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Resting Frontal Brain Asymmetry Predicts Affective Responses to Films

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This article assessed whether resting electroenchephalographic (EEG) asymmetry in anterior regions of the brain can predict affective responses to emotion elicitors. Baseline EEG was recorded from 32 female adults, after which Ss viewed film clips preselected to elicit positive or negative affect. Resting alpha power asymmetry in the frontal region significantly predicted self-reported global negative affect in response to clips and predicted the difference between global positive and negative affect. Analyses of discrete emotions revealed a strong relation between frontal asymmetry and fear responses to films. Effects were independent of Ss' mood ratings at the time at which baseline EEG was measured. Resting anterior asymmetry may be a state-independent index of the individual's predisposition to respond affectively.

Differences in the nature, probability, or intensity of affective responses to emotion elicitors are key features of individual differences in temperament (e.g., Buss & Plomin, 1975; Goldsmith & Campos, 1986). Thus, one critical test of a potential biological marker of such individual differences is whether it predicts variations in responsivity to affective stimuli (e.g., Davidson & Tomarken, 1989; Derryberry & Rothbart, 1984). This article reports the results of one such test. In particular, we assessed whether individual differences in patterns of hemispheric activation predict emotional reactions to affective films. Two recent observations about hemispheric asymmetry constitute the theoretical and empirical bases for this research.

The first observation is evidence indicating differential activation of anterior regions of the cerebral hemispheres during the experience or expression of positive and negative emotions. This evidence reveals greater relative activation in right anterior regions during the experience or expression of certain negative emotions, and greater relative left anterior activation during the experience or expression of certain positive emotions. This pattern of differential activation has been found in studies assessing electrophysiological (i.e., electroencephalogram, or EEG) asymmetries in depressives (e.g., Davidson, Schaffer, & Saron, 1985; Perris & Monakhov, 1979), and in normal adults (e.g., Ahern & Schwartz, 1985; Davidson, Ekman, Saron, Senulis, & Friesen, 1990; Tucker, Stenslie, Roth, & Shearer, 1981) and infants (e.g., Davidson & Fox, 1982; Fox & Davidson, 1987) experimentally induced to adopt positive and negative emotions (for reviews, see Davidson & Tomarken, 1989; Leventhal & Tomarken, 1986; Silberman & Weingartner, 1986). These findings are consistent with the results of studies on the emotional sequelae of unilateral brain damage (e.g., Gainotti, 1972; Sackeim et al., 1982). Especially relevant are recent findings by Robinson and his colleagues that indicate that left anterior cortical (Robinson & Benson, 1981; Robinson, Kubos, Starr, Rao, & Price, 1984) and subcortical (Starkstein, Robinson, & Price, 1987) lesions are associated with depressive symptomatology.

Previously, we have theorized that these findings reflect the operation of anterior systems that mediate approach and withdrawal motivation (Davidson, 1984; Davidson & Tomarken, 1989; see also Kinsbourne, 1978). In this view, heightened approach tendencies are associated with relative left anterior activation and heightened withdrawal tendencies are associated with relative right anterior activation.

None of the studies reviewed above has explicitly examined the relation between individual differences in anterior activation and affective reactivity to emotion elicitors. This omission is somewhat surprising in light of a second recent observation about hemispheric asymmetry. Individual difference measures of posterior activation asymmetry are stable over time and predict performance on cognitive tasks. For example, EEG studies have shown that resting asymmetry recorded from posterior sites (e.g., parietal and posterior temporal) has high test-retest stability (*r*s in the .7 to .9 range over the course of 1 to 3 weeks; e.g., Ehrlichman & Wiener, 1979; Morgan, McDonald, & McDonald, 1971) and is significantly correlated with performance on verbal and spatial tasks in a manner consistent with neuro-anatomical specialization of function (e.g., Davidson, Taylor, & Saron, 1979; Glass & Butler, 1977). Similar findings have been obtained in studies assessing the temporal stability and functional significance of individual differences in the asymmetry of cerebral blood flow (e.g., Dabbs & Chou, 1980; Gur & Reivich, 1980).

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Consistent with the results of these physiological investigations are studies conducted by Levy and her colleagues that indicate strong relations between behavioral indicators of hemispheric activation and performance on verbal and nonverbal cognitive tasks (Levy, Heller, Banich, & Burton, 1983). Taken together, these findings support Levy's (1983) distinction between hemispheric *activation* and hemispheric *specialization.* In this view, differences between individuals in the former are "superimposed on a relatively invariant pattern" (Levy, 1983, p. 476) in the latter, and account for individual differences in cognitive performance despite such invariance.

The present study represents an attempt to synthesize the two observations about hemispheric asymmetry noted above. Specifically, we assessed whether resting anterior asymmetry indexes individual differences in the readiness or predisposition to respond affectively. In other words, just as resting EEG asymmetry in posterior sites predicts performance on *verbal and nonverbal* cognitive tasks, does resting asymmetry in anterior sites predict *affective* behavior? One recent finding from our laboratory indicates that this may indeed be the case (Davidson & Fox, 1989). In this study, 10-month-old infants who demonstrated relative right anterior activation during a baseline period were more likely to cry when later separated from their mothers. Conversely, infants who demonstrated relative left anterior activation during the baseline period were likely not to cry in response to maternal separation. Importantly, infants did not differ on measures of emotional expressivity during the baselines themselves. This latter finding suggests that resting anterior asymmetry may be a state-independent marker of the individual's predisposition to respond affectively.

In the present experiment we attempted to extend this finding by assessing whether anterior EEG asymmetry predicts affective reactivity among adult subjects. In addition, we examined more precisely what affective dimensions and discrete emotions are predicted by resting anterior asymmetry. After resting EEG was recorded, two cohorts of subjects were exposed to film clips that elicited several positive (e.g., happiness and amusement) and negative (e.g., fear and disgust) emotions. Pooling across cohorts to ensure adequate statistical power, we assessed the relation between resting measures of anterior and posterior asymmetry and four aggregate indices of subjects' emotional responses to films. We assessed the relation between EEG asymmetry and composite measures for two reasons. First, in general, there is evidence that aggregate indices best represent the individual's general tendencies, and thus tend to yield higher and more stable estimates of relations with individual difference variables (for a review, see Rushton, Brainerd, & Pressley, 1983). Second, prior research indicates the importance of these four affective dimensions.

Two of the composite indices were subjects' global positive and negative affective responses to films. We assessed global positive and negative affect because of a wealth of factor-analytic and related evidence indicating that these two dimensions are independent and account for substantial variance in self-reports of emotion (e.g., Diener & Emmons, 1984; Watson, 1988; Watson & Tellegen, 1985). In addition, we examined the relation between resting asymmetry and the *sum* of subjects' self-reports of positive and negative emotional reactions to films. This index is a measure of generalized reactivity, independent of affective valence. An examination of this issue was warranted by the recent work of Diener, Larsen, and their associates. Their research indicates that individual differences in affective reactivity that are independent of emotional valence can be identified (e.g., Diener, Larsen, Levine, & Emmons, 1985; Larsen, Diener, & Emmons, 1986). That is, in these studies, those individuals who respond most strongly to positive affective stimuli also respond most strongly to negative affective stimuli.

We also examined the relation between resting asymmetry and the *difference* between self-reports of positive affect in response to positive films and negative affect in response to negative films. This measure of what might best be termed *affective valence* also has prior theoretical and empirical support. In particular, one contemporary model of the dimensional basis of emotion posits two primary dimensions, denoted as pleasantness–unpleasantness and arousal (e.g., Russell, 1980, 1983). In fact, these two dimensions are typically the primary ones yielded by factor analyses of mood self-reports before orthogonal rotation to simple structure yields distinct positive and negative factors. In this dimensional scheme, pleasantness–unpleasantness is a bipolar factor that represents the difference between, or relative balance of, positive and negative affect (Watson, 1988). We should add that our generalized reactivity measure corresponds conceptually to the "arousal" dimension. In a broader vein, we note that our use of the affective valence and generalized reactivity measures is consistent with prior evidence that certain basic dimensions of personality or motivation may essentially represent the sum of, or difference between, other dimensions (e.g., Gray, 1981; Gray, Owen, Davis, & Tsaltas, 1983).

Alternatives to dimensional representations of emotion are models that emphasize the importance of discrete emotions such as happiness, fear, and anger (e.g., Ekman & Friesen, 1975; Izard, 1977). For this reason, we conducted additional analyses on specific emotion scales when analyses of aggregate indices yielded significant effects.

Resting EEG asymmetry was assessed in two anterior brain regions (mid-frontal and anterior temporal) and two more posterior regions (central and parietal). The clear majority of EEG evidence for anterior asymmetry for emotions implicates the frontal regions specifically. For this reason, we predicted that increased relative right frontal activation would be associated with greater negative affect in response to negative films. Conversely, we predicted that increased relative left frontal activation would be associated with greater positive affective responses to positive films.

Concerning our predictions for the affective valence and generalized reactivity measures, it is important to note that (a) prior research has indicated that increased left frontal activation is associated with positive affect and that increased right frontal activation is associated with negative affect; and (b) relative left frontal hyperactivation is equivalent to relative right frontal hypoactivation (and vice versa) by the very nature of the asymmetry metric, which measures the difference in activation between homologous sites. Considered jointly, these two observations indicate that heightened relative left frontal activation has been associated both with increased positive affect and decreased negative affect in prior studies.[1] This pattern suggested that, in the present study, increased relative left frontal activation would be associated with notably greater positive than negative affective reactions to films. For this reason, we hypothesized that relative left frontal activation would predict the difference between positive and negative affective responses; that is, we hypothesized that it would be significantly correlated with our measure of affective valence.

No previous findings from our laboratory, and, to our knowledge, other laboratories, have indicated that relative left frontal activation is associated with both heightened positive and negative responses to films. As just noted, anterior asymmetry seems to more readily predict the disparity between, rather than the sum of, positive and negative affect. For this reason, we hypothesized that frontal EEG asymmetry would not significantly predict generalized reactivity to films, that is, the sum of positive and negative affective responses.

Although relatively few EEG studies to date have assessed the relation between anterior temporal asymmetry and emotion, some recent evidence indicates that the nature and direction of effects may parallel those associated with frontal asymmetry (e.g., Davidson et al., 1990). For this reason, we hypothesized that resting anterior temporal asymmetry would have effects on global affect ratings similar to those of resting frontal asymmetry. Our predictions concerning the anterior temporal region were, however, more tentative and speculative in nature than our predictions concerning the frontal region. Finally, we expected that central and parietal asymmetry would fail to predict emotional reactivity on any global index.

Method

Subjects

Subjects who had originally been run in two separate experiments were combined for the purposes of the present report. These two cohorts, who were completely independent, were exposed to different sets of affective films with no overlap between them. Otherwise, with the minor exceptions described below, experimental procedures were identical. These two groups of subjects were combined to (a) provide a sample size affording adequate statistical power for analyses of individual difference effects (total $N = 32$) and (b) allow for assessment of the generality of results and conclusions across differing sets of experimental stimuli.[2]

Cohort A. This cohort came from an original sample of 28 right-handed, female, paid community volunteers who were recruited in response to advertisements and who ranged in age from 17 to 41. They participated in a study originally designed to assess EEG patterns associated with facial expressions of emotion (Davidson et al., 1990; Ekman, Davidson, & Friesen, 1990). The sample was restricted to right-handed subjects (as assessed by the Edinburgh Handedness Inventory; Oldfield, 1971) because of evidence that patterns of hemispheric specialization for cognitive, and perhaps affective, functions may differ in left- and right-handers (e.g., Bryden, 1982). The mean score on the Beck Depression Inventory (BDI; Beck, Ward, Mendelson, Mock, & Erbaugh, 1961) for this cohort was 4.96 ($SD = 3.19$), with a range of 0 to 12. Thus, it is likely that no subjects met clinical criteria for depression, and that no subjects met even subclinical criteria given the typical cut-off scores currently used on the BDI (e.g., a score of 14 or above). Two subjects were eliminated from the present analyses because of the absence of artifact-free EEG during baseline periods, and five were eliminated because of the absence of complete film ratings. Thus, 21 subjects from this cohort were included in the present analyses.

Cohort B. This cohort came from an original sample of 15 right-handed, paid, female community volunteers, ranging in age from 20 to 54, who served as the nondepressed control group for a study assessing differences in EEG patterning between depressives and nondepressives (Henriques & Davidson, 1990). All subjects were nondepressed, as assessed by the Schedule for Affective Disorders and Schizophrenia (SADS, Endicott & Spitzer, 1978). The SADS was administered by one of two interviewers, both of whom had extensive training and experience using this interview format. We did not include depressed subjects from Cohort B because their exclusion maximized the comparability of the two cohorts and previous evidence from our laboratory indicates that depressed and nondepressed subjects differ in resting anterior asymmetry and in affective self-reports (e.g., Davidson et al., 1985). In addition, four men in the nondepressed control group were not included for the following, interrelated reasons: (a) Consistent with other studies and pilot work that we have conducted, there were sex differences on self-report responses to films in this cohort; (b) the effects of sex could not, however, be estimated in the present study because there were no men in Cohort A; and (c) as is evident from the above, the exclusion of men from Cohort B maximized the comparability of the two cohorts. Four subjects were eliminated from analyses because of equipment malfunction ($n = 2$) and excessive artifact during baselines ($n = 2$). Thus, 11 subjects from this cohort were included in the present analyses.

Procedure

All subjects were run individually. After arriving at the laboratory, subjects in both cohorts were informed that the purpose of the experiment was to assess physiological and subjective reactions to short film clips. After the experimenter applied electrodes for the measurement of EEG, the subject was informed that all necessary instructions for the experimental procedure would be presented on a rear-projection screen (Cohort A) or video monitor (Cohort B). During all phases of the experiment, subjects made responses on a numeric keypad to advance through the instructions at their own pace. Because this procedure allowed for minimal contact between the experimenter and subject, it maximized the degree to which subjects perceived themselves as viewing films privately and minimized the degree to which their reactions to films were affected by experimental demand or related factors. In addition, when the experimenter departed, the subject room was darkened. Subjects were told that the overhead lights were turned off in order to mimic a movie theater.

For subjects in both cohorts, the experiment began with two 30-s baseline recordings of resting EEG. During this time, subjects were told simply to sit quietly and avoid excessive movements or eye blinks. One resting baseline was recorded with eyes open and the second was recorded with eyes closed, with baseline order counterbalanced across subjects. After each trial, subjects indicated their emotional state during the trial on the following rating scales, in the order indicated: interest, happiness, amusement, sadness, anger, fear, and disgust. Rat-

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[1] It may well be the case that a more fine-grained classification of brain activity would yield patterns that are more uniquely linked to positive or negative affect (Davidson & Tomarken, 1989). Although this question could not be addressed in the present study because of the small sample size and relatively limited sampling of sites, research currently in progress in our laboratory is addressing this issue.

[2] Supplementary analyses conducted within the larger of the two cohorts (A) revealed that effects were comparable in magnitude to those yielded by analyses pooling over the two cohorts.

ings were made on 0 to 8 scales, with 0 indicating that the emotion was *not at all present* and 8 indicating that it was *felt very strongly.* Following the baselines, subjects were exposed to the emotional film clips (see description below). Subjects were informed by written instructions that immediately after viewing each clip, they would be asked to rate the emotions experienced while watching it on the same set of 0 to 8 scales noted above. The instructions emphasized the importance of rating the emotions actually elicited by each clip rather than, for example, the emotions that the clip was intended to elicit. Immediately following each clip, subjects used the numeric keypad to rate their emotional state during the clip. Following the final film clip, a second pair of 30-s eyes-open and eyes-closed baselines were recorded.

Emotional Film Clips

Cohort A. Subjects in this cohort were exposed to five film clips, each approximately 60 s in duration. Clips were presented using a Lafayette Model 925 Analyst film projector. All clips were in color. In addition, they were silent, to avoid the possibility that differing auditory patterns (e.g., speech and emotional sounds) associated with individual film clips would confound EEG measures of hemispheric activation (e.g., Carmon & Nachson, 1973). The first clip was neutral in affective tone, and was used to acclimate subjects to the procedure. Following this clip, subjects were exposed to two film clips designed to induce positive affect, after which they were exposed to two film clips designed to elicit negative affect. One positive clip showed a puppy playing with flowers and the second showed monkeys and a gorilla engaging in amusing activities at the zoo (e.g., playing and taking a bath). Both negative clips were portions of training films for nurses. These showed a leg amputation and a third-degree burn victim, respectively. Prior research with these clips had shown that subjects reported strong feelings of amusement and happiness to positive clips and strong negative affect, particularly fear and disgust, to negative clips (Ekman, Friesen, & Ancoli, 1980). Within the positive and negative categories, order of clips was counterbalanced across subjects.[3]

Cohort B. Subjects in this cohort were exposed to 8 film clips between 45 and 120 s in duration. As was the case for Cohort A, all film clips were silent and in color. Two film clips were designed to elicit positive affect, and six were designed to elicit negative affect. Clips in the latter category were selected because they primarily, although not exclusively, elicited one of three target emotions: sadness, anger, or disgust. There were two clips per target emotion. Clips were culled from feature films commercially available on videotape (e.g., *The Godfather*). They were selected from an initial pool of approximately 40 clips that were shown to undergraduate raters in groups of 10 to 15. One hundred twenty-two raters viewed each clip and rated it on the seven 0–8 rating scales described above. Clips were selected on the basis of high ratings on the target emotion assessed. On the basis of these group ratings, the intensity of the target emotion was comparable across each of the emotion categories (overall $M = 6.31$, range = 6.16 to 6.53).

Clips were shown to subjects in one of four orders, randomized with the constraint that one clip in each emotion category be presented before a second clip in that category. In order to maximize subjects' involvement in and reaction to the clips, and to promote better understanding of the events transpiring in the film sequence, a brief synopsis of each clip preceded it. Following each clip, subjects rated their emotional reactions to it on the 0–8 rating scales. Clips were presented using a Sony 6060U ¾-inch tape deck, and shown on a 27-in. Sony video monitor.

EEG Recording

In both cohorts, EEG was recorded using a lycra stretchable cap (manufactured by Electro-Cap, Inc.) that was positioned on the subjects' head using known anatomical landmarks. It has been shown that this procedure yields accurate electrode placements according to the 10-20 electrode system (Bloom & Anneveldt, 1982). EEG was recorded from the left and right mid-frontal (F3, F4), anterior temporal (T3, T4), central (C3, C4), and parietal (P3, P4) regions. All sites were referenced to vertex (Cz). This reference montage was used because it has been employed extensively in previous EEG studies of hemispheric asymmetries for emotion and cognition (see Davidson, 1988, for a review). All impedances were below 5K ohms, and the impedances of homologous sites (e.g., F3/F4) differed by 500 ohms or less. In order to faciliate artifact scoring, EOG was additionally recorded from the external canthus to the supra-orbit of one eye.

In the case of Cohort A, EEG was amplified with a Grass Model 7 polygraph using Model 7P5A preamplifiers (bandpass = 1 and 500 Hz; 60 Hz notch filter in). The amplified signal was passed through anti-aliasing low pass filters (Rockland Model 424) using a frequency setting of 44 Hz and a roll-off of 48 db/octave. The amplified and filtered signals were then digitized at 125 Hz by a PDP 11/34A laboratory computer. In the case of Cohort B, EEG was amplified with a Grass Model 12 Neurodata System using Model 12A5 preamplifiers (bandpass = 1 and 300 Hz; 60 Hz notch filter in) and passed through anti-aliasing filters set at a frequency setting of 85 Hz and characterized by a roll-off of 24 db/octave. EEG signals were then digitized at 250 Hz by the PDP 11/34A. It should be noted that the differences in the filtering characteristics used for the two cohorts are due to the differences in sampling rate. These differences in sampling rate and filtering have no effect on the measures of EEG power in the alpha frequency band (8–13 Hz) that are used in the present study.

Data Reduction and Quantification

EEG. Twenty-five and 50 uV 10 Hz sine waves were recorded on each channel and used to calibrate the digitized EEG. In addition, a paper record of the EEG and EOG was used to identify those portions of the data to be edited out because of eye movements, gross muscle and movement artifact, and other sources of artifact. When artifact occurred on a given channel, data from all channels were removed. Thus, across all channels equivalent epochs were extracted for analysis. All artifact-free EEG chunks that were 2.05 s in duration were extracted through a Hamming window, used to prevent spurious estimates of spectral power. In addition, chunks were overlapped by 75% to counteract the differential weighting of data points consequent to the use of the Hamming window (for a review, see Dumermuth & Molinari, 1987). A Fast Fourier Transform (FFT), which decomposes a complex waveform into its constituent sine wave components, was then used to derive estimates of spectral power (in uV^2) in different frequencies. Power values within an epoch were averaged and converted to power density (in uV^2/Hz), which is a measure of the average power within a given frequency band or range.

For the present article, we focused on analyses conducted on measures of power density in the alpha frequency band (8–13 Hz). We did so because (a) there is evidence that power in the alpha band is inversely related to measures of hemispheric activation (e.g., Shagass, 1972) and (b) power in this band has been most consistently linked to EEG asymmetries for emotion and cognition (e.g., Davidson, 1988; Davidson & Tomarken, 1989). In addition, we focused specifically on alpha power

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[3] Subjects in Cohort A rated positive films before negative films because of our initial concern that negative films would be more likely to have carryover effects on ratings of subsequent films. By the time the Cohort B experiment was run, we had ascertained that carryover effects of any sort were minimal. For this reason, positive and negative films were intermixed for these subjects.

Table 1
Varimax-Rotated Factor Structure of Affective Film Ratings

Emotion	Factor 1 loading	Factor 2 loading
Fear	.67	−.27
Disgust	.50	.17
Sadness	.58	.09
Anger	.75	.19
Happiness	.21	.61
Amusement	.12	.74
Interest	−.08	.73

Note. $N = 32$.

during the prefilm eyes-open resting baseline. We concentrated on prefilm baseline EEG because of our desire to assess whether resting EEG asymmetry can predict reactivity at a later point in time, and because of our concern that postfilm baseline EEG measures might be contaminated by lingering effects of the affective films. We focused specifically on the eyes-open prefilm resting baseline because (a) eyes-open conditions were used in the previous study conducted in our laboratory indicating that individual differences in resting EEG asymmetry predict reactivity to affective elicitors (Davidson & Fox, 1989) and (b) previous evidence that resting EEG predicts performance on cognitive tasks comes from studies that have measured EEG under eyes-open conditions (e.g., Davidson et al., 1979; Davidson, Taylor, Saron, & Stenger, 1980). We should add, however, that the results and conclusions reported here remain essentially unchanged if analyses are conducted on measures of resting asymmetry pooled over both the eyes-open and eyes-closed prefilm baselines.

Alpha power density averaged across all of the artifact-free chunks of the eyes-open resting baseline was computed for each site. After log transformation to normalize distributions, measures of EEG asymmetry were derived. Asymmetry was computed as the difference between log alpha power density in the right hemisphere lead and log alpha power density in the homologous left hemisphere lead (i.e., log R − log L alpha power). Because alpha power is inversely related to activation, higher scores on this asymmetry index indicate greater relative left hemisphere activation. This index was computed for each of the four regions of interest (mid-frontal, anterior temporal, central, and parietal).

Film ratings. Two stages of aggregation were used to generate composite affect measures from subjects' self-reports of emotion induced by films. First, for each cohort, we formed aggregate scores for each of the four negative affect rating scales (fear, disgust, sadness, and anger) by computing means on these scales across each of the films designed to elicit negative affect (two films in Cohort A and six films in Cohort B). Correspondingly, we formed aggregate scores for each of the three positive affect scales (happiness, amusement, and interest) by computing means on these scales across each of the two films designed to elicit positive affect. These indices were used in analyses of the relation between EEG asymmetry and discrete emotional responses to films. Rather than assessing negative affective responses to all clips (i.e., both positive and negative film stimuli) and positive responses to all clips, we examined only valence-specific affective responses to films of a given type because there was little variability, and substantial evidence of "floor effects," on subjects' negative affective ratings to positive films and positive affective ratings to negative films.

As a second stage of aggregation, we computed means across subjects' composite fear, disgust, anger, and sadness film ratings to yield a global negative affect index, and we computed means across subjects' composite happiness, amusement, and interest ratings to form a global positive affect index. To assess whether global positive and negative affect measures accurately reflected the dimensional structure of emotion ratings in the present sample, correlations among the seven aggregate emotion ratings were factor-analyzed using the principal axis method (using multiple R^2 as initial communality estimates). According to converging criteria (e.g., a scree test, examination of eigenvalues) and consistent with prior work on the dimensionality of emotion (e.g., Diener & Emmons, 1984; Watson & Tellegen, 1985), a two-factor solution was extracted and then subjected to a varimax rotation. Table 1 shows the rotated solution. As is evident from this table, distinct positive and negative dimensions were extracted, with all three positive scales loading highly on the former and all four negative affective scales loading highly on the latter. Although some degree of caution is necessary here because of the small sample size ($N = 32$), the results of this analysis indicate the presence of distinct positive and negative affect factors that are broadly consistent with the results of previous studies identifying these two dimensions (e.g., Watson & Tellegen, 1985). In addition, we should note that, consistent with previous findings, global positive and negative affect were essentially uncorrelated in the present sample ($r = .15$, $p > .50$).

In addition to positive and negative affect, we computed two other indices relevant to experimental hypotheses: the difference between global positive and negative affect (i.e., affective valence) and the sum of global positive and negative affect (i.e., generalized reactivity). Table 2 shows the within-cohort and overall means on these four aggregate indices.

Analyses

Because two independent cohorts of subjects who viewed differing sets of film clips were pooled for analyses, we tested predictions concerning the effects of EEG asymmetry on film ratings using an analytic strategy that also allowed us to (a) generate estimates of the effects of asymmetry on film ratings that were uncontaminated by any potential differences between cohorts on film ratings, and (b) assess whether the magnitude of the relation between EEG asymmetry and film ratings was conditional upon cohort. Specifically, a series of hierarchical multiple regression analyses were conducted (e.g., Cohen & Cohen, 1983). Dependent measures were the four global affect indices: global positive affect, global negative affect, affective valence, and generalized reactivity. Consistent with a hierarchical analytic strategy, predictors of a given dependent measure were entered in two successive steps. In the first step, a dummy variable denoting cohort and a given EEG baseline asymmetry measure (e.g., mid-frontal asymmetry) were entered simul-

Table 2
Global Emotion Ratings in Response to Films

	Cohort A ($n = 21$)		Cohort B ($n = 11$)		Overall ($N = 32$)	
Emotion	*M*	*SD*	*M*	*SD*	*M*	*SD*
Positive affect	4.29	1.45	5.29	0.97	4.63	1.37
Negative affect	4.02	2.01	3.81	0.79	3.94	1.68
Affective valence	0.27	2.30	1.48	0.88	0.69	2.01
Generalized reactivity	8.31	2.65	9.10	1.54	8.57	2.34

Note. Potential range of positive and negative affect = 0–8. Global positive affect is the average of ratings of both target and nontarget positive emotions to positive films. Global negative affect is the average of ratings of both target and nontarget negative emotions to negative films. Affective valence = global positive affect − global negative affect. Generalized reactivity = global positive affect + global negative affect. Cohort A viewed two negative and two positive films. Cohort B viewed six negative and two positive films.

taneously into the equation. In the second step, a Cohort × Asymmetry interaction term was added to the equation and its incremental contribution statistically tested.

The first step in the hierarchy noted above allowed for estimation of between-cohort mean differences on affect indices (see Table 2). More important, because of the inclusion of the cohort dummy variable, this procedure resulted in estimates of the effects of asymmetry that reflect the relation between EEG asymmetry and film ratings *only within* the two cohorts. More specifically, the regression coefficient for EEG asymmetry that is yielded by this procedure is the pooled within-cohort regression coefficient (e.g., Marascuilo & Levin, 1983). This coefficient reflects essentially the overall, or average, relation between EEG asymmetry and the dependent variable within each of the two cohorts. In addition, it should be noted that preliminary analyses indicated that there were no differences between cohorts in resting EEG asymmetry recorded from any of the four sites assessed (all $ps > .05$).

The interaction term entered in the second step allowed for evaluation of whether the direction and magnitude of the relation between EEG asymmetry and affective responses were different in the two cohorts (indicated by a significant interaction) or were generalizable across cohorts (indicated by a nonsignificant interaction). That is, this interaction term assessed whether the slopes of the regression of film ratings on asymmetry were equivalent in the two groups. These analyses were conducted for measures of asymmetry from each of the four brain regions (mid-frontal, anterior temporal, parietal, and central). All effects tested by these analyses were evaluated at the $p = .05$ level of significance.

When significant relationships between EEG asymmetry and global affect measures were found, two types of additional analyses were conducted. First, we examined the contribution of subjects' emotion ratings at the time of the baselines by (a) assessing the effects of EEG asymmetry on baseline mood ratings and (b) assessing whether EEG asymmetry significantly predicted film ratings above and beyond the variance accounted for by baseline mood ratings. Second, we assessed the effects of asymmetry on discrete emotions (e.g., composite fear). To aid in the control of Type 1 errors, these follow-up analyses were conducted only when analyses of the appropriate global affect index (e.g., global negative affect) yielded significant effects.

Results

EEG Asymmetry and Global Affective Responses to Films

We hypothesized that resting frontal asymmetry would be particularly likely to predict global affect ratings. Table 3 shows the results of the regressions of each of the four global affect measures on frontal asymmetry and on the cohort main effect and the Cohort × Frontal Asymmetry interaction term. Presented in this table are the squared semipartial correlations and the results of significance tests corresponding to each predictor. The squared semipartial correlations indicate the proportion of variance in the dependent variable uniquely accounted for by a given predictor. When reviewing Table 3, readers should also bear in mind that higher scores on the asymmetry index indicate increased relative left hemisphere activation (or, equivalently, decreased right hemisphere activation).

We predicted that increased relative left frontal activation would be associated with greater positive affect in response to films and with a larger difference between positive affective responses to positive films and negative affective responses to negative films. In addition, we hypothesized that increased relative right frontal activation (i.e., decreased left frontal activation) would be associated with greater negative affective responses.

Table 3
Regression of Film-Induced Global Affect on Frontal Asymmetry

Predictor	SR^2	t	p
Negative affect			
Cohort	.01	−.60	*ns*
Frontal asymmetry	.14	−2.19	<.05
Cohort × Frontal Asymmetry	.04	.36	*ns*
Positive affect			
Cohort	.13	2.06	<.05
Frontal asymmetry	.01	.45	*ns*
Cohort × Frontal Asymmetry	.06	−1.45	*ns*
Affective valence			
Cohort	.11	2.04	=.05
Frontal asymmetry	.14	2.25	<.05
Cohort × Frontal Asymmetry	.05	−1.37	*ns*
Generalized reactivity			
Cohort	.02	.76	*ns*
Frontal asymmetry	.05	−1.27	*ns*
Cohort × Frontal Asymmetry	.01	−.56	*ns*

Note. $N = 32$. SR^2 = squared semipartial correlation. $df = 29$ for frontal asymmetry and cohort effects; $df = 28$ for Cohort × Frontal Asymmetry interaction.

As shown in Table 3, two of these three predictions were supported. As hypothesized, increased relative right frontal activation was associated with heightened negative affective responses to the negative films. Neither the cohort main effect nor the Cohort × Frontal Asymmetry interaction were significant on this measure. The prediction that frontal EEG asymmetry would predict global positive responses to films was not supported. The only significant effect yielded by this regression was a main effect for cohort due to higher positive affect scores in Cohort B than in Cohort A.

As shown in Table 3, frontal asymmetry did, however, significantly predict affective valence, that is, the difference between global positive and negative affect in response to films. As hypothesized, across both cohorts, increased relative left hemisphere activation was associated with an increased disparity between positive and negative reactions. This analysis also yielded a significant main effect for cohort. More important, however, the Frontal Asymmetry × Cohort interaction was nonsignificant. Thus, the effects of frontal asymmetry were not conditional upon cohort.

Although we hypothesized that frontal asymmetry would predict affective valence, we expected no relationship between asymmetry and generalized reactivity to films. As expected, frontal asymmetry scores were not significantly related to this measure (see Table 3).

Given recent EEG evidence for emotion-related asymmetries in the anterior temporal (T3/T4) region, we advanced tentative hypotheses that baseline EEG recorded from this region would predict global affective responses to films. In contrast, the multiple regression analyses assessing the effects of anterior temporal EEG asymmetry yielded no significant main effects or interactions involving this region, all $ps > .30$. In addition, as expected, the multiple regression analyses assessing the effects of resting parietal (P3/P4) and central (C3/C4) asymmetry indicated that these EEG measures failed to significantly predict any global affective responses, all parietal and central asymmetry *ps* > .05. In short, only resting asymmetry recorded from the frontal region significantly predicted global affect ratings.

Frontal Asymmetry and Baseline Mood Ratings

A major question raised by the significant effects of frontal asymmetry on affective reactions to films is whether these effects are related to preexistent differences in mood ratings at the time that baseline EEG was recorded. We addressed this question in two ways. First, we assessed the relationship between frontal asymmetry and baseline mood ratings. We computed hierarchical multiple regression analyses in which frontal asymmetry and cohort were entered as predictors of baseline mood at the first step, with a Frontal Asymmetry × Cohort interaction term entered at the second step. Dependent measures were each of the four global affect measures computed on baseline mood ratings (e.g., global negative affect during baselines). There were no significant main effects or interactions involving frontal asymmetry on any of these analyses, all *ps* > .20. In short, baseline frontal asymmetry was unrelated to mood at baseline.

In addition, we more directly assessed whether frontal asymmetry predicted film ratings even when the variance attributable to baseline mood ratings was accounted for. We computed hierarchical multiple regressions in which frontal asymmetry, baseline mood rating, and cohort were simultaneously entered as predictors of film ratings as a first step, and terms denoting the two- and three-way interactions among these predictors were added in subsequent steps. As shown in Table 4, F3/F4 baseline asymmetry did, in fact, significantly predict global negative affect and affective valence even when adjusting for baseline mood ratings. Furthermore, as indicated by the absence of any interaction effects, the magnitudes of these effects were not conditional upon cohort or baseline ratings.

Table 4

Regression of Film-Induced Global Affect on Frontal Asymmetry (Baseline Mood Included)

Predictor	SR^2	t	p
Negative affect			
Cohort	.01	−.71	*ns*
Baseline negative affect	.01	.17	*ns*
Frontal asymmetry	.13	−2.01	=.05
Cohort × Frontal Asymmetry	.01	.06	*ns*
Baseline Negative Affect × Cohort	.01	.31	*ns*
Baseline Negative Affect × Frontal Asymmetry	.11	−1.56	*ns*
Baseline Negative Affect × Cohort × Frontal Asymmetry	.01	−.03	*ns*
Affective valence			
Cohort	.11	1.96	=.06
Baseline affective valence	.04	1.24	*ns*
Frontal asymmetry	.15	2.29	<.05
Cohort × Frontal Asymmetry	.05	−1.37	*ns*
Baseline Affective Valence × Cohort	.01	−.47	*ns*
Baseline Affective Valence × Frontal Asymmetry	.02	.91	*ns*
Baseline Affective Valence × Cohort × Frontal Asymmetry	.01	−.23	*ns*

Note. $N = 30$: Two subjects included in previous analyses were missing baseline film ratings. SR^2 = squared semipartial correlation. $df = 26$ for all main effects, $df = 23$ for all two-way interactions, $df = 22$ for all three-way interactions.

Effects of Frontal Asymmetry on Discrete Emotions

Because the analyses described above indicated significant relationships between resting frontal asymmetry and global negative affect and global affective valence, we conducted further analyses that assessed the effects of frontal asymmetry on specific negative affective responses to films (e.g., fear) and on the difference between specific pairs of positive and negative emotions (e.g., happiness minus fear). For these analyses, the composite scores (across films) for specific negative emotions or positive–negative pairs were regressed on frontal asymmetry and cohort, with a Frontal Asymmetry × Cohort interaction term added at a later stage.

Table 5 shows the frontal asymmetry main effects associated with these regression analyses. As revealed by this table, analyses of the four negative emotions indicated that relative right frontal activation was strongly associated with heightened fear responses to films. In addition, a nearly significant trend was evident on composite disgust. On the regressions of the differences between specific pairs of positive and negative composite ratings, frontal asymmetry significantly predicted the differences between each of the three positive emotions (happiness, amusement, and interest) and fear. In addition, frontal asymmetry significantly predicted the difference between happiness and disgust responses and nearly significantly predicted the differences between amusement and disgust and interest and disgust. All of these effects were in the predicted direction; that is, greater relative left frontal activation was associated with a higher positive − negative difference score. In addition, none of these effects were moderated by cohort, as indicated by consistently nonsignificant Cohort × Asymmetry interaction terms, all *ps* > .15. Finally, as was the case with the results for the global affect measures, subsequent analyses revealed that all of the aforementioned significant effects remained significant when baseline mood ratings were entered simultaneously in the regression equation and higher-order interaction terms were added in subsequent steps.

Discussion

In the present experiment, resting EEG asymmetry was recorded during a 30-s eyes-open resting baseline, after which subjects were exposed to film clips designed to elicit positive and negative affect. We hypothesized that resting anterior EEG asymmetry, particularly in the mid-frontal region, would predict subsequent positive and negative affective responses to film clips. We also hypothesized that it would predict affective valence, that is, the difference between positive and negative responses. In the case of frontal asymmetry, two of these three hypotheses were supported. Across both cohorts, resting frontal asymmetry significantly predicted global negative affective responses to film clips and global affective valence. Additional analyses of discrete emotions and the difference between dis-

Table 5
Regression of Film-Induced Discrete Emotions on Frontal Asymmetry

Dependent variable	Frontal asymmetry values SR^2	t	p
Negative affect			
Fear	.25	−3.13	<.005
Disgust	.08	−1.73	<.10
Anger	.01	−0.48	*ns*
Sadness	.05	−1.23	*ns*
Affective valence			
Happiness − fear	.22	3.35	<.005
Amusement − fear	.16	2.33	<.05
Interest − fear	.16	2.42	<.025
Happiness − disgust	.09	2.25	<.05
Amusement − disgust	.09	1.82	<.08
Interest − disgust	.07	1.70	<.10
Happiness − sadness	.08	1.66	*ns*
Amusement − sadness	.04	1.08	*ns*
Interest − sadness	.04	1.08	*ns*
Happiness − anger	.03	1.12	*ns*
Amusement − anger	.01	0.56	*ns*
Interest − anger	.01	0.48	*ns*

Note. $N = 32$; all effects were estimated with cohort included as a predictor in the regression equation. At a subsequent step, a Cohort × Frontal Asymmetry interaction term was added into the equation. No interactions approached significance. SR^2 = squared semipartial correlation. $df = 29$.

crete positive and negative emotions revealed particularly strong relations between frontal asymmetry and fear responses to films. Several significant or near-significant effects involving disgust also emerged.

As revealed by supplementary analyses, there were two additional significant aspects of the present data. First, effects were specific to the frontal region. As expected, neither central nor parietal asymmetry predicted global film ratings. Somewhat surprisingly, resting anterior temporal asymmetry also failed to significantly predict ratings. Second, the effects of frontal asymmetry did not appear attributable to its covariation with mood ratings at the time of the baselines. Frontal asymmetry was uncorrelated with baseline mood ratings, and frontal asymmetry significantly predicted film ratings above and beyond any potential contribution of baseline mood ratings.

Concerning the interpretation of these findings, we should note one caution. Measures of negative affect (e.g., global negative affect and composite fear) and affective valence (e.g., global affective valence and the composite fear–happiness difference) overlapped considerably in the present study. Negative affect measures were used in the arithmetic calculation of the affective valence measures. As noted in the introduction, there is a wealth of prior evidence that justified the inclusion of measures of *both* sets of constructs. Even so, the use of nonindependent measures is a significant limitation. In particular, it renders somewhat ambiguous the precise nature of the relation between anterior asymmetry and affective valence (or pleasure–displeasure). To further clarify the relation among resting frontal asymmetry, positive and negative affect, and affective valence and generalized reactivity, it is important for future studies to use independent measures of each emotion construct (cf. Tomarken, Davidson, Wheeler, & Doss, 1990).

Relation to Previous Findings

The present results are consistent with previous EEG findings and related evidence that indicate a relation between asymmetrical activity in the anterior regions of the cerebral hemispheres and emotion (for a review, see Davidson & Tomarken, 1989). Particularly notable are the parallels between the present findings and those of Davidson and Fox (1989), who recently showed that resting anterior asymmetry can predict infants' reactions to maternal separation. In both studies, asymmetries in the frontal region, but not in posterior sites, predicted subsequent affective reactivity to emotion elicitors. In addition, in both studies, anterior asymmetry was unrelated to measures of affective state at the time of baselines. In both contexts, then, frontal asymmetry operated as a state-independent marker of subjects' readiness or predisposition to respond affectively.

We should, however, caution that both the present study and the Davidson and Fox (1989) infant study used only female subjects. Although we would expect that resting frontal asymmetry would also predict the affective responses of males, future studies are necessary to resolve this issue more conclusively. In addition, given the nondepressed nature of the present sample, future studies are necessary to assess whether the present findings are generalizable across both depressives and nondepressives (e.g., Davidson et al., 1985).

We should also emphasize that although the effects of frontal asymmetry have been state independent in these two studies, their results do *not* imply that anterior asymmetry cannot covary with emotional states or changes in such states. There is a variety of evidence from our laboratory (e.g., Davidson et al., 1990; Davidson & Fox, 1982) and other laboratories (e.g., Ahern & Schwartz, 1985; Tucker et al., 1981) indicating that patterns of anterior asymmetry can indeed change when the individual is exposed to elicitors that induce changes in emotional state. Notably, however, we have found that even when these state changes are evidenced in within-subjects comparisons, they are superimposed on what appear to be stable differences among subjects in anterior asymmetry. For example, in a recent study assessing changes in EEG asymmetry in response to affective films, Davidson et al. (1990) reported that 100% of their subjects demonstrated increased relative right frontal activation during facial expressions of disgust compared with facial expressions of happiness. However, an examination of the individual asymmetry scores from this study reveals marked individual differences in the relative magnitude and direction of asymmetry that were preserved across the disgust and happiness conditions.

As noted above, baseline frontal asymmetry was uncorrelated with concurrent measures of emotional state in both the Davidson and Fox study (1989) and the present study. These null findings suggest that in the absence of a sufficiently strong elicitor of emotion, the individual's resting asymmetry may primarily reflect individual difference factors rather than state factors. We should add that the notion that EEG asymmetry reflects the joint contribution of both of these factors is also consistent with conclusions previously reached by Levy (1983), who has assessed activation asymmetries by behavioral methods. This notion is also consistent with recent evidence from our laboratory indicating that although anterior EEG asymmetry is generally stable over time, it is by no means perfectly so, and thus is susceptible to the effects of as yet unspecified situational factors (e.g., test–retest *r*s in the .65 to .75 range; Tomarken, Davidson, Wheeler, & Kinney, 1990). Notably, it was also found that the test–retest stability of EEG was maximized by aggregating over the eight 1-min resting baselines conducted in each session. In this light, it is remarkable that in the present study, at most only 30 s of EEG per subject was needed to predict affective responses at a later point in time.

Individual Differences in Anterior Asymmetry and Affective Reactivity

One important question raised by the present findings is precisely what predispositions are indexed by individual differences in resting anterior EEG asymmetry. A common thread that runs through otherwise disparate theories of biologically based individual differences in affective traits is that such differences are associated with altered thresholds for behavioral reactions to such stimuli (e.g., Kagan, Reznick, & Snidman, 1988; Tellegen, 1985; for a review, see Derryberry & Rothbart, 1984; see also Gallistel, 1980). From the perspective of these theories, then, the significant effects on global negative affect suggest that resting relative right frontal activation is linked to a lowered threshold for negative affective reactions to aversive stimuli. Alternatively, the significant effects on global affective valence suggest that relative right frontal activation is associated with a disparity in the threshold for negative, relative to positive, reactions. We should add that, though intuitively appealing, the notion that anterior asymmetry is linked to lowered thresholds for affective reactions is a hypothesis that requires several methodological features not included in the present experiment for a more adequate test (e.g., affect elicitors that induce emotion across a wide range of intensities).

We have previously hypothesized that the prime behavioral dimension indexed by anterior asymmetry is that of approach and withdrawal (e.g., Davidson, 1984; Davidson & Tomarken, 1989). Perhaps, then, the present results are attributable to an additional linkage between increased relative right frontal activation and lowered thresholds for withdrawal reactions or for withdrawal, relative to approach, reactions. Consistent with this notion were the results of analyses performed on the discrete emotion scales. These analyses revealed that fear and disgust were the two negative emotions that were significantly, or nearly significantly, predicted by frontal asymmetry. Notably, several emotion theorists have argued that fear and disgust are the two negative emotions that are most reliably associated with behavioral withdrawal (e.g., Ekman & Friesen, 1975; Plutchik, 1984).

Although neither frontal nor anterior temporal asymmetry predicted global reactivity to positive films in the present study, it would be premature to conclude that anterior asymmetry cannot index a predisposition for reactions to positively valenced stimuli. The stimuli used in the present context may not have been optimal. For example, if the primary dimension indexed by anterior asymmetry is approach versus withdrawal, it could be argued that the types of film clips used in the present study do not elicit the strong incentive motivation, focused engagement in ongoing activity, or accompanying behavioral signs (e.g., movement toward a stimulis) normally associated with approach motivation. In this regard, it is relevant that previous findings from our laboratory suggest that experimental paradigms that elicit such frank signs of approach (e.g., an infant's reaction to an advancing mother) are more reliably associated with relative left frontal activation (e.g., Fox & Davidson, 1987).

Similarly, it could be argued that the present films did not optimally elicit positive affect in the sense that this term is used by Watson and Tellegen and their colleagues (e.g., "active," "proud," "determined"; see Watson, Clark, & Tellegen, 1988). In support of this argument, we have recently found robust relations between individual differences in anterior asymmetry and generalized positive affect on a measure developed specifically by Watson et al. (1988) to measure this affective dimension (Tomarken, Davidson, Wheeler, & Doss, 1989). In general, as the preceeding points suggest, an important task for future research is to delineate the relations among anterior asymmetry, fundamental dimensions of motivation (e.g., approach/withdrawal), and basic dimensions of emotion (e.g., positive/negative affect).

In summary, in the present study resting EEG asymmetry recorded from mid-frontal sites significantly predicted affective responses to film clips. These effects were independent of mood state at the time of baselines. Resting asymmetry recorded from more posterior regions failed to significantly predict affective reactivity. These results appear to have important implications for understanding the relation between individual differences in cerebral functioning and affective behavior.

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