Research Article

PREFRONTAL BRAIN ASYMMETRY: A Biological Substrate of the Behavioral Approach and Inhibition Systems

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Abstract—*Resting anterior brain electrical activity, self-report measures of Behavioral Approach and Inhibition System (BAS and BIS) strength, and general levels of positive and negative affect (PA and NA) were collected from 46 unselected undergraduates on two separate occasions. Electroencephalogram (EEG) measures of prefrontal asymmetry and the self-report measures showed excellent internal consistency reliability and adequate test-retest stability. Aggregate measures across the two assessments were computed for all indices. Subjects with greater relative left prefrontal activation reported higher levels of BAS strength, whereas those with greater relative right prefrontal activation reported higher levels of BIS strength. Prefrontal EEG asymmetry accounted for more than 25% of the variance in the self-report measure of relative BAS-BIS strength. Prefrontal EEG, however, was not significantly correlated with PA or NA, or the relative strength of PA versus NA. Posterior asymmetry was unrelated to the self-report measures.*

Numerous investigations of adult personality structure have converged on a few broad dimensions of personality (e.g., Cloninger, 1987; Costa & McCrae, 1988; Eysenck, 1991; Goldberg, 1990; Tellegen, 1985; Zuckerman, 1994a). Descriptive dimensions related to motivation or affect are central to many of these models. Often, these dimensions can be understood in terms of individual differences in self-reported reactions to incentives and threats. In response to incentives, individuals appear to differ in general tendencies to experience positive affect or motivation (e.g., enthusiastic, lively) and to approach or engage appetitive stimuli. In response to threats, individuals seem to differ in general tendencies to experience negative affect or motivation (e.g., distressed, anxious) and to inhibit behavior or withdraw from aversive stimuli.

One major limitation of these studies is that emerging dimensions are based solely on analyses of responses to self-report measures in which adjectives or descriptive sentences are used to prompt responses using true/false or Likert scales. A number of proposals have attempted to move investigations of personality structure beyond the self-report domain by assigning a neurobiological basis to particular broad personality dimensions (e.g., Cloninger, 1994; Eysenck, 1991; Gray, 1994; Rothbart, Derryberry, & Posner, 1994; Zuckerman, 1994b). Yet there are few studies that have directly examined relations between specific self-report measures of broad personality dimensions and central nervous system indicators of putative systems underlying such individual differences, and most of those studies have relied on gross indicators of cortical arousal (for reviews, see, Eysenck, 1991; Gale, 1986) or systemic differences in neurotransmitter levels or reactivity (e.g., Depue, Luciana, Arbisi, Collins, & Leon, 1994). The present study investigated relations between self-report and regional electrophysiological measures purportedly indexing two broad, motivation-oriented dimensions of personality.

THE BEHAVIORAL APPROACH AND INHIBITION SYSTEMS

Gray (see 1994, for a recent review) has proposed the existence of two broad hypothetical systems that underlie learning and affect, the Behavioral Approach System[1] (BAS) and the Behavioral Inhibition System (BIS). The BAS is responsible for guiding behavior in response to incentives. This requires organization of limited resources and execution of sequential behaviors (e.g., approach) to attain the desired stimulus. The BIS is responsible for guiding behavior in response to threats and novel stimuli. This requires organization of limited resources and execution of behaviors leading to rejection or removal (e.g., withdrawal) of the undesirable stimulus, with an initial reaction of behavioral inhibition. On the basis of animal learning studies, Gray has described the underlying neurophysiological bases of these two systems, focusing mostly on subcortical contributions. Gray (e.g., 1981) has also proposed that individual differences in characteristics of the systems are related to primary descriptive dimensions of personality. For example, individuals with a relatively strong BAS (more sensitive and responsive to incentives) are more likely to be extraverted and impulsive. Individuals with a relatively strong BIS (more sensitive and responsive to threats) are more likely to be neurotic and anxious.

Recently, Carver and White (1994) developed the BIS/BAS scales, a self-report measure to assess individual differences in general strength of the BAS and BIS. In general, the BAS scale assesses the tendency to experience strong positive affect or behavioral approach when specific goal-oriented situations are encountered. The BIS scale assesses the tendency to experience strong negative affect or behavioral inhibition when perceived threats are encountered. Carver and White demonstrated that these measures exhibited high internal consistency and adequate test-retest reliability over an 8-week period. They also showed that the BIS/BAS scales were moderately correlated with other

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1. Fowles (1980) has labeled this the Behavioral Activation System, which has the same acronym of BAS. Carver and White (1994) also used the label Behavioral Activation System.

pertinent measures (e.g., extraversion and dispositional positive affect; trait anxiety and dispositional negative affect). Most important, the BIS/BAS scales predicted self-reported affective responses to a laboratory incentive and a threat, respectively, whereas other pertinent personality measures did not.

APPROACH, WITHDRAWAL, AND ANTERIOR BRAIN ASYMMETRY

Over the past decade, our laboratory has pursued a research program aimed at characterizing the central nervous system substrates of fundamental dimensions of affect and affective style. Emphasis has been placed on behavioral approach (and associated positive affect), behavioral withdrawal or inhibition (and associated negative affect), and the asymmetric relations of these fundamental dimensions of behavior and affect with activity in anterior cortical regions (see Davidson, 1994, 1995a, for recent reviews). Clinical and laboratory observations suggest that left prefrontal cortex is a biological substrate of approach behavior and positive affect, whereas right prefrontal cortex is a biological substrate of withdrawal behavior, behavioral inhibition, and negative affect. More specifically, clinical reports have shown that patients with damage to left prefrontal cortex or left caudate (which projects to the prefrontal cortex) are more likely than patients with damage to other brain regions to exhibit depressive symptomatology (see Robinson & Downhill, 1995, for a review). Lesions of these brain regions may result in a deficit in approach behavior, which, when combined with requisite negative life events, culminates in depressive symptomatology (Davidson, 1993). In the laboratory, affect has been manipulated using film clips (Davidson, Ekman, Saron, Senulis, & Friesen, 1990), monetary reward and punishment (Sobotka, Davidson, & Senulis, 1992), tastes differing in hedonic valence (Fox & Davidson, 1986), and preparation for giving a speech (Davidson, Marshall, Tomarken, & Henriques, 1996) while brain electrical activity was measured from multiple scalp sites. These manipulations systematically changed the asymmetry of electrical activity in anterior, but not posterior, scalp regions. Pleasant film clips, pleasant tastes, and monetary incentive all increased left-sided anterior activation, whereas unpleasant film clips, unpleasant tastes, threat of monetary loss, and preparation for giving a speech increased right-sided anterior activation (the latter among social phobics only).

Laboratory studies also have shown that stable individual differences in the level of activity of these circuits are related to personality, temperament, and depressive symptomatology. Tomarken, Davidson, Wheeler, and Kinney (1992) showed that individual differences in baseline (resting) electroencephalogram (EEG) asymmetry from these scalp regions are stable over time (3 weeks) and exhibit excellent internal consistency reliability, which strongly suggests that these measures index a traitlike construct. Furthermore, several studies have established that such individual differences in anterior brain asymmetry are associated with dispositional positive and negative affect (Tomarken, Davidson, Wheeler, & Doss, 1992), subjective reactions to pleasant and unpleasant film clips (Wheeler, Davidson, & Tomarken, 1993), repressive-defensive coping style (Tomarken & Davidson, 1994), childhood temperament (Davidson, 1992), affective disorder diagnosis (e.g., Henriques & Davidson, 1991), and immune function (Kang et al., 1991). Moreover, similar stable individual differences in prefrontal activation were observed in rhesus monkeys, and these differences were related to indices of temperament (Davidson, Kalin, & Shelton, 1993).

This study assessed relations between a self-report and a biological measure of the strength of the approach and inhibition (withdrawal) systems. As noted, previous studies have assessed relations between self-report dimensions of personality and anterior EEG asymmetry. However, this study is of unique interest because of the manifest similarity in the description of Gray's (e.g., 1994) BAS and BIS, and Davidson's (e.g., 1994) approach and withdrawal (inhibition) systems, respectively. More specifically, relations between resting EEG measures of prefrontal activation and Carver and White's (1994) measures of BAS and BIS strength were assessed. In addition, the general version of the Positive and Negative Affect Schedule (PANAS; Watson, Clark, & Tellegen, 1988) was included to examine discriminant validity by comparing relations between the EEG measures and two different self-report measures—the BIS/BAS scales, with the emphasis on reactions to stimuli, and the PANAS, with the emphasis on levels of dispositional affect. Furthermore, EEG and self-report measures were collected twice in order to assess relations among aggregated, more stable indices of the personality dimensions. We predicted that subjects with relatively greater left-sided prefrontal activity would have higher BAS scores, whereas subjects with relatively greater right-sided prefrontal activity would have higher BIS scores. We expected that these relations would be more robust than those between anterior EEG asymmetry and scores of dispositional positive and negative affect as measured by the PANAS.

METHOD

Participants

Forty-six (23 female) volunteers received course credit for initial participation in the two baseline (resting) EEG sessions in the fall 1994 semester and $25 for participation in two non-EEG sessions in the spring 1995 semester. Subjects were not selected for any self-report characteristic. Twelve additional volunteers participated in the two EEG sessions, but chose not to participate in the non-EEG sessions. Subjects were 18- to 22-year-old, right-handed (scores ≥11 on the Chapman Handedness Inventory; Chapman & Chapman, 1987) native English speakers with no reported history of psychiatric disorder, neurological disorder, or brain trauma. All participants provided written informed consent prior to the experiment.

Procedure

Each subject volunteered by signing up in a folder amid myriad folders for the numerous experiments offered to introductory psychology students for earning extra credit. The volunteer was then contacted via telephone for screening purposes. Screening included a brief description of the EEG sessions, the handedness inventory, and questions concerning medical and psychiatric history.

Each subject participated individually in the first baseline EEG session between the 3rd and 6th weeks of the fall 1994 semester. Electrodes were placed and checked within the first 50 min of the subject's arrival. While the experimenter monitored the recording equipment from an adjacent room, computer instructions led the subject through a series of eight 1-min baselines during which EEG was recorded while the subject sat quietly with eyes opened and closed in counterbalanced trials. The eight baselines were usually completed in less than 15 min. Following the removal of electrodes, the subject completed a set of self-report inventories, including the general version of the PANAS. The second EEG session was completed exactly 6 weeks later. It was identical to the first session with two exceptions: A different counterbalanced order of eyes-opened and eyes-closed trials was used, and the BIS/BAS scales (Carver & White, 1994) were administered at this session, in place of the PANAS.

Approximately 3 months following participation in the second EEG session, each subject was invited to participate in a two-session study during which a battery of cognitive and behavioral tasks was administered. The second non-EEG session was completed between 4 and 6 months following the second baseline EEG session. Near the end of this 2-hr session, the subject completed the PANAS and BIS/BAS scales for a second time.

Data Reduction and Analysis

EEGs from 29 sites (13 homologous pairs and 3 midline sites) of the 10-20 electrode system were recorded using a Lycra stretchable cap (Electro-Cap International, Inc., Eaton, Ohio) positioned according to standard anatomical landmarks. All electrode impedances were less than 5,000 ohms, and impedances for homologous sites were within 2,000 ohms. All EEG signals were referenced to an electrode placed on the left ear lobe (A1). An electrode was also placed on the right ear lobe (A2, referenced to A1) so that a derived averaged-ears reference could be used in analyses. For the purposes of artifact scoring, vertical and horizontal eye movements (electro-oculograms) were also recorded. Electrode pairs were placed at the supra- and suborbit of one eye (randomly selected), and at the external canthi of each eye.

EEGs were amplified with Grass Model 12 Neurodata System amplifiers after passing through Model 12A5 preamplifiers with bandpass filters set at 1 and 300 Hz and the 60-Hz notch filter in, and passing through antialiasing, low-pass, 36-dB/octave rolloff filters set at 200 Hz (MF6, National Semiconductor Corp., Santa Clara, California). Electro-oculograms were processed in a similar manner, with the exception that there was no antialiasing filtering and amplification was occasionally lowered to 20,000 ohms. All EEG and electro-oculogram signals were digitized at 500 Hz using SnapStream (HEM Data Corp., Springfield, Michigan) and a 486 DX2-66 computer.

Digitized EEG signals were calibrated using 25-μV and 50-μV 10-Hz signals recorded immediately before and after each session. These signals were visually reviewed off-line by a trained assistant. Portions of each 1-min baseline containing eye movement, muscle movement, or other sources of artifact were removed prior to further analysis. The designation of artifact in any one channel resulted in the removal of data in all channels to ensure that data preserved in all channels were derived from the identical time periods. Then, 1.024-s chunks of artifact-free EEG were used for spectral analysis. If fewer than 10 chunks of artifact-free data were available in a given 1-min baseline, the baseline was dropped from further processing and analysis (1.6% of baselines).

The derived averaged-ears reference was used for all further data reduction. Chunks of artifact-free EEG were extracted through a Hamming window in order to reduce spurious estimates of spectral power. Adjacent chunks were overlapped 50% in order to minimize the loss of data due to Hamming window extraction. For each chunk, a Fast Hartley Transform (Bracewell, 1984) was used to derive estimates of spectral power (μV^2) in different 1-Hz frequency bins for each electrode site.[2] Spectral power values were then averaged across all chunks within a single baseline. Power values were then converted to power density values (μV^2/Hz) for the standard EEG bands. Analyses focused on the alpha band (8–13 Hz) because previous data indicated that power in the alpha band is inversely related to activation (e.g., Shagass, 1972) and is more strongly related to behavior than power in other frequency bands (Davidson, Chapman, Chapman, & Henriques, 1990).

Power density values were normalized via log-transformation. An asymmetry score was calculated for each of the 13 homologous electrode pairs by subtracting the log-transformed power density value in the alpha band for the left site from that for the right site (e.g., log F4 − log F3).[3] Positive asymmetry scores reflect greater left-side activation (greater alpha band power density on right than on left). In order to assess internal consistency reliability, we calculated an asymmetry score for each 1-min baseline. Weighted averages (weighted by the number of artifact-free chunks in a trial) across the eight 1-min baseline periods within Sessions 1 and 2 were calculated in order to assess test-retest reliability. A simple mean based on weighted averages for Sessions 1 and 2 was calculated as the final, aggregate estimate of EEG asymmetry used to assess relations with the self-report measures.

Carver and White's (1994) 24-item BIS/BAS scales inventory was used to measure strengths of the BIS and BAS. Scores for the 13-item BAS scale and 7-item BIS scale were calculated following Carver and White (i.e., summing 4-point Likert scale responses). In order to obtain a self-report metric conceptually similar to EEG asymmetry (i.e., relative strength), we calculated a BAS-BIS difference score by subtracting the z-transformed BIS scale score from the z-transformed BAS scale score. Positive BAS-BIS difference scores reflect relatively greater BAS activity. The general version of the 20-item PANAS (Watson et al., 1988) was used to measure self-reported dispositional levels of positive affect (PA) and negative affect (NA). The PA and NA measures were calculated following Watson et al. (1988). As with the BIS/BAS scales, a PA-NA difference score was calculated by subtracting the z-transformed NA score from the z-transformed PA score. For assessment of relations among the various measures,

2. The Fast Hartley Transform method of spectral analysis is conceptually analogous to the Fast Fourier Transform, provides identical output, and is computationally more efficient.

3. Asymmetry scores are used because they can control for nonneurogenic sources of individual differences (e.g., skull thickness) in power density values (see Wheeler et al., 1993, for further details).

self-report scores were averaged across the two administrations of each inventory. Differences between various dependent correlations (e.g., BAS-BIS difference score and mid-frontal asymmetry vs. PA-NA difference score and mid-frontal asymmetry) were assessed using the technique described by Cohen and Cohen (1983, p. 57).

RESULTS

Table 1 presents descriptive statistics for the self-report measures. Internal consistency reliability as indexed by Cronbach's coefficient alpha (1951) was high for all self-report measures. Intraclass correlations were used to assess the test-retest stability of the self-report scores, including the derived BAS-BIS and PA-NA difference scores. The two administrations of the PANAS and of the BIS/BAS scales were separated, on average, by 6.5 and 5 months, respectively. In general, the difference scores exhibited higher test-retest stability than did the scale scores. Furthermore, the test-retest stability of PA was adequate, but relatively low. The correlation between PA and NA scores was significant ($r = -.34$, $p = .02$). The correlation between BAS and BIS scores was not significant ($r = -.17$, $p > .26$). Correlations between BIS and NA scores ($r = .37$) and between BAS-BIS and PA-NA difference scores ($r = .52$) were significant ($ps < .02$). The correlation between BAS and PA scores was not significant ($r = .23$, $p > .11$).

The average baseline EEG asymmetry score was near zero, ranging from −0.02 (mid-centroparietal sites, CP3 and CP4) to 0.18 (posterior temporal sites, T5 and T6). Standard deviations

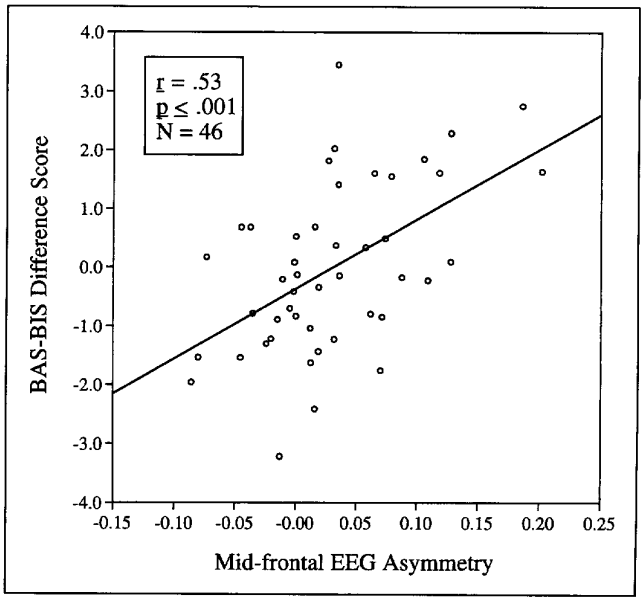

Fig. 1. Scatter plot of the correlation between mid-frontal (F3 and F4) electroencephalogram (EEG) asymmetry and BAS-BIS difference scores (score for Behavioral Approach System, BAS, minus score for Behavioral Inhibition System, BIS). Higher EEG asymmetry scores reflect greater relative left-frontal activation. Higher BAS-BIS difference scores reflect greater relative BAS activity.

Table 1. *Descriptive statistics for the self-report measures*

Measure	Mean	*SD*	Alpha	Test-retest stability
Behavioral Approach Scale (range: 13–52)				
Fall 1994	42.1	4.8	.83	
Spring 1995	42.0	5.6	.87	.72
Behavioral Inhibition Scale (range: 7–28)				
Fall 1994	19.4	3.4	.73	
Spring 1995	20.1	3.3	.78	.68
BAS-BIS difference (of *z* scores)				
Fall 1994	−0.01	1.53	—	
Spring 1995	−0.02	1.50	—	.81
Positive Affect (range: 10–50)				
Fall 1994	34.2	6.6	.90	
Spring 1995	35.4	4.4	.75	.45
Negative Affect (range: 10–50)				
Fall 1994	17.2	5.1	.87	
Spring 1995	18.5	5.7	.87	.57
PA-NA difference (of *z* scores)				
Fall 1994	0.04	1.48	—	
Spring 1995	−0.02	1.68	—	.69

Note. Alpha is Cronbach's (1951) coefficient alpha; test-retest stability is the intraclass correlation of the fall 1994 and spring 1995 assessment; BAS-BIS difference is the *z*-transformed Behavioral Activation score minus the *z*-transformed Behavioral Inhibition score (positive values represent relatively greater Behavioral Activation); PA-NA difference is the *z*-transformed Positive Affect score minus the *z*-transformed Negative Affect score (positive values represent relatively greater Positive Affect).

ranged from 0.05 (frontal pole sites, FP1 and FP2) to 0.35 (posterior temporal sites). Baseline EEG asymmetry was also analyzed for internal consistency and test-retest reliability. The average coefficient alpha across the 13 asymmetry measures and across the first and second assessment of baseline EEG was high at .87. The average intraclass correlation (6 weeks between sessions) across the 13 asymmetry measures was modest at .57.

As predicted, subjects with greater left-sided mid-frontal (F3 and F4) asymmetry had higher BAS scores ($r = .40$, $p < .01$), whereas those with greater right-sided mid-frontal asymmetry had higher BIS scores ($r = -.41$, $p < .01$). The difference between these dependent correlations was significant, $t(43) = 4.04$, $p < .001$. The correlation between the BAS-BIS difference score and mid-frontal EEG asymmetry was .53 ($p < .001$). Figure 1 displays a scatter plot depicting this relation.

Figure 2 presents a topographic map of the distribution of correlations between EEG asymmetry and the BAS-BIS difference score. This map was created by taking the correlations among the BAS-BIS difference score and the 13 asymmetry scores, interpolating among them, color-coding the output, and displaying the resulting map on a left lateral head view. As can be seen, the relation between EEG asymmetry and the BAS-BIS difference score is specific to anterior brain regions. For example, the correlation between the BAS-BIS difference score and EEG asymmetry was .26 ($p < .08$) at the central scalp sites (C3 and C4) and was .03 ($p > .80$) at the parietal scalp sites (P3 and P4). Furthermore, the difference between the correlation of the BAS-BIS difference score with mid-frontal asymmetry versus the correlation of the BAS-BIS difference score with parietal asymmetry was significant, $t(43) = 2.79$, $p < .01$, thus underscoring the specificity of the relation to anterior brain regions.

Unlike the correlations with the BIS/BAS scales measures, the correlations between mid-frontal asymmetry and PA ($r = .06$), NA ($r = -.20$), and the PA-NA difference score ($r = .16$) were all nonsignificant ($ps > .18$). Furthermore, the correlation between the BAS-BIS difference score and mid-frontal asymmetry was significantly greater than the correlation between the PA-NA difference score and mid-frontal asymmetry, $t(43) = 2.87$, $p < .01$, indicating a significantly more robust prediction by frontal EEG asymmetry of the BAS-BIS difference score than the PA-NA difference score.

DISCUSSION

This study demonstrated that baseline prefrontal activation, as indexed by EEG alpha power asymmetry, is related to the strength of Gray's (e.g., 1994) BAS and BIS as reflected in Carver and White's (1994) BIS/BAS scales. In addition, prefrontal EEG asymmetry was correlated with the BAS-BIS difference score, a

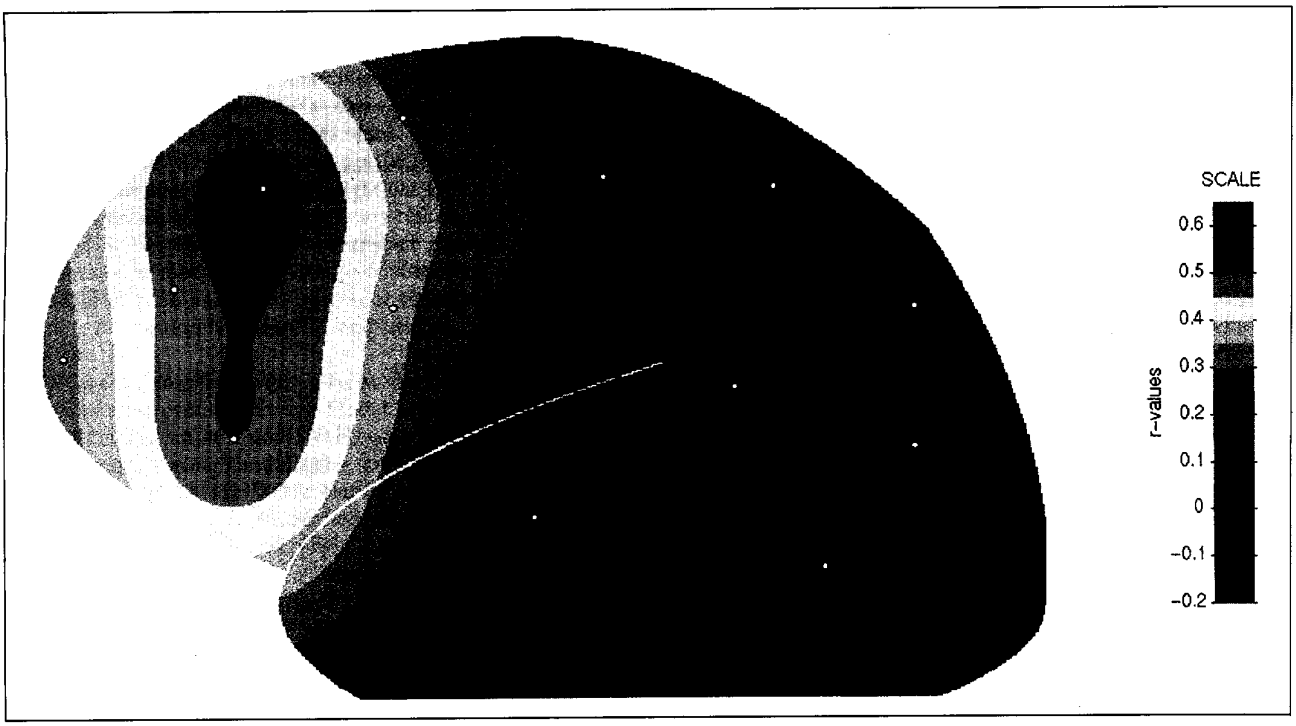

Fig. 2. Topographic map of the relation (Pearson correlation coefficient) between resting electroencephalogram asymmetry (log right minus log left alpha band power density) and the BAS-BIS difference score (z-transformed score for Behavioral Approach System minus z-transformed score for Behavioral Inhibition System). The asymmetry score for each homologous electrode pair (represented by small circles) was correlated with the BAS-BIS difference score. These correlations were used to generate a spline-interpolated map across a lateral view of the head. This map is used for display purposes only. All inferential statistics are based on actual measured values at specific scalp electrode sites.

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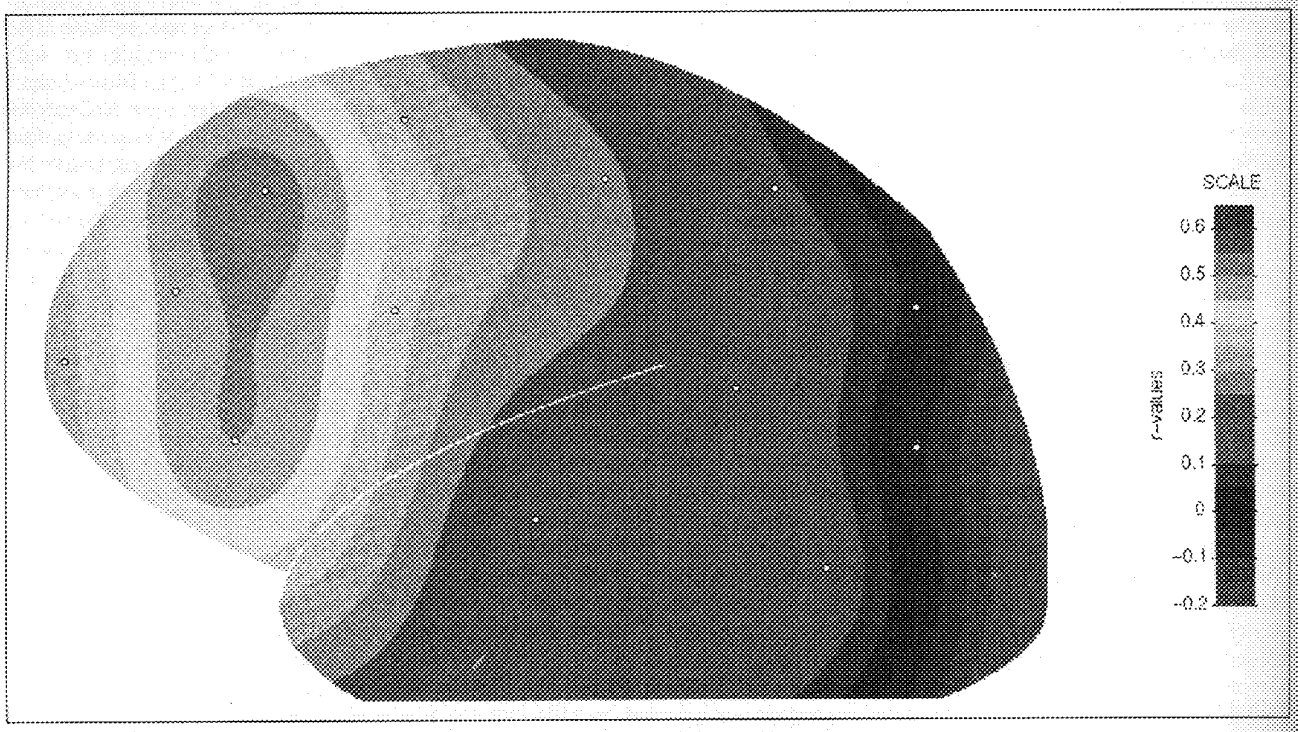

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measure of the relative strength of the BAS over the BIS. Moreover, these relations were specific to anterior scalp regions. Correlations between posterior EEG asymmetry measures (extracted from identical points in time) and the BAS-BIS difference score were not significant. These findings underscore the importance of approaches that examine the topographic patterning of brain activity rather than, following the more traditional approach, examining differences in "cortical arousal" associated with different personality types (for reviews, see Eysenck, 1991; Gale, 1986).

Discriminant validity was established by showing that our measures of prefrontal asymmetry better predicted the BAS-BIS construct than the PA-NA construct operationalized by scores on the PANAS (Watson et al., 1988). Tomarken et al. (1992) previously demonstrated a relation between dispositional positive and negative affect and anterior EEG asymmetry using subjects who exhibited extreme left or right mid-frontal EEG asymmetry. The findings from the present study, however, are not inconsistent with those earlier results. As reported in Table 2 of Tomarken et al., unselected subjects exhibited a .22 correlation between mid-frontal asymmetry and the PA-NA difference score. This correlation was not significant and is similar to the .16 correlation found in this study. Had a much larger number of subjects participated in the present study, subjects with extreme left and right mid-frontal EEG asymmetry could have been selected for a comparable analysis.

Gray's theorizing on the biological substrates of the BAS and BIS has featured subcortical structures, in large part because of the empirical sources of Gray's conjectures, which largely derive from animal learning studies. Though he has acknowledged the potentially important role of neocortex in these motivational systems (Gray, 1982), this topic has not received attention in the empirical literature. In humans, it is likely that the neocortical components of these systems are more extensive and influential. Davidson (1994, 1995a) has speculated that left prefrontal cortex is a biological substrate of approach behavior and "pre-goal attainment positive affect" (e.g., eagerness) because it facilitates representation of desired goal states in the absence of explicit sensory cues, thus guiding behavior toward the acquisition of these goals. We think that individuals with tonically more active left prefrontal regions are, in turn, more likely to organize limited resources in support of goal-approaching behaviors (i.e., BAS activity). This predisposition may lead these individuals to experience positive affect more frequently and intensely than those individuals with tonically less active left prefrontal regions (e.g., Wheeler et al., 1993). Similarly, these individuals may be more likely to exhibit a repressive-defensive coping style when faced with conditions that would tend to elicit negative affect (Tomarken & Davidson, 1994). Right prefrontal cortex may be a biological substrate of behavioral inhibition-withdrawal and negative affect (e.g., anxiety) because it mediates vigilant attention and alerting (see Posner, 1995, for a review). A variety of studies have demonstrated that state and trait anxiety are characterized by heightened attention toward threat-related stimuli (for reviews, see, McNally, in press; Williams, Watts, MacLeod, & Mathews, 1988). Therefore, individuals with tonically active right prefrontal regions may be predisposed to become vigilant for threat-related stimuli, concurrently inhibiting behavior, organizing resources for behavioral withdrawal, and experiencing negative affect (i.e., BIS activity).

Whereas the EEG measures used in this and comparable studies are noninvasive, are relatively inexpensive, and have good temporal resolution, they also have two notable disadvantages. First, they have relatively poor spatial resolution, preventing the definitive identification of the intracranial sources of scalp-recorded brain electrical activity. Second, the measures primarily reflect activity in cortex. EEG measures do have their place and can be significantly improved by increasing the spatial density of electrode arrays (e.g., Tucker, 1993); however, they will always be somewhat limited in the range of brain activity that can be realistically sampled. In light of these limitations, we recently have used functional magnetic resonance imaging and positron emission tomography to examine (with considerably greater spatial precision) regional brain function underlying different components of affect and affective style (e.g., Davidson, 1995b).

Two major extensions of this work are needed. First, we need to move beyond self-report measures in examining the nomological network of associations that characterize appetitive and aversive motivation systems. To do so, we currently are exploring relations between prefrontal activity and aversive conditioning, affective reactions to appetitive and aversive pictures, information processing biases for pleasant and unpleasant linguistic stimuli, and motivated behavior in a simple laboratory task. Second, the corpus of related, replicated findings on relations between prefrontal EEG activity and self-report, behavioral, and biological measures that reflect positive and negative emotional reactivity (see Davidson, 1995a, for review) raises the prospect of identifying or categorizing subjects not on the basis of existing dimensions, many of which have been inherited from 19th-century theorizing (e.g., introversion/extraversion), but rather on the basis of baseline (resting) prefrontal activation. Investigators can then elucidate the constellation of characteristics associated with these neurobiological dimensions of personality. Indeed, this is precisely the approach our laboratory has adopted in a number of recent studies (e.g., Kang et al., 1991; Wheeler et al., 1993).

In conclusion, this study found an association between individual differences in prefrontal activation and strength of Gray's (e.g., 1994) BAS and BIS. The findings support the hypothesized role of lateralized prefrontal systems in approach and withdrawal (or inhibitory) motivational tendencies and underscore the utility of EEG measures for examining the underlying biological substrates of individual differences in personality and vulnerability to psychopathology. We view the approach adopted in this report as one small step in refocusing the study of the proximal biological substrates of personality dimensions.

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