal region (ln[F4] – ln[F3]) predicting BIS and BAS scores. The regression equations depicted are: BIS = (– 4.42)(midfrontal asymmetry) + 18.00; BAS = (12.84) (midfrontal asymmetry) + 37.03.

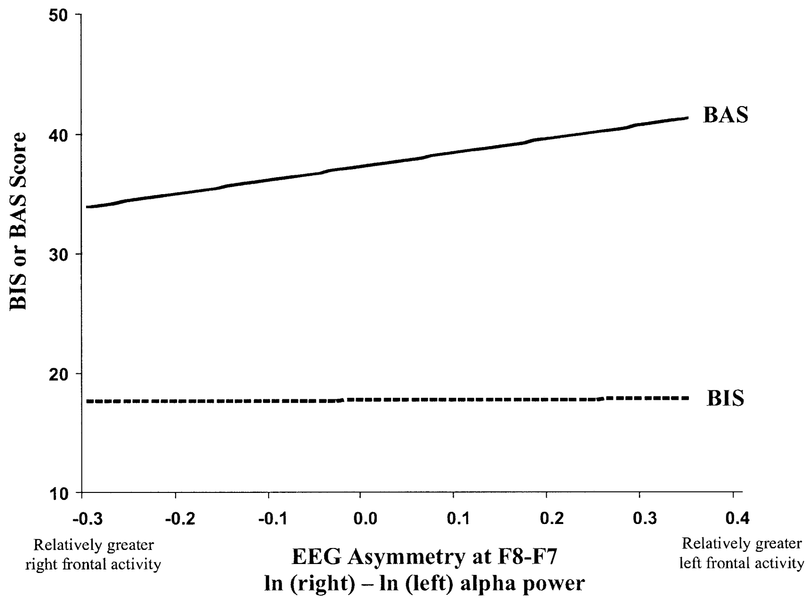

Figure 4. Regression lines for EEG asymmetry in the lateral-frontal region (ln[F8] – ln[F7]) predicting BIS and BAS scores. The regression equations depicted are: BIS = (0.38)(lateral–frontal asymmetry) + 17.81; BAS = (11.57) (lateral–frontal asymmetry) + 37.47.

midfrontal trend reported here is .04, whereas the effect size for the same relationship reported by Sutton and Davidson was approximatel .17.

Hemispheric Specificity

A question of major interest in studies of EEG asymmetry concerns the relative contributions of each hemisphere to any given asymmetry score. To this end, a second hierarchical general linear model was calculated in order to identify specific hemispheric patterns associated with the relationships between BAS score and the two identified frontal regions. In this second model, BAS scores were the dependent variable to be predicted by (a) reference scheme, and (b) natural log-transformed alpha power in the left (F3 and F7) and right (F4 and F8) hemispheres. In this model, main effects of each hemisphere were of interest, as well as the interaction between hemisphere (left, right) and region (midfrontal, lateral-frontal). As before, interactions with reference scheme were entered into the model to determine whether relationships between site and BAS scores were dependent upon reference scheme.

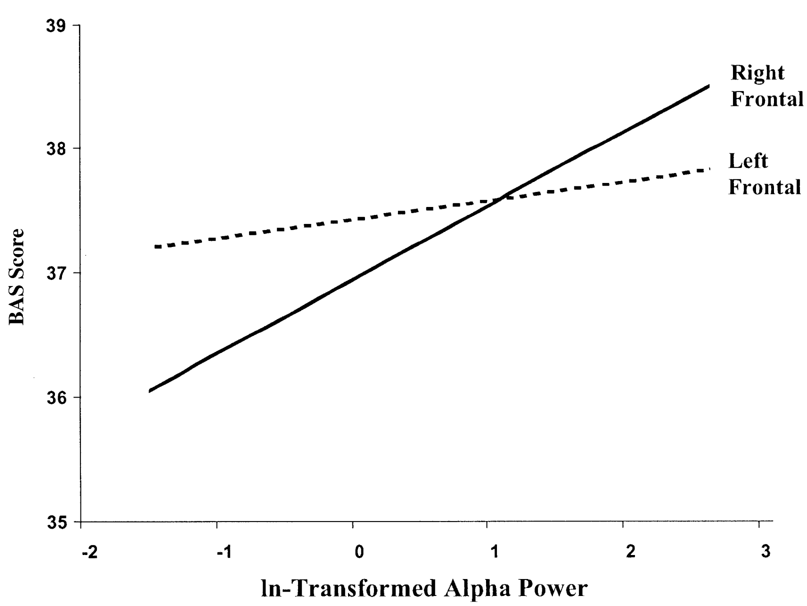

Figure 5. Regression lines for left and right frontal ln-transformed alpha power predicting BAS scores. The regression equations depicted are: BAS = (0.15) (Left) + 37.44; BAS = (0.60) (Right) + 36.98. Left includes ln-transformed power at F3 and F7, and right includes ln-transformed power at F4 and F8.

The overall model was significant, $F(15,112) = 1.85$, $p < .05$, adjusted $R^2 = 0.09$. Results indicated a main effect of the right hemisphere, $F(1,112) = 23.24$, $p < .001$, $\eta^2 = .17$. No interactions between hemispheres or between either hemisphere and region were observed, indicating that individual differences in right frontal activity were related to differences in BAS scores. Again, the main effect of the right hemisphere was not dependent upon reference scheme. Figure 5 depicts specific left/right relationships with BAS scores, independent of region.

Discussion

In this sample, greater relative left frontal cortical activity corresponded with greater BAS scores as predicted. Additionally, although trait EEG asymmetry was generally not correlated with the BIS, there was a weak statistical trend toward relatively greater right frontal activity corresponding to higher BIS scores in the midfrontal region only. When relationships between frontal activity and the BAS were assessed by hemisphere, activity in the right hemisphere appeared to be accounting for asymmetry effects in both the mid- and lateral-frontal regions. That is, less right frontal—not greater left frontal—activity corresponded with higher BAS scores. Each of these findings was independent of reference scheme (either averaged reference or computer linked mastoids). Both this study and the one by Harmon-Jones and Allen (1997) thus only partially correspond with the findings of Sutton and Davidson (1997), who found that trait frontal EEG asymmetry was robustly related to both the BAS and the BIS, in positive and negative directions, respectively.

Trait Frontal EEG Asymmetry and the BAS

In now three studies, relatively greater left frontal brain activity has been associated with higher levels of behavioral activation as measured by the behavioral activation scale (Carver & White, 1994). These results cohere with the growing consensus that the BAS and approach motivation, as constructs, overlap substantially (e.g., Carver, 1996; Gray, 1994; Harmon-Jones & Allen, 1997; Sutton & Davidson, 1997; although see also Hagemann et al., 1999). Thus behavioral activation or approach motivations appear to have good construct validity as a higher-order system that links together diverse EEG asymmetry findings in the temperament, emotion, and psychopathological domains.

Trait Frontal EEG Asymmetry and the BIS

Although Sutton and Davidson (1997) found that higher BIS scores were related to relatively greater right frontal activity, this was not found by Harmon-Jones and Allen (1997). In this report, only a weak statistical trend toward a relationship between frontal EEG asymmetry and the BIS was found in the midfrontal region, and the effect size was substantially smaller. This discrepancy may reflect heterogeneity among the constructs of withdrawal and BIS. Indeed, Davidson's (1998) withdrawal construct refers to a system that motivates, or potentially motivates, organisms to *withdraw* from sources of aversive stimulation, whereas the BIS is described as a system that, among other things, *interrupts* ongoing behavior, increases arousal, and increases attention (Gray, 1994), none of which inevitably leads to a withdrawal response. Moreover, aspects of the withdrawal motivational construct described by Davidson could conceivably overlap with functions included in any of the motivational systems described by Gray. For example, withdrawal tendencies may be motivated by BAS functions that respond to the positively reinforcing properties of safety cues in the context of the pursuit of negative reinforcement or the avoidance of punishment, in BIS functions that are sensitive to cues of threat, and in fight–flight system functions such as unconditioned escape behavior (Fowles, 1987; Harmon-Jones & Allen, 1997). By extension, only some of the functions of the BIS may be related to relatively greater right frontal brain activity, which would suggest that the ability to identify a relationship between the BIS and relative right frontal brain activity may be sample or situation dependent.

An additional complexity in assessing the relationship between self-report BIS scores and frontal brain asymmetry stems from a lack of data regarding the relationship between self-reported BIS scores and inhibition *behaviors* (e.g. interrupting ongoing actions, experiencing heightened arousal and attention). By extension, there are also no data addressing the relationship of frontal brain activity to these same behaviors. Carver and White's (1994) BIS/BAS scales likely tap, at least in part, a trait propensity to engage in behaviors motivated by the BIS, via a heightened sensitivity to threat cues (although the degree to which the scales actually tap this sensitivity has been questioned—see Heubeck, Wilkinson & Cologon, 1998). The construct validity of the BIS, as measured by the BIS scale, would be enhanced by an examination of the extent to which BIS scores predict behaviors in humans analogous to those thought to signify BIS activity in animals (cf. Gray & McNaughton, 2000).

Methodological Considerations

There exists a methodological variation between the study of Sutton and Davidson (1997), on the one hand, and the present study and that of Harmon-Jones and Allen (1997), on the other. This methodological variation may be relevant to the notion that sample- or situation-specific factors may influence the ability to find a relationship between the BIS and frontal brain asymmetry. Sutton and Davidson based their analysis on EEG and self-report data aggregated across two assessment sessions, which would tend to provide a better estimate of trait variance, and minimize occasion-specific fluctuations (see also Coan & Allen, in press; Hagemann, Naumann, Thayer, & Bartussek, 2002). It remains an empirical question whether this aggregation accounts for Sutton and Davidson's (1997) finding of a relationship between the BIS and anterior brain asymmetry. It seems likely, however, given the statistical trend reported here, that aggregation may be an important consideration in detecting an EEG asymmetry/BIS relationship. On the other hand, it is clear that the relationship between anterior brain asymmetry and the BAS is sufficiently robust to identify with a single occasion of measurement.

A second consideration involves the power of each study to detect an effect. Sutton and Davidson examined 46 participants, Harmon-Jones and Allen examined 37, and the present study examined 32. One might question whether the present study had sufficient power to uncover an effect. However, the effect size of the statistical trend between frontal EEG asymmetry and the BIS reported here was less than a third of the size of the comparable effect reported by Sutton and Davidson, suggesting that power alone is an unlikely candidate for the difference between the two studies.

Clues from Emotion Research

Just as the empirical basis of Davidson's withdrawal construct involves studies of emotion, further refinement of Gray's BIS construct may derive from similar investigations. Gray has asserted that the BIS, when manifest, reveals itself emotionally as anxiety (Gray, 1994). Initially, this might suggest a parallel to the diathesis tapped by a relative right frontal activity pattern such as that reported by Sutton and Davidson (1997). Anxiety, however, has had an inconsistent history of frontal hemispheric specificity on the one hand, and caudal specificity within right hemisphere activity on the other (see Heller & Nitscke, 1998). Heller, Nitschke, Etienne, and Miller (1997) have conceptualized anxiety as being comprised of two distinct though related processes, anxious apprehension and anxious arousal, which are manifest in EEG recordings as relatively greater *left frontal* activity and relatively greater *right parietal* activity, respectively (Heller et al., 1997). Despite data supportive of this model (Heller et al., 1997), others (e.g., Davidson et al., 2000; Wiedemann et al., 1999) have found that anxiety corresponds to relatively greater *right frontal* activity compared to controls. Heller and Nitschke (1998) have argued that this discrepancy is attributable to affective valence, which, they argue, is implicated in anterior cortical regions in ways that apprehension and arousal are not (see also Heller, 1990). Thus, according the Heller and colleagues, anxiety can be represented cortically either left frontally, right frontally, or right parietally, depending on the relative presence or absence of apprehension, arousal, and negative affective valence. To the extent that behavioral in-hibition is related to anxiety—as Gray has argued—behavioral inhibition may manifest itself *cortically* similarly to anxiety, further suggesting the sample and/or situation specificity of its relationship to relatively greater right frontal activity.

Thus, the BIS may not be neatly subsumed under the approach/withdrawal model. The extent to which it resembles the withdrawal construct in terms of cortical asymmetries may correspond to the extent to which both the BIS and Davidson's withdrawal construct correspond to aspects of anxiety. A study of different expressions of anxious apprehension and anxious arousal in high- and low-BIS subjects may assist in clarifying these relationships and lead to greater clarity on the nature of the as yet relatively ephemeral relationship between frontal brain asymmetry and the BIS.

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