

## Frontal brain asymmetry and emotional reactivity: A biological substrate of affective style

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### Abstract

Individuals differ dramatically in the quality and intensity of their response to affectively evocative stimuli. On the basis of prior theory and research, we hypothesized that these individual differences are related to variation in activation of the left and right frontal brain regions. We recorded baseline brain electrical activity from subjects on two occasions 3 weeks apart. Immediately following the second recording, subjects were exposed to brief positive and negative emotional film clips. For subjects whose frontal asymmetry was stable across the 3-week period, greater left frontal activation was associated with reports of more intense positive affect in response to the positive films, whereas greater right frontal activation was associated with more intense reports of negative affect in response to the negative film clips. The methodological and theoretical implications of these data are discussed.

**Descriptors:** Emotion, Cerebral asymmetry, Laterality, Frontal lobes, EEG, Electrophysiology

Individual differences in affective reactivity are central components of both temperament and personality (e.g., Birns, Barten, & Bridger, 1969; Buss & Plomin, 1975; Goldsmith & Campos, 1982; Rothbart & Derryberry, 1981; Thomas, Chess, & Birch, 1968; Thomas, Chess, Birch, Hertzog, & Korn, 1963). The identification of the underlying biological substrates of such individual differences in affective reactivity would be of considerable importance for both theoretical and pragmatic reasons. This article reports on the association between individual differences in electroencephalographic (EEG) measures of frontal activation asymmetry and affective reactivity. To provide the relevant background for this research, empirical findings and theoretical formulations are reviewed that support the claim that the left and right frontal regions differentially subserve approach-related positive affect and withdrawal-related negative affect, respectively. Individual differences in tonic levels of asymmetric activation in this brain region predict differences in temperament, affective reactivity, and dispositional mood.

### *Approach/Withdrawal, Emotion, and Cerebral Asymmetry*

For at least 100 years, clinicians have noted that unilateral left- and right-sided lesions produce different emotional reactions in patients (e.g., Jackson, 1878). Many reports have appeared on

relations between asymmetric hemispheric activation and emotion in both neurologically impaired psychiatric and normal populations (for reviews, see Davidson, 1992a, in press; Davidson & Tomarken, 1989; Gainotti, 1989; Silberman & Weingartner, 1986). To a number of scholars, the evidence suggests a greater involvement of the left hemisphere, particularly the left anterior regions, in certain positive emotions and a greater involvement of the homologous right hemisphere regions in certain negative emotions (Davidson & Tomarken, 1989; Heller, 1990; Silberman & Weingartner, 1986).

On the basis of the now extensive literature in this area, Davidson (1984a), following Kinsbourne (1978), proposed that the fundamental basis of the anterior affective asymmetry is approach/withdrawal. Specifically, the left frontal region was conceptualized as a major site within a brain circuit mediating approach-related behavior and the corresponding region in the right hemisphere was described as a major site within a circuit mediating withdrawal-related behavior. To the extent that certain positive and negative emotions involve approach and withdrawal behavior, respectively, we hypothesized that these behaviors would be associated with differential asymmetric activation in the frontal region. The various bases upon which our model was formulated have been extensively described in a number of recent reviews (Davidson, 1988a, 1992a, in press; Davidson & Tomarken, 1989).

### *Individual Differences in Anterior Asymmetrical Activation: A Biological Substrate of Affective Style*

Individuals differ dramatically in their affective responses to emotional provocations. One major dimension along which individuals differ is in their propensity to approach or withdraw from novel and unfamiliar situations (Rothbart & Derryberry, 1981). These individual differences in action have been theor-

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ically linked with differences in emotional responsivity (Davidson, 1984a; Davidson & Tomarken, 1989). Those individuals with strong approach tendencies are also characterized as exhibiting intense positive affect in response to appropriate elicitors, whereas those subjects with strong withdrawal tendencies are likely to display intense negative affect in response to elicitors of this type of emotion. Such individual differences appear early in life (Kagan, 1988), show moderate stability over time (Reznick et al., 1986), and are probably in part heritable (Matheny, 1989). We propose that baseline or resting levels of activation in the left and right frontal regions constitute a major substrate of individual differences in affective reactivity. Specifically, those subjects with strong left-sided frontal activation should show more intense positive affect and less intense negative affect in response to elicitors of these dimensions of emotion. Subjects with strong right-sided frontal activation should show the opposite pattern of affective reactivity. We view individual differences in frontal activation asymmetry as a diathesis, which in combination with the requisite situational or contextual factors, will result in the predicted type of emotional response. Frontal asymmetry is thought to be neither sufficient nor necessary for the experience of approach-related positive and withdrawal-related negative emotion. Rather, frontal asymmetry is regarded as a contributory cause of such emotional states. As such, individual differences in frontal asymmetry render some subjects more and other subjects less vulnerable to the elicitors of particular positive and negative emotions. The precise mechanisms that underlie such individual differences and result in differential vulnerability to certain classes of emotion in some subjects and not others is not known and is the subject of current research.

Our view of frontal asymmetry as a diathesis, which culminates in an emotional response only in conjunction with the requisite environmental input, helps to explain many of the apparent anomalies in the neurological literature on laterality and emotion (see Davidson, in press). Some investigators have been puzzled over the failure to find clear changes in emotion in all patients with unilateral lesions or hemi-barbiturization with sodium amytal (e.g., Gainotti, 1989). The fact that only a portion of subjects show changes in emotion with these neurological changes is consistent with our diathesis/stress model. Alterations in the balance of activation between the left and right frontal regions is not in itself sufficient to produce a change in emotion. Such activation changes alter an individual's vulnerability to certain classes of emotion. A change in emotion will only be realized if the change in activation is also accompanied by the requisite situational events or elicitors. In the absence of such elicitors (or in the presence of certain buffering conditions), an individual with markedly asymmetrical frontal activation may not display an extreme positive or negative affective reaction.

The results of several previous studies from our laboratory help to establish individual differences in frontal asymmetry as an important basis for understanding what Davidson (1992b) termed "affective style." Findings on relations between individual differences in frontal asymmetry and emotional reactivity in normal subjects are most relevant to the present study. In several studies, baseline frontal asymmetry predicted reactivity to emotion elicitors in both infants and adults. In 10-month-old infants, Davidson and Fox (1989) reported that those who cried in response to maternal separation had more right and less left frontal activation than babies who did not cry in response to

this stressor. In an earlier, independent study, using a small sample, we found that greater relative right-sided frontal activation at rest predicted more intense negative affect in response to negative film clips (Tomarken, Davidson, & Henriques, 1990). In all of these studies, parietal asymmetry recorded at the same time as the frontal measures was unrelated to indices of affective reactivity.

#### *The Present Study*

The present study incorporated several features that were not present in any of the previous research. EEG measures of frontal asymmetry were obtained in a large group of individuals on two occasions separated by approximately 3 weeks, which allowed examination of relations between asymmetry and affective reactivity for those subjects who displayed stable patterns of frontal asymmetry across this period. In the second session, after the baseline EEG recordings, subjects were exposed to short film clips designed to elicit the emotions of happiness, fear, and disgust. The two negative emotions were chosen to be those most likely to involve withdrawal behavior, and the positive film clips were designed to maximize energetic involvement with and interest in the clip (i.e., approach behavior). Our primary analyses focused on the relation between frontal asymmetry and four aggregate indices derived from self-reports of emotion experienced in response to the film clips: global positive affect (to the positive clips), global negative affect (to the negative clips), affective bias (positive affect to the positive clips minus negative affect to the negative clips), and global reactivity (positive affect to the positive clips plus negative affect to the negative clips). The experiment was designed to test a series of hypotheses concerning the relation between individual differences in frontal asymmetry and measures of affective reactivity provided by these four aggregate indices.

1. Subjects with greater relative left frontal EEG activation at baseline should report more positive affect in response to the positive film clips compared with subjects showing greater relative right-sided activation.
2. Subjects with greater relative right frontal activation (compared with those showing left-sided frontal activation) should report more negative affect in response to the negative film clips.
3. Because the frontal asymmetry index (right minus left activation) reflects the difference in relative activation between brain regions predicted to be differentially involved in approach-related positive affect and withdrawal-related negative affect, this index should best predict the difference in intensities of positive versus negative affect. That is, because the frontal asymmetry index and the affective bias index both reflect the difference between measures that putatively reflect positive and negative affect, they should be strongly correlated.
4. Frontal asymmetry should not significantly predict the sum of global positive and global negative affective responses (global reactivity). This measure provides an index of the overall intensity of experienced emotion, irrespective of valence. Prior research in our laboratory has indicated that the asymmetry of frontal activation is associated only with bias in emotional responding and not with valence-independent levels of intensity.

These hypotheses were predicted to hold specifically for measures of frontal asymmetry and not for asymmetry elsewhere on the scalp. This prediction emerges from previous research that underscored the heterogeneity of functional hemispheric specialization along the rostral-caudal plane and specifically implicated the frontal region in affective regulation.

## Methods

### Subjects

Subjects were 90 right-handed undergraduate women who were recruited from the Introductory Psychology pool at the University of Wisconsin-Madison. Subjects ranged in age from 17 to 21 years. Only female subjects were used because previous studies from our laboratory that demonstrated relations between individual differences in anterior EEG asymmetry and emotional reactivity have used female subjects (Davidson & Fox, 1989; Tomarken et al., 1990). All subjects were right handed as assessed by the Edinburgh Handedness Inventory (Oldfield, 1971).

Because of equipment malfunctions or other technical problems, EEG data from four women were not usable for at least one of the two experimental sessions. Film ratings were unusable for five women. Therefore, a final sample size of 81 was used in most analyses.

### Procedure

There were two experimental sessions approximately 3 weeks apart. Baseline measures of EEG were recorded in both sessions, and women completed questionnaires (Session 1) or watched film clips (Session 2) selected to elicit specific emotional responses. Two sessions were held because of our interest in distinguishing between women with stable and unstable patterns of resting EEG asymmetries and their affective traits.

**Session 1.** Each woman was tested individually. After arriving at the laboratory, women were given instructions about the tasks to be administered at each session and were then asked to sign consent forms.

EEG was recorded during eight 1-min baseline resting periods. Four baselines were administered with eyes open, and four were administered with eyes closed. The eight baselines were administered in two randomly assigned counterbalanced orders. Women were asked to rate their emotional experience before and after the eight rest periods of EEG recording. Emotional experience was rated on seven emotion scales: interest, amusement, happiness, fear, sadness, disgust, and anger. A 0-9 scale was used; 0 indicated the emotion was not being experienced, and 9 indicated the emotion was overwhelming.

A video monitor (Sony 27-inch [61-cm] XBR) controlled by a computer was used to present instructions. Women used a numeric key pad to advance through the instructions at their own pace and to record their emotion ratings. After the baselines were recorded, women filled out several questionnaires that will not be considered in this article (see Tomarken, Davidson, Wheeler, & Doss, 1992a).

**Session 2.** As in Session 1, eight 1-min rest periods of EEG were recorded and emotion ratings collected prior and subsequent to EEG recording.

After the resting periods of EEG recording, women watched nine short (40-125 s) film clips. Two films were selected to elicit positive affect, and seven films were selected to elicit negative

affect. The EEG was also recorded during the film clips and will be the subject of future reports.

### Film Stimuli

The film clips used in this study were taken from movies commercially available on videotape. The film clips chosen, based on ratings of female introductory psychology students, were those that elicited two different intensities of happiness and fear and five different intensities of disgust.<sup>1</sup> Films selected were as affectively pure as possible, that is, they elicited the highest ratings on the target emotion and the lowest ratings on nontarget emotions. Women rated their emotional reaction to each film immediately after seeing it on the seven emotion-rating scales, which were also subsequently used to assess mood during the baselines and emotional response to films during Session 2.

### EEG Recording and Quantification

EEG was recorded using a modified lycra electrode cap (Electro-cap; see Blom & Anneveldt, 1982). The cap was positioned on the woman's head using known anatomical markers. For the first several cohorts of women ( $n = 46$ ) in Session 1, EEG was recorded from four scalp locations: left and right midfrontal (F3, F4) and left and right anterior temporal (T3, T4). For the remainder of women in Session 1<sup>2</sup> and all women in Session 2, EEG was recorded from 10 additional locations: homologous lateral frontal (F7, F8), central (C3, C4), posterior temporal (T5, T6), and parietal (P3, P4) sites and midline frontal (Fz) and parietal (Pz) sites. All placements were referenced to vertex (Cz). Two additional channels were recorded to derive an averaged ears reference: Cz-A1 and Cz-A2 (A1 = left earlobe, A2 = right earlobe; see Davidson [1988b] and Davidson, Chapman, Chapman, & Henriques [1990] for a detailed description of EEG recording and analysis procedures). Electrode impedances were all under 5,000 ohms and the impedances for homologous sites were within 500 ohms. Eye movement (electrooculogram [EOG]) was recorded from the external canthus to the supraorbit of one eye, randomly determined across women, to facilitate artifact editing of the EEG.

EEG and EOG were amplified with a 20-channel Grass Model 12 Neurodata System that had a bandpass of 1-100 Hz, with the 60-Hz notch filter in. All analog signals were passed through active, low-pass Rockland model 424 filters set at 65 Hz with a 24-dB/octave rolloff. The EEG was digitized at the rate of 200 samples/s on a PDP 11/34A minicomputer. Prior to analysis, the EEG was visually edited to remove all portions associated with eye movement (identified from the EOG channel) or other artifact. When an artifact was detected in any channel, data from all channels were removed. Our procedures for visually inspecting and editing data are highly reliable. Interrater reliability of artifact scoring computed on data from 10 women was assessed as the percentage of seconds of agreement over the total duration of EEG per session (480 s); agreement was 95.7%.

A Fast Fourier Transform (FFT) was performed on all artifact-free 2.56-s chunks of data (extracted through overlapping

<sup>1</sup>In future analyses, we will examine brain activity during the presentation of the film clips. We included five levels of disgust to examine relations between frontal asymmetry and intensity of a withdrawal-related negative emotion in a dose-response fashion.

<sup>2</sup>When it was realized that the additional cost, in time, to record from additional sites was relatively minor, the additional sites were added.

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Hamming windows) to derive estimates of spectral power ( $\mu V^2$ ) in different frequency bands. The FFT output was then converted to power density ( $\mu V^2/Hz$ );<sup>3</sup> these values were then log-transformed to normalize the data (Gasser, Bacher, & Mocks, 1982).

The analyses reported in this article focus on measures of power in the alpha band (8–13 Hz) because evidence indicates that power in this band is inversely related to activation (e.g., Davidson, Chapman, Chapman, & Henriques, 1990; Shagass, 1972). Moreover, previous research from our laboratory has consistently demonstrated more robust associations between EEG asymmetry and measures of both emotion and cognition for measures derived from alpha band power than power in any other frequency band (see Davidson, Chapman, et al., 1990).

To derive a measure of resting asymmetry from the baseline trials, we computed a weighted average of log alpha power values across all eight trials, weighting by the amount of artifact-free data available for each individual trial, using the averaged-ears reference. Such a procedure results in the most stable measure of spectral power (Tomarken, Davidson, Wheeler, & Kinney, 1992). The asymmetry metric was computed by subtracting left-sided alpha power from right-sided alpha power (log right minus log left power). Because of the inverse relation between alpha power and activation, positive values on this metric denote left-sided activation and negative values denote right-sided activation.

#### Film Ratings

The major goal of this research was to relate individual differences in frontal asymmetry to emotional experience induced by short film clips. Individuals differ greatly in how they use rating scales; some subjects tend to use the upper ranges of the scale more often than others. Although some of the variance in global ratings may reflect valence-independent affect intensity (e.g., Diener, Larsen, Levine, & Emmons, 1985), at least a portion of the variance is probably related to a global rating bias. Accordingly, for some of the analyses, we computed residualized discrete emotion rating scores by removing that portion of the variance in individual emotion ratings shared with a global rating index. We also examined the relation between frontal asymmetry and the global rating index.

To compute the global rating index, the following procedures were adopted. Across the two positive films, the mean of the three positive emotion ratings (happiness, interest, and amusement) and the mean of the four negative emotion ratings (fear, anger, disgust, and sadness) were obtained. The arithmetic mean of these two values was then determined, thereby correcting for the fact that there were four negative but only three positive emotion ratings. This same procedure was then duplicated for the seven negative films. The arithmetic mean of the values obtained from the positive and negative films was then computed to provide the global rating index, giving equal weight to the positive and negative films and to the positive and negative ratings and correcting for the unequal number of each.

Regressions were performed on each emotion rating for each film where the common variance that the emotion rating shared with the global rating index was removed. The residual value that remained for each emotion rating reflected the rating for

that emotion with the variance associated with a global rating bias and/or generalized affect intensity difference removed.

Composite affect measures were then computed on these residualized values in two steps of aggregation. First, we formed aggregate scores for each of the three positive affect rating scales (interest, happiness, and amusement) by computing means on these scales across both of the films selected to elicit positive affect, resulting in an aggregate score across the two positive films for each of the three discrete positive emotion ratings. The same procedure was then done for the four negative affect rating scales (fear, disgust, anger, and sadness) across the five negative films, resulting in aggregate scores for each of the four discrete negative emotion ratings.

In the next step of this aggregation, we computed means across composite interest, happiness, and amusement film ratings to yield a global positive affect index. A similar procedure was adopted to form a global negative affect index by averaging across the fear, disgust, anger, and sadness ratings.

In addition to the global positive affect index, global negative affect index, and a generalized reactivity index (global positive plus global negative affect), we computed one other index relevant to our experimental hypotheses: the difference between global positive and negative affect (i.e., affective bias).

#### Design and Analysis

Using the measure of asymmetry, we found that the test-retest correlation for frontal (F3/F4) alpha power asymmetry for the entire sample was .66 ( $p < .0001$ ). The magnitude of this correlation indicates that some women had more stable frontal asymmetry than others. Relations between frontal asymmetry and affective reactivity should be more stable for those women who had stable asymmetry (cf. Bem & Allen, 1974); our sample was therefore divided into women who exhibited more vs. less stable frontal asymmetry using the following procedure.<sup>4</sup> EEG asymmetry scores were standardized separately by session. A woman's asymmetry score was considered stable if her standardized score at Session 2 was within  $\pm .33$  standard deviations (SDs) of her standardized score at Session 1. Relations between an aggregate measure of frontal asymmetry (across Sessions 1 and 2) and rating measures were then examined for these stable women ( $n = 26$ ).<sup>5</sup> We also separately examined the relation

<sup>4</sup>The procedure of dividing subjects into stable and unstable groups might produce spurious correlations between the trait index and a criterion measure because of statistical artifact (e.g., Paunonen, 1988). Therefore we computed correlations between each woman's Session 1–Session 2 standard deviation and the aggregate frontal asymmetry score. Both the linear ( $r = .04$ ) and quadratic ( $r = .06$ ) correlations were close to zero. Thus, there was no linear or curvilinear relation between a woman's frontal asymmetry score and the variability of her score from Session 1 to Session 2. We also directly compared the means and variances of the asymmetry scores in the stable and unstable groups. There were no significant differences in the means or variances between the two groups (all  $ps > .32$ ). These findings suggest that any differential relation between frontal asymmetry and our criterion measures for the stable and unstable asymmetry groups was not a function of psychometric artifact.

<sup>5</sup>With the exception of generalized reactivity, no significant relations were found between midfrontal asymmetry (for Session 1 or Session 2 or across Sessions 1 and 2) and the aggregate rating measures for the total sample (all  $ps > .47$ ) or for the unstable women (all  $ps > .10$ ). There was a significant relation between asymmetry across Sessions 1 and 2 and generalized reactivity for the unstable women ( $r = .37, p = .006, n = 55$ ) and for the total sample ( $r = .27, p = .01, n = 81$ ), reflecting a general tendency for women with greater left midfrontal activation to self-report both higher positive and higher negative emotions.

<sup>3</sup>For brevity, the term *power* will be used in place of *power density* in the remainder of this paper.

between Session 1 and Session 2 asymmetry and the rating measures to determine if the earlier measure (obtained approximately 3 weeks prior to film exposure) was as predictive of emotional reactivity as the measure obtained just prior to film exposure. Secondary analyses addressed the question of specificity of the frontal effects by examining the relation between asymmetry in other brain regions and affective reactivity. When significant relations between asymmetry and the aggregate rating measures were found, we decomposed these effects by examining the relations between the asymmetry measure and the separate discrete emotion measures from which the aggregate measures were comprised. Finally, all of the analyses were performed on rating measures both with and without measures of baseline mood partialled out.

## Results

### EEG Asymmetry and Aggregate Measures of Film Reactivity

We hypothesized that stable resting frontal asymmetry would be particularly likely to predict measures of global positive and negative affect and affective bias. Table 1 shows the results of the correlations between each of the four global affect measures and the frontal asymmetry of the stable women at Session 1, at Session 2, and averaged across Sessions 1 and 2 (higher values on the asymmetry index denote greater relative left-sided activation).

We predicted that women with greater relative left-frontal activation during baseline would report more positive affect in response to films selected to elicit positive affect compared with women showing greater relative right-sided activation. Women with greater right-sided activation were predicted to report more negative affect in response to films selected to elicit this type of emotion compared with women showing left-frontal activation. In addition, we predicted that frontal asymmetry would predict the difference between global positive and global negative affect (affective bias). All of these predictions were supported (Table 1). The correlation with the affective bias index indicates that women with greater relative left-sided frontal activation report more positive affect to the positive films and less negative affect to the negative films compared with women showing right-sided frontal activation. The correlation between the generalized reactivity index (overall positive plus negative affect)

**Table 1.** Correlations of Midfrontal EEG Asymmetry with Global Affect Ratings

Global affect	Time 1	Time 2	M, Times 1 & 2
Generalized reactivity	-.07	.04	-.01
Global positive affect	.45*	.45*	.45*
Global negative affect	-.47**	-.50**	-.49**
Affective bias	.56***	.57***	.57***

Note:  $n = 26$ . These correlations are for women with stable Session 1–Session 2 asymmetry; generalized reactivity refers to the sum of global positive and global negative affect; global positive affect refers to the sum of positive affect ratings to positive films; global negative affect refers to the sum of negative affect ratings to negative films; affective bias refers to the difference between global positive affect and global negative affect.

\* $p < .03$ ; \*\* $p < .02$ ; \*\*\* $p < .01$ .

and frontal asymmetry is also presented (Table 1). Frontal asymmetry is unrelated to the overall amount of valence-independent emotion reported.<sup>6</sup>

In light of recent evidence from our laboratory that activation in the anterior temporal region shows reliable asymmetrical shifts in response to certain positive and negative emotion elicitors (Davidson, Ekman, Saron, Senulis, & Friesen, 1990), we examined whether individual differences in baseline anterior temporal asymmetry predicted the four aggregate measures of film reactivity. In contrast to the findings for the frontal leads, correlations between anterior temporal asymmetry and the aggregate film rating measures yielded no significant effects for the group as a whole or for women showing stable or unstable anterior temporal asymmetry (based upon the same .33 *SD* criterion applied to the anterior temporal asymmetry data from Time 1 and Time 2).

To further assess the specificity of midfrontal asymmetry in predicting emotional responses to the films, we computed correlations of stable lateral frontal (F7, F8), central (C3, C4), posterior temporal (T5, T6), and parietal (P3, P4) EEG asymmetry with each woman's global affect rating. Because we only recorded EEG from these additional sites in Session 1 for approximately half of the women, we had only a subset of the data from which to derive stable groups ( $n = 42$ ).<sup>7</sup> Relations between midfrontal and anterior temporal asymmetry and measures of affective reactivity were recomputed for this subgroup. All correlational analyses assessing the effects of anterior temporal, lateral frontal, central, posterior temporal, and parietal asymmetries on aggregate measures of affective reactivity were insignificant (mean  $r$  based on absolute values = .20, range = .02–.48). Although the number of women in the stable midfrontal asymmetry group for these analyses was cut in half ( $n = 13$ ), the relation between individual differences in asymmetry in this region and global positive affect ( $r = .48, p = .10$ ), global negative affect ( $r = -.54, p = .06$ ), and affective bias ( $r = .58, p = .04$ ) remain significant or nearly significant. Only resting asymmetry recorded from the midfrontal region significantly predicted aggregate measures of affective reactivity.

### Frontal Asymmetry and Baseline Mood Ratings

The significant effects of frontal asymmetry on aggregate measures of affective reactivity to the films may be a result of pre-existing differences in mood at the time baseline EEG was recorded. We addressed this issue in two different ways. First we assessed the relation between frontal asymmetry and baseline mood ratings. Baseline mood ratings were residualized as described above for affective ratings to films and aggregated to

<sup>6</sup>We also conducted analyses to assess relations between frontal asymmetry and ratings of discrete positive (e.g., amusement) and negative (e.g., fear) emotional responses to the films. In response to positive films, all three positive emotions were positively correlated with baseline frontal asymmetry, although only the correlation for amusement reached statistical significance ( $r = .45, p < .03$ ). Analyses of the negative emotions aggregated across all negative films indicated that reports of fear, anger, and disgust were all associated with increased relative right frontal activation, although only the correlation for fear reached significance ( $r = -.41, p < .05$ ).

<sup>7</sup>Stable and unstable groups were derived based upon asymmetry data in these other regions using criteria identical to those adopted for the main analyses. A stable pattern of asymmetry in a particular region was defined as a standardized asymmetry score for that region at Time 2 that was within .33 *SD* of the asymmetry score at Time 1.

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form measures of generalized reactivity, global positive affect, global negative affect, and affective bias baseline mood ratings. These aggregate measures from the baseline period were then correlated with frontal asymmetry. There were no significant correlations between baseline mood ratings and frontal asymmetry in any of these analyses (all  $ps > .24$ ).

In addition, we more directly assessed whether frontal asymmetry predicted film ratings even when the variance attributable to baseline mood was statistically removed. Regressions were computed on aggregate rating measures after partialing out the common variance shared with their respective baseline mood rating (i.e., baseline fear was partialled out of the affective rating of fear to a film). These regressions were computed on aggregate Time 1–Time 2 measures. Baseline frontal asymmetry did significantly predict aggregate positive and negative affect and affective bias even when adjusting for baseline mood ratings. The correlations with baseline mood measures statistically removed were virtually identical to the zero-order correlations ( $r = .43, -.50, \text{ and } .57$  for global positive affect, global negative affect, and affective bias, respectively).

#### *Which Hemisphere Accounts for the Significant Relations Between Frontal Asymmetry and Affective Responsivity?*

All the preceding results are based on an asymmetry index that is computed by subtracting the mean log power in a left hemisphere lead from the mean log power in the homologous right hemisphere lead (i.e.,  $\log R - \log L$  power). Although this index provides information about asymmetry per se, it cannot specify which hemisphere is contributing to the effects in question. The obvious solution, to compute correlations between ratings and measures of individual site power, is not straightforward because a major contributor to the absolute power recorded from any given scalp site is skull thickness, in which there are pronounced individual differences (Leissner, Lindholm, & Peterson, 1970). A second important contributor to variance in absolute power at a given site is volume conducted activity from the homologous site. The asymmetry index is a very convenient way of removing the variance associated with these two potential sources of artifact. By taking the difference in power between the hemispheres, the common variance at each site due to skull thickness and volume conduction from the homologous site is removed.

Our laboratory has devised an analytic procedure for computing power at an individual site, with the variance presumably due to variations in skull thickness and volume conduction from the homologous site removed. The procedure uses a hierarchical regression model to predict power in the target electrode location. The first predictor entered into the model is the average power across all 15 scalp electrodes. The second predictor is power from the homologous site. From this equation, the power at the target site is residualized using these two variables as predictors. The activity at the target site remains, following statistical removal of the variance associated with whole head power and power at the homologous site. These measures were computed for left and right midfrontal (F3 and F4) power. Because these analyses required power values from the whole head for their computation, they could be performed only on Session 2 data because EEG data were only recorded from four electrode sites for half the subjects in Session 1.

The results of correlations between residualized alpha power values of the Session 2 EEG data for the stable midfrontal sub-

**Table 2.** Correlations of Residualized Midfrontal EEG Alpha Power with Global Affect Ratings

Global affect	Left (F3)	Right (F4)
Generalized reactivity	-.04	.04
Global positive affect	-.49**	.44*
Global negative affect	.33	-.58***
Affective bias	-.49*	.62****

Note:  $n = 24$ . These correlations are for stable women only; affect measures are the same as those described in Table 1.  
\* $p < .04$ ; \*\* $p < .03$ ; \*\*\* $p < .004$ ; \*\*\*\* $p < .002$ .

jects and aggregate indices of affect are shown in Table 2. Both increased absolute left frontal activation (as reflected by decreased alpha power) and decreased absolute right frontal activation (as reflected by increased alpha power) predicted greater positive affect in response to films selected to elicit positive affect.

The pattern of results for the prediction of the aggregate negative affect variable are different. For this variable, only increased right frontal activation (decreased alpha power) predicted increased negative affect. Left frontal power was not significantly associated with negative affect (see Table 2). Greater relative positive vs. negative affect (i.e., affective bias) was predicted by both increased left and decreased right frontal activation. All of the significant results remained virtually unchanged when baseline mood was partialled out. As expected, residualized power at the midfrontal sites for unstable women did not predict any of the global affect measures (all  $ps > .13, n = 55$ ).<sup>8</sup>

#### Discussion

This experiment evaluated the hypothesis that individual differences in frontal activation asymmetry predict reactivity to emotionally provocative events. In general, the findings from the experiment strongly confirmed our original hypotheses. Women with more relative left-sided frontal activation at rest reported more intense positive affect in response to the positive film clips compared with those showing more relative right-sided frontal activation. In contrast, in response to the negative film clips, women showing more relative right-sided frontal activation at rest reported more intense negative affect than their more left-frontally activated counterparts. The results obtained in this study replicate and extend those recently reported by Tomarken et al. (1990).

These effects were evident only for women in whom the EEG measures of frontal activation asymmetry were stable across the two electrophysiology testing sessions, held 3 weeks apart. These

<sup>8</sup>As for the asymmetry metric, we computed correlations between residualized power at individual left and right hemisphere frontal sites and ratings for each discrete emotion. Amusement was significantly predicted by both increased left frontal ( $r = -.53, p < .009$ ) and decreased right frontal ( $r = .52, p < .01$ ) activation. Interest was significantly predicted only by increased left frontal activation ( $r = -.43, p < .05$ ). In response to the negative clips, the emotions of fear, disgust, and anger were all predicted by individual differences in right, but not left, frontal activation ( $rs$  between  $-.47$  and  $-.50, ps < .03$ ).

results resemble other findings in the personality literature where a number of investigators have reported robust relations between individual differences on a trait dimension and behavior only in subjects for whom the trait was stable (Baumeister & Tice, 1988; Bem & Allen, 1974). Frontal activation asymmetry may be considerably more variable for some subjects than for others. For subjects with variable frontal asymmetry, it may be necessary to aggregate many separate measures (i.e., across different sessions) to obtain an accurate estimate of their true baseline asymmetry. With such increased density of measurement occasions, the effects reported here in the stable women may be demonstrable across an unselected sample.

The effects we observed between frontal asymmetry and self-reports of emotional experience in response to the film clips were independent of mood at baseline. When the variance associated with baseline mood was statistically removed, baseline frontal asymmetry remained as significant a predictor of reactivity to the film clips as it did prior to the removal of this variable.

The relation between individual differences in activation asymmetry and reactivity to the film clips was specific to measures of asymmetry from the midfrontal region. Other evidence on the effects of physically aroused emotion on EEG measures of asymmetry (Davidson, Ekman, Saron, Senulis, & Friesen, 1990) indicates that individual differences in anterior temporal asymmetry might be related to film reactivity in the same direction as the frontal measures. Our data did not support this possibility. Further research is needed to clarify the functional significance of activation asymmetries in these two different cortical regions.

When the new statistical procedures for evaluating activation at an individual electrode location were applied to the present data, we found differences between the positive and negative emotions with respect to which hemisphere accounted for the most variance in the intensity levels of the reported emotions. Both increased left-sided and decreased right-sided frontal activation were correlated with more intense reports of amusement to the positive films. However, only increased left frontal activation was correlated with reports of more intense interest in response to the positive films. Variations in the intensity of reported fear, disgust, and anger in response to the negative films were predicted only by individual differences in right-sided frontal activation. Left-sided activation was not significantly related to reports of any negative emotion.

What do individual differences in frontal asymmetry actually reflect? Davidson has proposed (Davidson, 1992a, in press; Davidson & Tomarken, 1989) that frontal activation asymmetry acts as a diathesis that renders individuals more or less vulnerable to certain positive and negative emotions in response to

the requisite environmental elicitors. According to this model, individual differences in frontal asymmetry are contributory causes of affective reactions. A specific pattern of frontal asymmetry is neither necessary nor sufficient for a particular emotion to be elicited. Thus, an individual may have extreme right-sided frontal activation at baseline but may not show signs of strong negative emotion. However, such a person would be expected to show intense negative affect in response to the requisite elicitor. It might also be possible for a situational elicitor to be so powerful that it would elicit a particular class of emotion in virtually any individual, irrespective of their baseline frontal asymmetry.

The mechanism(s) responsible for rendering an individual more or less vulnerable to specific classes of affective stimuli is not currently known. Individual differences in frontal asymmetry may be related to threshold differences for triggering an affective reactivity. A threshold mechanism would cause a subject with extreme right frontal activation to show a negative affective response to a very low intensity negative affect elicitor. Alternatively, frontal asymmetry may be unrelated to threshold differences but may index differences in a gain parameter. According to such a model, differences among individuals in the intensity of their reaction to a particular elicitor would be due to differences in the gain applied to response processes. Other mechanisms are also plausible. For example, frontal asymmetry may primarily index the recovery function of an affective reaction. According to this mechanism, differences among subjects in the intensity of their affective reaction to an elicitor would be primarily a function of the rapidity with which the emotional response was terminated, once it was triggered. Subjects with right frontal activation may be specifically impaired in their ability to terminate a negative affective response once it has begun. To distinguish among these various alternative mechanisms will require research specifically designed to address the different possibilities.

Individual differences in frontal activation asymmetry appear to offer considerable promise in understanding the dramatic variability in how people respond to emotionally provocative stimuli. Individual differences in frontal asymmetry have already been usefully related to the study of infant temperament (Davidson, Finman, Straus, & Kagan, 1992; Davidson & Fox, 1989), affective disorders (Davidson, 1988a; Henriques & Davidson, 1990, 1991), dispositional mood in normal adults (Tomarken et al., 1992a) and variability in immune function (Kang et al., 1991). On the basis of this accumulating evidence, parsing individual differences on the basis of established measures of brain function may be more effective at "carving nature at its joints" than traditional psychological categories.

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