

Approach-Withdrawal and Cerebral Asymmetry: Emotional Expression and Brain Physiology I

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In this experiment, we combined the measurement of observable facial behavior with simultaneous measures of brain electrical activity to assess patterns of hemispheric activation in different regions during the experience of happiness and disgust. Disgust was found to be associated with right-sided activation in the frontal and anterior temporal regions compared with the happy condition. Happiness was accompanied by left-sided activation in the anterior temporal region compared with disgust. No differences in asymmetry were found between emotions in the central and parietal regions. When data aggregated across positive films were compared to aggregate negative film data, no reliable differences in brain activity were found. These findings illustrate the utility of using facial behavior to verify the presence of emotion, are consistent with the notion of emotion-specific physiological patterning, and underscore the importance of anterior cerebral asymmetries for emotions associated with approach and withdrawal.

This and the accompanying report (Ekman, Davidson, & Friesen, 1990) represent the convergence of two independent yet overlapping lines of research. One is theory and evidence from Ekman's laboratory, which, from an evolutionary perspective, takes the position that each emotion is characterized by unique patterns of expressive behavior and physiological activity (e.g., Ekman, 1977, 1984). The second is research from Davidson's laboratory on cerebral asymmetry and emotion, which indicates the differential involvement of the two cerebral hemispheres in the control of certain positive and negative emotions (e.g., Davidson, 1984a, 1984b, 1987; Davidson & Tomarken, 1989).

Psychophysiological Specificity and Emotion

The degree to which different emotions are accompanied by unique patterns of physiological activity is a question as old as the study of emotion itself. Two diametrically opposed positions on this issue have been advanced, with ardent supporters of each view. Cognitive theorists (e.g., Mandler, 1975; Schachter & Singer, 1962), following Cannon (1927), have claimed that different emotions are accompanied by the same pattern of undifferentiated physiological arousal. The second position, con-

sistent with the theoretical writings of Darwin (1872/1955) and James (1890), asserts that different emotions are accompanied by unique patterns of physiological activity (e.g., Ax, 1953). Ekman (1984) has specifically suggested that unique central or autonomic patterns will differentiate among the primary emotions of happiness, sadness, anger, fear, disgust, and surprise. There are now data available that are beginning to illuminate this debate. Ekman and his colleagues (Ekman, Levenson, & Friesen, 1983; Levenson, Ekman, & Friesen, in press) have uncovered evidence for unique patterns of autonomic activity that differentiate among the negative emotions of fear, anger, disgust, and sadness, and differences between these negative emotions and happiness. Other investigators have also reported reliable differentiation among some negative emotions on the basis of measures of autonomic physiology (e.g., Schwartz, Weinberger, & Singer, 1981).

To date, there has been little research that has explored the hypothesis of distinctive central nervous system patterns that differentiate among the primary emotions. A number of elementary circuits for certain constellations of emotional behavior have been described (see Papez, 1937, and MacLean, 1949, for early analyses of this problem and Panksepp, 1982, for a more modern view), although the degree to which these map onto discrete emotions in humans is not entirely clear. Because unique expressive signals and subjective experience characterize each of these primary emotions, one would expect them to be associated with distinctive, invariant patterns of central nervous system activity at some level of the neuraxis. One important goal of the present research is to advance knowledge regarding this unexplored topic.

Cerebral Asymmetry, Approach-Withdrawal, and Emotion

It is the second body of research that provides a useful theoretical guide for specific hypotheses about the distinctive central

This research was supported by grants from the National Institute of Mental Health (MH 40747 and MH 43454) and the Graduate School of the University of Wisconsin to Richard J. Davidson and by Research Scientist Award MH 06092 from the National Institute of Mental Health to Paul Ekman.

We wish to thank Andrew Tomarken for valuable comments on an earlier draft of this article, and Linda Kinney, Barry Cohen, Barry Gordon, and Andrea Straus for assistance with the data analysis.

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nervous system activity for some of the emotions. Davidson and others have amassed a variety of evidence over the past 10 years that indicates that the anterior regions of the two hemispheres of the brain (frontal and anterior temporal) are differentially involved in certain positive and negative emotions (see reviews by Davidson, 1984a, 1984b; Davidson & Tomarken, 1989; Kinsbourne & Bemporad, 1984; Leventhal & Tomarken, 1986; Silberman & Weingartner, 1986; Tucker & Frederick, 1989). Davidson (1984a, 1987), following an early suggestion of Kinsbourne's (1978) concerning the relation between approach behavior and the left hemisphere, has theorized that the fundamental continuum along which the anterior cortical regions are lateralized is approach-withdrawal, with the left anterior region subserving an approach system and the homologous right hemisphere region subserving a withdrawal system. Davidson has further argued that to the degree that approach and withdrawal are components of different emotions, such emotions should differentially activate the anterior regions of the two cerebral hemispheres. For example, several emotion theorists (e.g., Ekman & Friesen, 1975; Plutchik, 1980) have noted that both fear and disgust often include behavioral components of withdrawal, although in somewhat different fashions. For fear, Ekman proposes that withdrawal entails escaping from the threatening stimulus, whereas in disgust the withdrawal entails terminating the input, whether it be olfactory, oral, or visual.

In this experiment, we sought to examine the pattern of brain electrical activity derived from multiple scalp loci during these two withdrawal emotions, fear and disgust. The brain activity during these emotions was to be compared to an approach emotion, happiness, and a baseline condition. We used short, 1-min positive and negative film clips to arouse these different emotional states.

Methodological Desiderata for Psychophysiological Research on Emotion

Below we note eight characteristics that ideally should be incorporated into all research on the biological substrates of human emotion and that apply to studies of both autonomic and central nervous system components of emotion. We then illustrate how the present research conforms to these desiderata.

1. *Emotion must be actually elicited.* Although this requirement may seem trivial, many experiments that purport to study emotion may not actually involve the production of emotion in subjects. Some studies focus more on the perception of emotional information, whereas others examine the language that is used to describe emotion. If the goal of the research is to characterize the psychophysiology of emotion, then there must be evidence, apart from the dependent variable of interest, that emotion was actually produced.

2. *Adequate procedures must be used to verify the presence of the intended emotion.* One of the noteworthy characteristics of emotion is the lack of an isomorphic relation between an elicitor and a particular emotion (see Ekman, 1984). In other words, the same elicitor will often produce an array of different emotions across subjects. Even in response to elicitors that are specifically chosen to target a particular discrete emotion, subjects typically will report a range of different emotions if given the opportunity (e.g., Ekman, Friesen, & Ancoli, 1980). Sometimes these other emotions are experienced at different points in time over the course of an eliciting event and, at other times, emotions might

be produced in blends, with different emotions experienced simultaneously. Whatever the time course of the different emotions, we believe that the use of self-report is insufficient to verify the presence of the emotion intended by the investigator, if a self-report instrument asks only about the targeted emotion. Such a measure will not be sensitive to the possibility that other emotions might have been experienced in addition to the target emotion.

We believe that one of the major methodological inadequacies in previous psychophysiological research on emotion has been the failure to verify with precision that the intended emotion was elicited in every subject. Typically, it is only the investigator's presumption that supports the possibility that the emotion elicitor produced the intended emotion. The physiology in response to the elicitor is usually examined without regard to verifying the investigator's presumption.

3. *Epochs of different discrete emotions must be separable.* Given the likelihood that any given elicitor will produce more than one emotion that may change sequentially over time, it is imperative to identify separate epochs during which different discrete emotions are present. Only in this way can the physiology that accompanies different emotions be compared. Note that this requirement necessitates a method, such as the analysis of facial behavior, that provides a continuous or near-continuous measure of emotional state. Using such a measure, an investigator can then extract, post hoc, those periods during which different discrete emotions were present. Because most physiological studies aggregate data over the entire length of the eliciting stimulus, emotions other than the intended one would contribute to the physiological changes observed. Previous failures to find physiological differentiation among emotions may, at least in part, be attributable to the failure to compare different discrete emotions. Most investigators unwittingly compare between two or more blends of emotion.

4. *Behavioral and physiological measures of emotion must be appropriately synchronized.* If a continuous behavioral measure of emotion is used to flag epochs during which different discrete emotions are present, the behavioral and physiological data streams must be accurately synchronized. This necessitates the use of common, simultaneously produced signals on the videotape record and the computer in which the physiological data are stored.

5. *The physiological measures chosen for study must have a sufficiently fast time constant to reflect brief periods of emotion.* Given the relatively fleeting nature of emotion, with most episodes lasting less than 4 s (Ekman, 1984), it is clear that only those physiological processes that have a relatively fast time constant are logical candidates to examine the physiological substrates. Certainly, other affective phenomena related to emotion, such as mood, have longer durations and would therefore be expected to involve other physiological systems whose response properties are more enduring.

6. *At least two emotions and a baseline condition must be compared.* Many experiments on the psychophysiology of emotion, including some of our own previous studies (e.g., Davidson, Schwartz, Saron, Bennett, & Goleman, 1979), have only included two emotion conditions. The problem with this strategy is that no nonemotion reference condition is included. Thus, it would be impossible to conclude which, if any, of the emotion conditions would differ from a baseline period. In a study involving a comparison of two emotions, it is possible

that the two conditions could differ from each other, but not from a baseline condition. It is also possible that only one of the emotion conditions would differ from baseline. In studies that compare only one emotion condition with a baseline, it is impossible to conclude whether the physiological changes observed during the emotion period are unique to that specific emotion or are nonspecific changes associated with any emotion. For this reason, at least two emotion conditions and a baseline are required.

7. *The intensity of the elicited emotion must be matched among conditions.* When two or more emotions are compared, it is imperative to match the intensity of emotion so that differences in intensity do not confound the emotion-specific comparisons. Many investigators who have compared two or more emotions have not used any procedure to match the intensity of the elicited emotions (e.g., Schwartz et al., 1981). If two emotions differ in some parameter of physiology, but also differ in intensity, it is not possible to disentangle whether the physiological differences are simply a function of the intensity of emotion-related activation per se, or rather are associated with the specific emotion that was elicited.

8. *The data must be of sufficient duration for each emotion under study.* Precisely what constitutes a sufficient duration will vary as a function of the physiological measures of interest. If stable estimates of physiological activity are to be obtained, a certain minimum amount of artifact-free data is required. Within-subject aggregation is performed to arrive at a single index of a particular physiological variable for a certain emotional state for each subject. For example, if physiological activity during smiling was of interest, all instances of the artifact-free physiology during the target smiles would be extracted, analyzed, and then aggregated for each subject. If the dependent measure was the electroencephalogram (EEG), a minimum of approximately 10 s (across all instances of the target emotion) would be required to obtain a stable estimate of spectral power (Davidson, 1988). Note that although 10 total seconds are required, each individual epoch of smiling can be quite brief, as short as 1 s per expression period.

The study reported here was designed to accommodate each of these eight methodological desiderata. Short film clips were used to elicit emotion. These clips have been used extensively in previous emotion research and have been found to elicit both self-report and facial signs of positive and negative emotion that are comparable in intensity (e.g., Ekman et al., 1980). To verify the presence of the target emotion, we used a combination of facial behavior and self-report criteria. The facial behavior was used to flag the onset and offset of different facial signs of emotion. We used self-report criteria to ensure that subjects were reporting emotions whose valence was consistent with the film clip used and to ensure that the intensity of the reported positive and negative affect was matched. We extracted happy epochs from positive film clips and disgust epochs from the negative film clips. We had expected to be able to also extract fear epochs, but happy and disgust were the only facial expressions that occurred with sufficient frequency.

The EEG measures were precisely synchronized with the facial behavior by having the same triggers produce event marks on the video record and the computer data base simultaneously. The use of EEG, and the analytic method employed to quantify the EEG, ensured that a sufficiently accurate time resolution was achieved. Chunks of EEG 1.02 s in duration served as the

epoch length for analysis. These chunks were overlapped by 75%. The analysis epoch started at the precise time of the onset of the facial expression. Our study compared three periods—happy expressions, disgust expressions, and baseline—thus enabling us to specify both the degree to which EEGs during each expression type differed from each other and from a resting baseline. Finally, we required a minimum of 10 s of artifact-free EEG during each expression type (aggregated across multiple instances of the expression) to use a subject's data for that expression. This ensured that a sufficient amount of EEG was available to compute stable estimates of spectral power (see Mocks & Gasser, 1984). Finally, we included a control procedure to evaluate the efficacy of our elaborate data extraction procedure. EEG was analyzed in a manner similar to what is typically done in studies on the psychophysiology of emotion. Data from both positive films were aggregated and compared with the data from the two negative films, irrespective of facial behavior. We predicted little difference in anterior asymmetry between the positive and negative film conditions because the data for this comparison are aggregated across all nonfacial and facial expression periods, including those that are inconsistent with the target emotion.

To summarize, the goal of this study was to compare epochs of brain activity coincident with the expression of different emotions. Facial signs of happiness and disgust occurred with sufficient frequency to compare EEG activity coincident with each. We recorded EEG over the left and right hemispheres in the frontal, anterior temporal, central, and parietal regions and videotaped subjects unobtrusively while they watched short emotional film clips. We specifically predicted that activation asymmetry would differentiate between happy and disgust emotions in the frontal and anterior temporal regions. The central and parietal regions were assumed to be relatively uninvolved in the generation of emotion. Brain electrical activity was measured from these sites to serve as a comparison with the more anterior sites and to evaluate the degree to which the valence-dependent asymmetries were specific to the anterior regions.

The following specific hypotheses were tested in this experiment:

Hypothesis 1. EEG asymmetry from the entire film period, independent of facial behavior, will not discriminate between positive and negative film conditions.

Hypothesis 2. Frontal and anterior temporal activation asymmetry will discriminate between happiness and disgust. Specifically, disgust will be associated with greater right-sided anterior activation compared with happiness. Conversely, happiness will be associated with more left-sided activation compared with disgust. We specifically offer no predictions regarding between-hemisphere differences within emotion conditions. The rationale for not making such predictions is based on the fact that substantial individual differences in baseline asymmetry exist, upon which are superimposed task-dependent changes (see Davidson & Tomarken, 1989, for a review). Thus, for a subject with tonic extreme right frontal activation, we would not necessarily expect that happiness would be associated with absolute left frontal activation (i.e., greater activation in the left compared with the right frontal lead). However, we would still predict the between-condition, within-hemisphere differences described above.

Hypothesis 3. Both disgust and happiness will be discrimi-

nated from baseline on measures of anterior activation asymmetry. We specifically predicted that disgust would be associated with a significant increase in right-sided anterior activation compared with baseline and that happiness would be accompanied by a significant increase in left-sided anterior activation compared with baseline.

Method

Subjects

A total of 37 right-handed (assessed with the Edinburgh Handedness Inventory; Oldfield, 1971) women between the ages of 17 and 41 years were tested. The sample was restricted to right-handed subjects because hemispheric specialization is known to differ in left-handed subjects. Of these 37 subjects, 26 had at least one instance each of a happy and disgust expression during the positive and negative film clips. Of these 26, 17 had at least one instance of each of these expressions that were accompanied by artifact-free EEG (EEG was scored for artifact prior to any analysis; see below). Two of these 17 subjects were eliminated because of failure to meet the duration criteria, which was a minimum of 10 total seconds of artifact-free EEG during each expression type. Four other subjects were eliminated because they reported negative affect (i.e., fear, sadness, disgust, or anger) at a level of 3 or more on a 0-8-point scale during at least one of the positive films from which the happy expressions were extracted. We were thus left with a final sample of 11 subjects. The percentage of subjects who were excluded is similar to previous studies in which EEG data were extracted during facial expression periods (Fox & Davidson, 1988).

Procedure

Subjects were tested individually. Prior to commencement of the study, subjects were told that the experiment was concerned with subjective and physiological reactions to short emotional film clips. After signing a consent form that indicated that film clips designed to elicit both positive and negative emotion would be presented, an experimenter applied electrodes for the measurement of the EEG. The subject was told that no intercom existed between the rooms and that if the subject needed to speak with the experimenter for any reason during the session, she could press a button mounted on one arm of the chair that would ring a signal in the control room, at which point the experimenter would enter. We specifically designed the situation in this fashion to maximize the degree to which subjects perceived themselves to be viewing the film clips "privately," with little experimenter contact.

To further increase the degree to which subjects believed that they were not being observed during the film viewing periods, the room was darkened at the time the experimenter departed. The subject was told that the purpose of the darkened room was to mimic a movie theater. Two small red lights provided low-level ambient illumination, which was required for subjects to view the number pad on which their ratings were made (see below).

The experimenter answered any general questions that the subject had and explained that the remainder of the instructions would be presented on the rear-projection screen toward which they faced. Instructions were presented in a self-paced fashion. A screenful of instructions was presented at a time, at the bottom of which was the phrase "press to continue." The subjects advanced through all of the instructions at their own pace.

The experiment began with baseline recordings of physiology, after which the film clips were presented. Following the presentation of the film clips, another set of baseline trials was presented. Each set of baseline periods consisted of the presentation of one eyes-open and one eyes-closed trial, each 30 s in duration. The order in which these trials were presented was counterbalanced within and between subjects. The onset

and offset of the baseline trials were marked by the presentation of tone pips.

Emotion-Arousing Stimuli

There were five film trials, each comprising a different short film of approximately 60 s in duration. The first clip was used to acclimate subjects to the procedure. The next two were intended to evoke positive emotions, and the last two were designed to evoke negative emotions. Prior research with these films (Ekman et al., 1980; Ekman & Friesen, 1974) had found that subjects reported strong feelings of amusement and happiness and showed smiling expressions during the positive films. Feelings of fear, sadness, disgust, and pain and a variety of negative emotional expressions occurred in response to the negative films.

All the films were silent and in color. Silent films were desirable for our purposes because different auditory patterns might conceivably elicit different patterns of hemispheric activation solely as a function of the acoustic variation among the clips (e.g., Carmon & Nachson, 1973). One of the positive films showed a puppy playing with flowers. The second was a clip of monkeys playing and a gorilla taking a bath in the zoo. The order in which the two positive film clips were presented was counterbalanced across subjects.

The two negative film clips always followed the positive clips. The rationale for this was based on both previous work by Ekman et al. (1980) and our own pilot work, which indicated that the negative affect elicited by the negative films tended to persist longer than the positive affect elicited by the positive films. If we had counterbalanced the order of positive and negative films, the persisting negative mood would have interfered with the intended effect of the positive films, decreasing the number of positive emotional expressions that would have occurred in response to these clips. The negative film clips were taken from training movies used in the teaching of nurses. One clip depicted a leg amputation and the other was the scene of a third-degree burn victim. Both were quite gruesome. The order in which the amputation and burn clips were presented was counterbalanced across subjects.

Films were presented with a Lafayette Model 925 Analyst film projector, which generated a frame count pulse for automated control. Digital logic counted these pulses for precise timing of film onset and offset.

Subjective Ratings of Emotion

After each of the baseline and film trials, subjects rated the emotions they had experienced during the preceding trial on a series of unipolar scales. Separate scales were included for interest, happiness, amusement, contentment, excitement, fear, sadness, anger, disgust, pain, and arousal. The instructions informed the subject that zero represented no emotion and 8 the most intense feeling of that emotion. These rating scales were projected one at a time on the rear projection screen. The subjects entered their rating by pressing a number on their key pad.

For the subjects who were retained in the analyses (see above), the intensity of amusement (the dominant emotion reported during the positive clips) during the positive clips and disgust during the negative clips was comparable. In addition, there were no differences in the intensity of any of the rated emotions between the subjects who were retained for the EEG analysis and those who were excluded. Table 1 presents the mean ratings of the positive and negative emotions in response to the positive and negative film clips for the subjects who were retained and those who were excluded.

Video Recordings

During each of the film clips, subjects were videotaped unobtrusively through a wire mesh screen that served as the border of the rear projection screen. The camera (G.E. Site Guard II) was mounted in the projection room, which was adjacent to the subject room, along with the film projector. The camera was absolutely invisible to the subject, and not one subject suspected that she was being videotaped. After the experi-

Table 1
Ratings of Emotional Intensity for Subjects Retained and Excluded

	Interest	Amusement	Contentment	Excitement	Happiness	Fear	Sadness	Pain	Disgust	Anger
Positive film clips										
Subjects included (<i>n</i> = 11)										
<i>M</i>	5.60	5.60	3.95	2.65	4.45	0.40	1.18	0.45	0.75	1.00
<i>SD</i>	1.29	1.60	1.91	1.60	2.14	0.88	1.06	0.83	0.95	1.29
Subjects excluded (<i>n</i> = 15)										
<i>M</i>	5.50	6.05	3.68	2.73	4.68	0.50	1.35	0.18	0.95	0.86
<i>SD</i>	1.92	1.44	1.93	1.69	1.85	1.02	1.83	0.34	1.42	1.43
Negative film clips										
Subjects included (<i>n</i> = 11)										
<i>M</i>	5.00	1.35	0.25	2.40	0.25	4.10	2.90	4.50	5.70	3.00
<i>SD</i>	2.07	1.63	0.54	2.23	0.79	2.65	2.29	3.16	2.98	2.59
Subjects excluded (<i>n</i> = 15)										
<i>M</i>	5.52	1.55	0.45	2.15	0.50	4.45	3.30	3.80	6.70	3.60
<i>SD</i>	2.38	1.64	1.42	2.47	1.41	2.53	2.79	2.82	2.53	2.97

Note. This table illustrates mean intensity (and standard deviation) of self-reported emotion (on a 0–8 scale) in response to the two positive and two negative film clips. For each subject, a mean for each emotion for the positive films was created by averaging the ratings across the two positive film clips and a mean for each emotion for the negative films was created by averaging the ratings across the two negative films. The subjects included were those on whom the EEG analyses are based. The excluded subjects are those who were removed as a function of excessive artifact during happy or disgust expressions or because they reported excessive negative affect during the positive films (see text).

ment was completed, subjects were thoroughly debriefed, and written consent was requested to use their videotapes for scientific purposes. The subject was told that if she did not wish for the tape to be used, it would be erased. No subject declined our request to use her tape.

At the time the video recording was made, a video stopwatch (Fora VTG-22) marked the time that had elapsed since the commencement of the experiment on the videotape. In addition, the beginning and end of each new condition (both baseline and film) were marked by automatically changing the digits on the video clock from black to white and back. The trigger used to change the video stopwatch from black to white and back also was sent to a PDP 11/34A computer to signal the onset and offset of all experimental trials. Using this system, we were able to precisely synchronize the video and physiological data streams.

EEG Recording Procedure

The EEG was recorded from the left and right frontal, central, anterior temporal, and parietal regions (F3, F4, C3, C4, T3, T4, P3, P4) all referred to vertex (Cz) using a lycra stretchable cap (Electro-Cap).¹ All impedances were below 5K ohms. The EEG was amplified with a Grass Model 7 polygraph and Model 7P5A amplifiers and then low-pass filtered at 44 Hz (48 db/octave roll-offs) to prevent aliasing. The filtered, amplified signals were then led into the A/D converter of the PDP 11/34A computer system. The EEG was sampled at 125 samples per second. The EEG was calibrated by inputting before and after each subject a series of 25 and 50 μ V sine waves at 10 Hz. The computer used these known signals to calibrate each of the channels.

Data Analysis

Scoring facial behavior. All of the observable facial activity shown by each subject during the positive and negative films was measured with Ekman and Friesen's (1976, 1978) Facial Action Coding System (FACS). Using this information, the onset and offset times of each emotional expression were determined. Intercooder reliability has been established for this scoring procedure in a number of laboratories (cf. Ekman & Friesen, 1976; Ekman et al., 1980; Ekman, Friesen, & O'Sul-

ivan, 1988; Ekman, Friesen, & Simons, 1985; Fox & Davidson, 1988; Krause & Steimer, 1988; Ruch, 1987; Steiner, 1986). See the accompanying article (Ekman et al., 1990) for additional detail concerning the scoring of facial behavior and the reliability of the measurement procedure.

FACS scoring revealed that the two types of facial actions that occurred with the most frequency were happy expressions in response to the positive film clips and disgust expressions in response to the negative film clips. The type of happy expression used in this analysis was the "felt smile" (Ekman & Friesen, 1982), which has since been termed Duchenne's smile (see Ekman et al., 1988). In a number of studies, Ekman and his colleagues have found that only the frequency and duration of this smile, rather than other types of smiles, is significantly correlated with self-reports of happiness (e.g., Ekman & Friesen, 1982; Ekman et al., 1988). For each subject, the onset and offset of each happy and disgust expression were identified by FACS. These times were then input into the computer so that EEG coincident with these expressions could be extracted.

Artifact editing of EEG. All EEG records were visually scored for artifact. All eye movement and muscle artifacts were removed from the data prior to analysis. If artifact was present on any channel, data from all channels were removed so that the EEG data were always taken from coincident points in time.

EEG analysis. There were three major sets of EEG data that formed the basis of our analyses. The first set was derived from the positive film clips during those periods when happy expressions were present and from the negative film clips during those periods when disgust expressions were present. The second set was based on the entire durations of the positive and negative film clips, respectively. For this analysis, EEG was aggregated for all artifact-free periods, independent of facial expression, to form one set of data for the positive film clips and one for the negative film clips. The third data set consisted of the eyes-open baseline

¹ Vertex was used as a reference because of the extensive use of this recording montage in EEG studies of differential hemispheric activation (see Davidson, 1988, for a review).

condition, averaged across the pre- and postfilm trials. We considered the eyes-open baseline condition the most appropriate for comparison with the films because subjects had their eyes open during the film presentations.

For the data during facial signs of happiness and disgust, the onset and offset times of these facial expressions were entered into the computer along with the times during which artifact was not present. The computer then extracted those portions of the EEG record that were 1.02 s or longer in duration for analysis that corresponded to the overlap of these two criteria. For the analyses of the entire film period and the baseline trials, chunks of 2.05 s were extracted for analysis. Chunks of EEG (1.02- or 2.05-s periods) were extracted using a Hamming window. The purpose of the Hamming window is to minimize spurious frequencies in the estimates of spectral power. Chunks were overlapped by 75% to counteract the attenuating effect of the Hamming window and to improve the temporal resolution of the measure (see Dumermuth & Molinari, 1987, and Davidson, 1988, for a discussion of these methodological issues). A Fast Fourier Transform (FFT) was applied to each chunk of EEG. The FFT is an algorithm that decomposes any complex waveform into its underlying sine wave components. When applied to EEG, the FFT permits the computation of the amount of power at different frequencies. Power values from all chunks within an epoch were averaged (see Dumermuth and Molinari, 1987, for an extensive overview of this data-analytic procedure).

The dependent measures that were extracted from this analysis were power density (in $\mu\text{V}^2/\text{Hz}$) in the alpha (8–13 Hz) and beta (13–20 Hz) bands. These data were log transformed to normalize their distribution because power values are positively skewed (see Davidson, 1988, for a review of methodological issues in EEG asymmetry research). Power in the alpha band is inversely related to activation (e.g., Lindsley & Wicke, 1974) and has been the measure most consistently obtained in studies of EEG asymmetry (Davidson, 1988). Alpha power has been found to be more reliably related to task performance compared with power in other frequency bands, when the tasks that are compared are carefully matched on psychometric properties (Davidson, Chapman, Chapman, & Henriques, in press). We therefore expected that the emotion conditions would reliably differ on measures of alpha power asymmetry. Beta power was examined in light of some suggestions that alpha and beta power may reflect different components of activation (e.g., Ray & Cole, 1985). However, on the basis of our own previous findings, we expected the most consistent differences in asymmetry to be found for the alpha band.

Results

Hypothesis 1: EEG from the entire film period, independent of facial behavior, will not discriminate between positive and negative film conditions. For this analysis, all artifact-free EEG during each of the two positive and two negative films was analyzed. EEG power during each of the two positive films and each of the two negative films was separately averaged, to provide composite positive and negative data sets for each subject. Repeated measures analyses of variance (ANOVAs) were computed separately on the data from each of the four regions: frontal, anterior temporal, central, and parietal. The factors were condition (positive–negative films) and hemisphere (left–right). Evidence of a difference in asymmetry between the conditions would be revealed in a significant Condition \times Hemisphere interaction. For measures of alpha power, this interaction did not reach significance for any region. The highest F value was for the central leads, where the Condition \times Hemisphere interaction was $F(1, 6) = 2.59, p > .15$. All other F values for this interaction were below 1.5. No main effects for hemisphere were obtained for any region. The only condition main effect was found for the central leads, where the negative films were

associated with less alpha power compared with the positive films, $F(1, 6) = 51.81, p < .001$.

On measures of beta power, there were also no significant Condition \times Hemisphere interactions. The highest F value was for the central leads, where the Condition \times Hemisphere interaction was $F(1, 8) = 1.22$. All other F values were below 1.0. There were no significant main effects in any of these analyses.

These analyses on the entire film period indicate that when averaged across the whole film period, positive and negative film clips do not produce any reliable differences in EEG asymmetry in either the alpha or beta bands.

Hypothesis 2: Anterior asymmetry will discriminate between happy and disgust conditions. We predicted that the disgust condition would be associated with more right-sided and less left-sided frontal and anterior temporal activation compared with the happy condition. For these analyses EEG during facial signs of happiness and disgust was compared in ANOVAs with condition (happy–disgust) and hemisphere as factors. These ANOVAs were performed on EEG power in the alpha and beta bands, separately by region. The alpha data will be presented first.

The Condition \times Hemisphere interaction for the frontal region was highly significant, $F(1, 9) = 32.10, p < .0005$. As can be seen from Figure 1, the disgust condition was associated with less alpha power (i.e., more activation) in the right frontal region compared with the happy condition ($p < .01$). When individual subject data were examined, we found that 100% of the subjects showed more right-sided frontal activation during disgust versus happiness. Within the disgust condition, there was significantly less right alpha power compared with left frontal alpha power ($p < .01$). Although the happy condition was associated with less left frontal alpha power than the disgust condition, this difference failed to reach significance. In addition, there was no significant difference between the hemispheres within the happy condition. No main effects were obtained on measures of frontal alpha power in this analysis.

Hypothesis 2 also predicted the same interaction for the anterior temporal region. The ANOVA on alpha power in this region revealed a significant Condition \times Hemisphere interaction, $F(1, 9) = 6.32, p = .03$. These data are displayed in Figure 2.² As we had hypothesized, the disgust condition was associated with more right-sided activation (less alpha power) than the happy condition ($p < .01$) and the happy condition was associated with more left-sided activation than the disgust condition ($p < .05$). In addition, within the happy condition, there was less left- than right-sided alpha power ($p < .01$). Alpha power did not differ significantly between the two hemispheres in the disgust condition. When individual subject data were examined, we found that 70% of the subjects showed more relative right-sided anterior temporal activation during the disgust compared with the happy condition.

The same analyses as described above for the frontal and anterior temporal alpha data were also performed on beta power. Consistent with our previous work on cognitive asymmetries (Davidson et al., in press), no significant Condition \times Hemisphere

² As can be seen from Figure 2, the scale of power density in the anterior temporal region is different from that displayed for the frontal region in Figure 1. This difference between regions in absolute power is expected. The frontal region typically displays the least overall amount of alpha power (e.g., Ingvar, Sjolund, & Ardo, 1976).

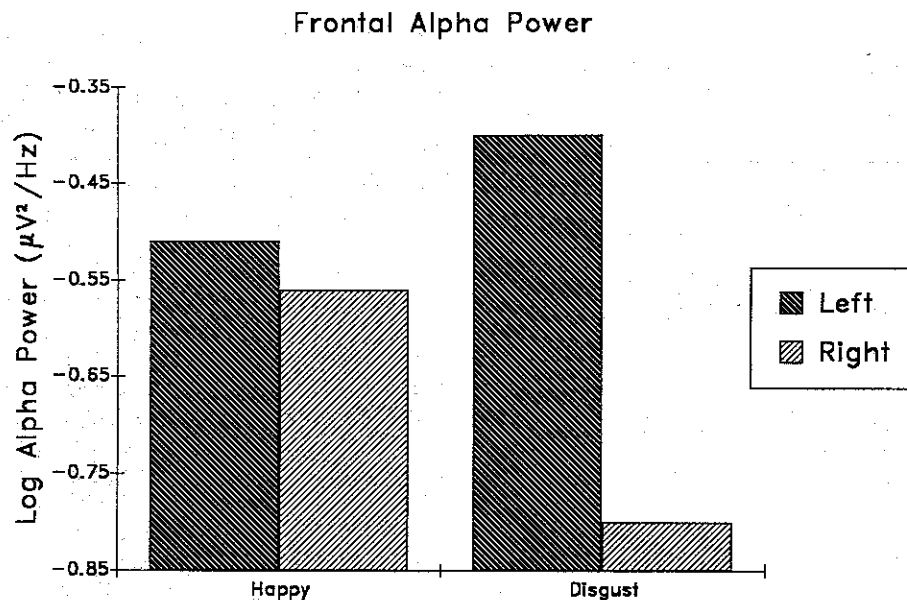


Figure 1. Mean log-transformed alpha power (in $\mu\text{V}^2/\text{Hz}$) for the left and right frontal regions (F3 and F4) during the happy and disgust facial expression conditions. (More negative numbers indicate less alpha power. The negative numbers are a function of the log transformation. Lower numbers (i.e., more negative) are associated with increased activation.)

sphere interaction was found for either frontal, $F(1, 9) = 0.33$, or anterior temporal, $F(1, 9) = 0.21$, beta power. In addition, no main effects were obtained in these analyses.

EEG was recorded from the central and parietal regions to ascertain the degree to which the asymmetries associated with emotion were specific to the anterior regions. The Condition (happy-disgust) \times Hemisphere interaction for alpha power data from the central and parietal regions failed to reach signifi-

cance: central, $F(1, 8) = 3.6$, $p < .10$; parietal, $F(1, 9) = 3.16$, $p > .10$. These same analyses were performed on beta power and again showed no significant Condition \times Hemisphere interaction: central, $F(1, 8) = 0.96$; parietal, $F(1, 9) = 2.33$, $p > .15$.

Thus, for activation measures based on alpha power, in both the frontal and anterior temporal regions, the disgust condition produces significant increases in right-sided activation compared with the happy condition. In the anterior temporal re-

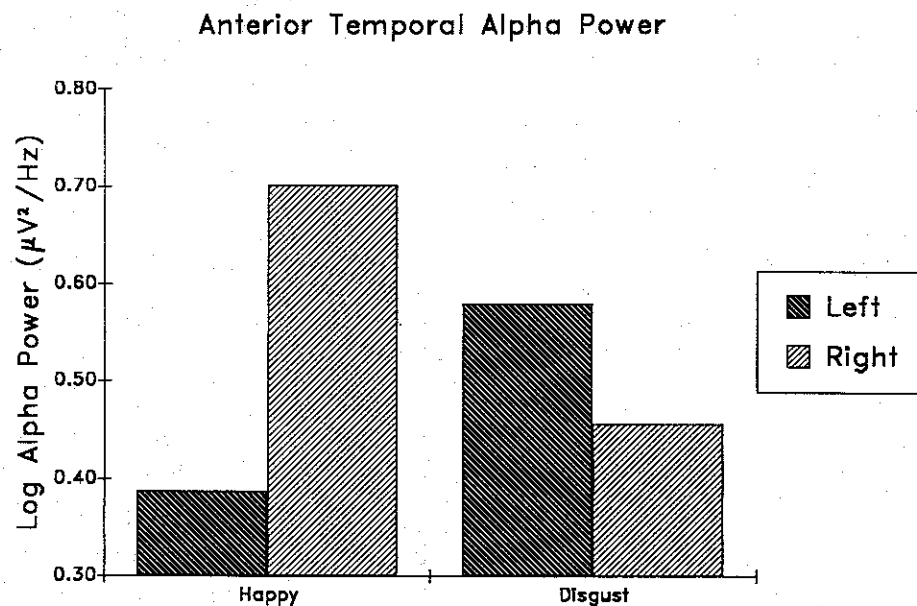


Figure 2. Mean log-transformed alpha power (in $\mu\text{V}^2/\text{Hz}$) for the left and right anterior temporal regions (T3 and T4) during the happy and disgust facial expression conditions. (Lower numbers are associated with increased activation.)

Table 2
Means of Left and Right Frontal Log Alpha Power
for the Baseline and Disgust Conditions

Condition	Left	Right
Baseline	-.168	-.163
Disgust	-.403	-.800

Note. The baseline means are the average of the pre- and postfilm eyes-open baseline periods. The negative sign of the numbers is due to the log transformation. Lower numbers are indicative of increased activation.

gion, but not in the frontal region, the happy condition is associated with more left-sided activation compared with the disgust condition. No differences in either alpha or beta power asymmetry between the happy and disgust conditions were found in the central or parietal regions.

Hypothesis 3: Both disgust and happiness will be discriminated from baseline on measures of anterior asymmetry. This hypothesis predicted that the disgust condition would be associated with a significant increase in right-sided anterior activation compared with baseline and that happiness would be accompanied by a significant increase in left-sided anterior activation compared with baseline. To test this hypothesis, we compared each emotion condition with baseline (average of pre- and postfilm baselines) in a series of 2×2 ANOVAs with condition (baseline-disgust or baseline-happy) and hemisphere as factors on both alpha and beta power data.

When disgust was compared with baseline in the frontal region, a significant Condition \times Hemisphere interaction was obtained, $F(1, 9) = 6.55, p < .04$. This interaction was a function of the disgust condition producing significantly less frontal alpha power in the right hemisphere compared with baseline ($p < .001$). No difference between the baseline and disgust conditions was found in left frontal alpha power. The relevant means are presented in Table 2. When individual subject data were examined, we found that 80% of the subjects showed more relative right-sided frontal activation during the disgust condition compared with baseline.

The comparison of the baseline and disgust conditions for the anterior temporal region failed to reveal a significant Condition \times Hemisphere interaction, $F(1, 9) = 1.89$.

To ascertain whether the difference between the baseline and disgust condition in alpha power asymmetry in the frontal region was a specific regional effect, we computed Condition (baseline-disgust) \times Hemisphere ANOVAs on the central and parietal data. The Condition \times Hemisphere interaction was not significant for either the central, $F(1, 8) = 1.38$, or parietal, $F(1, 9) = 4.00, p = .08$, regions.

We compared the baseline and disgust conditions on measures of beta power. The Condition \times Hemisphere interaction failed to reach significance for both the frontal, $F(1, 9) = 0.91$, and anterior temporal, $F(1, 9) = 3.98, p = .08$, regions. Thus, only in the frontal region and only for alpha power was disgust associated with significantly more right-sided activation (i.e., less alpha power) compared with baseline.

We next compared the happy condition with baseline. The Condition \times Hemisphere interaction for the alpha power data in the frontal and anterior temporal regions was not significant: frontal, $F(1, 9) < 1$; anterior temporal, $F(1, 9) = 1.13, p > .30$.

When these analyses were performed on measures of beta power, the Condition \times Hemisphere interactions were again not significant: frontal, $F(1, 9) < 1$; anterior temporal, $F(1, 9) < 1$. These findings indicate that the happy and baseline conditions do not differ on measures of anterior asymmetry computed on the basis of alpha or beta power.

Discussion

The findings from this study provide support for the proposal that patterns of brain physiology during the arousal of affect are emotion specific rather than undifferentiated. More specifically, this study is consistent with an approach-withdrawal model of lateralization for affect. The findings indicated that activation asymmetry in the anterior cortical regions differentiates between positive and negative emotions that have been associated with approach and withdrawal. Finally, the manner in which this study was conducted and the pattern of results that emerged have important methodological implications for physiological studies of emotion. We first will discuss the methodological implications and limitations of this research and then consider the substantive theoretical issues on which these findings bear.

Methodological Implications and Limitations

The findings from this study indicate that when data are averaged across the entire film period, positive and negative film conditions are not reliably distinguished on the basis of EEG asymmetry. The manner in which the data from the entire film period are analyzed is the typical strategy used in the study of physiological responses to emotion elicitors. In this type of analysis, no procedures are used to verify that the intended emotion was actually produced in the subject. When an individual is exposed to an elicitor such as a film, there are periods during the presentation of the stimulus when little or no emotion is present as well as periods during which emotions inconsistent with the target emotion are produced. The difference in the outcome of the analyses from data extracted on the basis of facial signs of emotion is considerable. When facial criteria are used to verify the presence of the target emotion and to specify onset and offset times for data extraction, differences in asymmetry emerge that distinguish between disgust and either happy or baseline conditions.

In the search for physiological differentiation among emotions, it is imperative to verify the presence of the target emotion using both self-report and behavioral criteria. One advantage of using facial behavior to flag portions of the physiological record to be extracted for analysis is that onset and offset times for an emotion condition can be readily specified. This would not be possible using conventional self-report methods.

One limitation of the use of facial action to flag onset and offset times is the current lack of knowledge concerning the significance of these time markers. It is not certain whether the onset of the facial expression denotes the onset of an emotional experience, or whether emotional experience may begin prior to the onset of emotional expression. Perhaps even more problematic is the significance of facial expression offset. It may be that facial action returns to baseline after a certain period of time has elapsed solely as a function of muscular fatigue. Whether the return of the face to a neutral expression in such a situation also signifies the attenuation of emotion is not cur-

rently known. We attempted to examine brain activity before and after facial signs of emotion. However, we were unable to extract a sufficient duration of artifact-free periods that were temporally isolated from adjacent expressions. It is clear that future studies must begin to unravel the complex temporal relations among expressive, physiological, and subjective signs of emotion. Until basic research of this nature is performed, the dynamic relations among the subcomponents of the emotion "package" remain elusive.

In this study, we computed measures of activation based on both alpha and beta power. As we had expected, the emotion conditions were discriminated only on measures of alpha power. We believe that many of the previous studies in the cognitive EEG asymmetry literature that have found task-dependent changes in beta activity suffer from two significant flaws: (a) the failure to match the cognitive tasks that were used on basic psychometric characteristics, and (b) the failure to convincingly remove muscle artifact from the EEG. The latter problem is very significant because the frequency spectrum of EEG and muscle activity overlap in the beta range. In this study, the positive and negative film clips were carefully matched and care was taken to remove all muscle and movement-related artifact from the EEG. When similar controls are exercised in cognitive studies, it is also asymmetries in alpha power, not beta power, that best discriminate between verbal and spatial cognitive tasks (Davidson et al., in press).

There were three specific methodological limitations of this study that deserve emphasis. The first concerns the fact that the positive and negative film clips were not counterbalanced. The positive clips always preceded the negative clips. We chose to present the clips in this order because of our concern with carry-over effects. Although it is true that the manner in which we selected the epochs for analysis would guarantee that EEG was extracted during a discrete facial expression of emotion, we expected that if the negative films were presented first, the negative mood produced by the negative film clips would carry over and decrease the incidence of facial expressions of happiness. When these same film clips were used in previous research, the positive clips were always presented first (Ekman et al., 1980). Nevertheless, it is possible that the differences in anterior EEG asymmetry between happiness and disgust may be a function of the order in which these clips were presented. Subjects might have been more fatigued later in the session, with the fatigue affecting the threshold for change in certain brain regions more than others. We consider this explanation unlikely because in the comparison between the happy and disgust conditions in anterior asymmetry, there were no main effects for condition across hemisphere. If subjects were more fatigued during the disgust compared with the happy condition, we would have expected overall differences in brain activation. Moreover, the fact that the disgust condition was found to differ from baseline in frontal asymmetry cannot be attributed to shifts over the course of the session in baseline activity because the baseline data used in the analyses were the average of the pre- and postfilm baselines. Thus, the baseline trials came from both the beginning and end of the session. Nevertheless, in future studies, the positive and negative film clips could be presented on separate days, with the day on which each type is presented counterbalanced.

The second methodological limitation of this study is the manner in which intensity was matched for the positive and negative films. We established that self-reports in response to

these film clips are equated in intensity. However, the self-report data presumably reflect the subjects' aggregation over the entire length of the film clip. This procedure does not ensure that the specific expression periods that were extracted for analysis were matched on intensity. It is not even clear how such intensity matching should be accomplished. It may be possible in future research to have subjects retrospectively review a split-screen image of their facial behavior and the film clip and have them make ratings of those moments during which the target expressions were present. It should be noted that Ekman et al. (1980) examined the relation between a measure of facial expression intensity and self-reports of emotional intensity in response to the same clips used in this study. Ekman et al. reported a significant correlation between these measures, suggesting that when subjects rate intensity in response to these particular clips, their ratings reflect the intensity of their facial expressions.

The third limitation that deserves mention is the substantial subject attrition that was present. Thirty percent of the original sample was eliminated initially as a function of not showing at least one instance each of a happy and disgust expression during the positive and negative film clips. This figure is comparable to what has been previously reported using the identical film clips (Ekman et al., 1980). Most of the remaining subjects who were eliminated were removed because of excessive artifact in the EEG. We unfortunately did not record the electrooculogram (EOG) on our computer and therefore could not use an automated eye-movement correction algorithm (e.g., Gasser, Sroka, & Mocks, 1986; Gratton, Coles, & Donchin, 1983). However, such a procedure would only have recovered a small number of records because most of the artifact was movement related. We should note that the differences in self-reported emotion between the subjects who were retained and those who were removed (after the initial cut made on the basis of the presence of the target facial expressions) were slight and nonsignificant. The subjects who were removed rated the intensity of the target emotions slightly more extremely than the subjects who were retained. Thus, if anything, the artifact rejection procedure actually biased the final sample in the direction of less intense emotional responses. One strategy we attempted in the pilot experimentation prior to the conduct of this study was to instruct subjects to remain very still during the presentation of the film clips, to reduce the amount of movement-related artifact. Although the provision of such an instruction did succeed in reducing movement artifact, it also had the unfortunate effect of dramatically reducing facial behavior in response to the film clips. We thus eliminated this instruction, believing that we would actually obtain more usable data without it. It is clear that research of this kind requires a very substantial sample size so that subject loss due to artifact is tolerable. A very large sample would also facilitate the study of the temporal relation between changes in brain activity and facial behavior. In this study, we were prevented from performing such analyses because of the paucity of available data.

Physiological Differentiation Among Emotions

As noted in the introduction, there is increasing support for the notion that emotions differ in their underlying physiological patterns. Ekman (1984) predicted that such differentiation would be found in both the autonomic and central nervous sys-

tems. Ekman, Levenson, and their colleagues (Ekman et al., 1983; Levenson et al., in press) have obtained robust autonomic differentiation between positive and negative emotions and among four negative emotions.

Although the data presented in this report only involve two emotions, the evidence is nevertheless consistent with the general notion of physiological differentiation. The degree to which EEG asymmetry will distinguish among different emotions is currently not known. However, as noted above, we would predict that to the degree that an emotion is associated with either approach or withdrawal, it should be associated with left- versus right-sided anterior activation. Thus, according to this model, two emotions that are each associated with withdrawal (such as fear and disgust) should both be associated with right-sided anterior activation. It should be noted that this view is not inconsistent with the notion of psychophysiological specificity. Two emotions that are similar in anterior activation asymmetry should differ in some other measure of central nervous system function. For example, a number of workers (e.g., Garcia, Quick, & White, 1984) have noted that disgust is associated with heightened sensitivity to the perceptual attributes of the eliciting stimulus. We would therefore expect more neural activity in circuits that mediate certain perceptual processes during disgust compared with fear.

Cerebral Asymmetry and Approach-Withdrawal

The findings from this study provide support for the hypothesis that negative affect associated with withdrawal is accompanied by right-sided anterior activation. In both frontal and anterior temporal regions, the disgust condition produces significantly more right-sided activation compared with the happy condition. In addition, in the frontal region, the disgust condition produced more right-sided activation compared with baseline.

We predicted that the happy condition would produce more left-sided activation compared with both the disgust condition and baseline. In the anterior temporal region, the happy condition did produce significantly more left-sided activation compared with disgust. However, there was no difference in asymmetry between the happy and baseline conditions in any brain region. Therefore, one component of Hypothesis 3 was not confirmed by our results.

Davidson (1984a) has proposed that the fundamental basis of the anterior asymmetry associated with emotion is approach-withdrawal. To the extent that a positive emotion is accompanied by approach, he would expect it to be associated with left anterior activation. However, not all forms of positive affect include an approach component. Ekman and Friesen (1982) proposed that the "happiness" expression coded in this study can mark a number of rather different positive affective states including amusement as well as several forms of happiness. The primary positive emotion elicited by the positive film clips in this study was amusement. Although some types of amusement may involve the activation of approach behavior, we believe that in this study, in which amusement was aroused by watching a film of monkeys and gorillas playing, the tendency to approach was weak or nonexistent. We believe this is the reason for our failure to find left anterior activation relative to baseline during the happy condition. Other forms of positive affect are associated with unambiguous approach, such as the reaction of many

10-month-old infants to the advance of their mothers. Infants in this situation often reach out toward the mother as she draws nearer, showing a clear behavioral manifestation of approach. In this situation, evidence of strong left frontal activation relative to baseline has been found (Fox & Davidson, 1987, 1988).

It would be essential to examine EEG asymmetry during such "approach happiness" and compare it in the same subjects to other nonapproach forms of positive affect, such as some forms of amusement, in order to evaluate this hypothesis. One major methodological problem in evaluating this hypothesis is the need to obtain an independent measure of "approach tendency." In adults, it may be possible to obtain an index of this construct with a self-report inventory. Measurement of electromyographic activity in the forearm or leg might also provide a useful index. It would be ideal to include both self-report and electromyographic measures in the same subjects to establish construct validity. In infants, approach tendencies are typically quite overt and are easily measured. In the Fox and Davidson (1988) study, most infants in the mother approach condition literally reached out toward their mothers.

It is essential to note that the rationale presented above is admittedly post hoc, and other alternative interpretations of our data are possible. For example, it might be argued that the right-sided activation observed during disgust reflects the arousal of emotion per se and is not a specific sign of negative affect. It is clear that subjects are reporting positive emotion in response to the positive film clips and that such positive emotion is significantly correlated with the duration of facial signs of felt happiness (see Ekman et al., 1990). However, right-sided activation was not found during this condition. This finding argues against the suggestion that right-sided anterior activation is indexing the arousal of emotion per se.

One question raised by the approach-withdrawal interpretation of our data is whether the anterior asymmetry is reflecting emotion or approach-withdrawal per se. We believe that certain emotions include hard-wired approach or withdrawal tendencies. For example, both fear and disgust include a withdrawal component, whereas certain forms of anger and happiness include an approach component. Superimposed on these hard-wired action tendencies are learned components that can accentuate, attenuate, or even replace the approach or withdrawal patterns. For example, some individuals learn to approach situations they fear. Anger is an emotion that is sometimes associated with approach and at other times associated with withdrawal. In future research it will be instructive to compare instances of the same emotion when it is accompanied by approach versus withdrawal so that the relative contributions to anterior asymmetry of the emotion per se and the action tendencies with which it is associated can be systematically disentangled.

Activation asymmetry in the central and parietal regions failed to differentiate between the happy and disgust conditions. This finding, in conjunction with the frontal and anterior temporal differences, underscores the importance of asymmetry in these anterior cortical zones for emotion. Both the frontal and anterior temporal regions have extensive anatomical reciprocity with limbic circuits that have been directly implicated in the control of emotion (e.g., Myers, 1972; Nauta, 1971). Moreover, a number of recent studies that have used the appropriate procedures for measuring either activation or neurochemical activity in these subcortical regions in humans have uncovered

asymmetries related to emotion and cognition (e.g., Reiman, Raichle, Butler, Herscovitch, & Robins, 1984; Reynolds, 1983). Many investigators have proposed an important role for the frontal and anterior temporal cortical regions in emotion (e.g., Rolls, 1986). The lack of a difference in parietal asymmetry between the happy and the disgust periods suggests that these conditions did not differ in the cognitive processes that are mediated by this brain region. The data from this study also indicate that central asymmetry does not distinguish between happiness and disgust. If the difference between these conditions had been associated with asymmetries in motor control, we would have expected the central region to reliably distinguish between them. The fact that it did not suggests that the difference between these conditions is in a process other than motor asymmetries per se.

Although this article has treated emotion across individuals as an independent variable, we believe that the approach has important implications for the study of individual differences in emotional reactivity. The task-dependent differences in anterior EEG asymmetry that we demonstrated in this study are superimposed on wide-ranging individual differences in the direction and magnitude of asymmetry in this region. Such individual differences in activation asymmetry have been noted by a number of investigators (e.g., Glass, 1987; Levy, 1983). Individual differences in EEG measures of activation asymmetry have been found to be stable over time (e.g., Amochaev & Salamy, 1979; Ehrlichman & Wiener, 1979). In several recent studies, we have demonstrated that individual differences in anterior EEG asymmetry are related to emotional reactivity and vulnerability to psychopathology in both infants and adults (Davidson & Fox, 1989; Tomarken, Davidson, & Henriques, 1989; see Davidson & Tomarken, 1989, for a review). We have interpreted such individual differences in anterior asymmetry to mark a threshold for the experience of certain positive and negative emotions.

A central purpose of this study was to examine differences in anterior asymmetry between a withdrawal-related negative emotion and an approach-related positive emotion. The data strongly supported our hypothesized difference in asymmetry between these conditions in both the frontal and anterior temporal regions. The study was also designed to illustrate the use of a multiprocess research paradigm in the study of the psychophysiology of emotion. Using such a paradigm, we demonstrated the importance of rigorous verification criteria to establish that the intended emotion was actually produced. The accompanying report (Ekman et al., 1990) of our joint research shows the importance of distinguishing among different forms of smiling if one is to separate moments of enjoyment from other experiences. It also underscores the significance of cerebral asymmetry for the study of emotion and provides a second example of the utility of combining measures of brain activity and facial expression in emotion research.

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Received June 29, 1988

Revision received May 25, 1989

Accepted July 17, 1989 ■