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Frontal Brain Asymmetry Predicts Infants' Response to Maternal Separation

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Examined whether certain features of infant temperament might be related to individual differences in the asymmetry of resting frontal activation. EEG was recorded from the left and right frontal and parietal scalp regions of 13 normal 10-month-old infants. Infant behavior was then observed during a brief period of maternal separation. Those infants who cried in response to maternal separation showed greater right frontal activation during the preceding baseline period compared with infants who did not cry. Frontal activation asymmetry may be a state-independent marker for individual differences in threshold of reactivity to stressful events and vulnerability to particular emotions.

In a series of studies, we have recently reported differential activation of the cerebral hemispheres during the processing of positive and negative emotion in young infants (Davidson & Fox, 1982; Fox & Davidson, 1986, 1987, 1988). Specifically, using electrophysiological procedures to infer asymmetric hemispheric activation in response to a wide variety of affect elicitors, we have reported that the left frontal region is relatively more active during the expression of certain positive emotions and the right frontal region is more active during the expression of certain negative emotions (for reviews, see Davidson & Fox, 1988; Fox & Davidson, in press). These findings are similar to studies in adults using both behavioral measures (e.g., Davidson, Mednick, Moss, Saron, & Schaffer, 1987) and electroencephalographic (EEG) measures of regional hemispheric activation (e.g., Ahern & Schwartz, 1985; Davidson, Schwartz, Saron, Bennett, & Goleman, 1979; Tucker, Stenslie, Roth, & Shearer, 1981; for reviews, see Davidson, 1984, 1988a; Leventhal & Tomarken, 1986; Silberman & Weingartner, 1986; Tucker, 1981).

These observations are consistent with evidence from research on brain-damaged subjects showing differences in emotional expressivity associated with left- and right-hemisphere lesions (Gainotti, 1972), particularly in the frontal region (e.g., Robinson & Benson, 1981; Robinson, Kubos, Starr, Rao, & Price, 1984). Robinson and his colleagues (Robinson et al., 1984) have found that left anterior lesions are associated with depressive symptomatology whose phenomenology is strikingly similar to that observed in unipolar "functionally" depressed patients (Lipsey, Spencer, Rabins, & Robinson, 1986).

Several authors have noted the pronounced variability in degree and nature of hemispheric asymmetry found among right-handed subjects performing tasks during which behavioral measures of asymmetrical processing are obtained. In accounting for this diversity, Levy and her associates have argued that such variation may be largely due to individual differences in "hemispheric arousal" (Levy, 1983; Levy, Heller, Banich, & Burton, 1983). In advancing this notion, these investigators emphasized the distinction between hemispheric activation and hemispheric specialization and suggest that diversity among individuals in the former may be "superimposed on a relatively invariant pattern" (Levy, 1983, p. 476) in the latter. As Levy (1983) herself noted, individual differences in baseline or resting EEG activation asymmetry may provide a potentially more direct measure of hemispheric activation than behavioral measures permit.

Such individual differences in hemispheric activation may be important in our understanding of temperamental differences in infants and young children. For example, Goldsmith and Campos (1986) have defined temperament as individual differences in the probability of experiencing and expressing the primary emotions. Kagan and his associates have suggested that individual differences in the tendency to approach or to withdraw from unfamiliar events is a major dimension of temperamental variation among infants as well as adults (e.g., Coll, Kagan, & Reznick, 1984; Kagan, Reznick, Clarke, Snidman, & Coll, 1984; Kagan, Reznick, & Snidman, 1988). Moreover, Kagan (1984) noted that individual differences in the tendency to become distressed is a highly stable quality from the beginning of life. Additional evidence suggests that this tendency is influenced by genetic factors (Wilson, Brown, & Matheny, 1971). The study of such individual differences in infancy is particularly attractive because it is commonly assumed that the link between temperament and behavior is relatively direct at this age but becomes more complex as the child matures (Goldsmith et al., 1987).

Very few studies have examined relations between individual differences in resting frontal activation asymmetry and affective

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style. Resting EEG spectral power and the asymmetry of spectral power are both highly stable over time (e.g., Amocheav & Salamy, 1979; Ehrlichman & Weiner, 1979; Fein, Galin, Yingling, Johnstone, & Nelson, 1984; Gasser, Bacher, & Steinberg, 1985; Morgan, McDonald, & MacDonald, 1971; Tomarken & Davidson, 1988a), although none of these studies used infants as subjects.[1] A recent study (Schaffer, Davidson, & Saron, 1983) found that resting asymmetries in the frontal region were related to individual differences in self-reports of depression. Those subjects who had high scores on the Beck Depression Inventory showed more relative right-sided frontal activation during a resting baseline compared with subjects scoring in the nondepressed direction. We have recently successfully replicated these findings on a larger group of similarly selected subjects (Davidson & Henriques, 1988). Studies using measures of resting regional cerebral glucose utilization have also found individual differences in the asymmetry of these indices to predict aspects of affective function (Reiman, Raichle, Butler, Herscovitch, & Robins, 1984). Such individual differences in anterior activation asymmetry have been conceptualized as indexing a vulnerability to biased emotional responding whose valence is dependent upon the direction of asymmetric activation. According to this scheme, right frontal activation marks a specific vulnerability to experience certain negative emotions, which in conjunction with the presence of an appropriate elicitor, will result in the expression of such negative affect.

The present study was designed to examine the relation between individual differences in baseline frontal EEG asymmetry and the behavioral response of 10-month-old infants to maternal separation. We chose to focus on individual differences in response to this stressor because several workers have noted the pronounced differences among infants of this age in response to this situation (e.g., Shiller, Izard, & Hembree, 1986; Weinraub & Lewis, 1977). Moreover, infants' response to this stressor at this age period is related to a constellation of behaviors that are associated with individual differences in the vulnerability to distress, a dimension of temperament for which impressive longitudinal stability has been demonstrated (for review, see Kagan, 1984). We specifically predicted that infants who responded with distress to maternal separation would show more right frontal activation during a baseline assessment of EEG compared with infants who were not distressed by the situation.

Method

Subjects

Thirty-five 10-month-old female infants (mean age = 10.2 months), each born to two right-handed parents, were tested in this study. Female infants were tested because all of our previous infant work has involved female subjects (e.g., Davidson & Fox, 1982; Fox & Davidson, 1987, 1988). We were able to obtain usable behavioral and sufficient EEG data during the baseline period (see later) on 13 of the subjects. The high subject attrition was due to excessive movement and related artifact present in the EEG records. Attrition rates between 40% and 65% have been the norm in our previous research using infants of this age (Davidson & Fox, 1982; Fox & Davidson, 1987) as well as in other electrophysiological research with infants (e.g., Nelson & Salapatek, 1986).

To ascertain whether the infants who were eliminated because of excessive artifact were temperamentally any different from those that were retained, we had the mothers rate their infants' on the Carey (1970) scale of infant temperament. We found no differences on any measure between the infants who were eliminated compared with those who were retained.

Procedure

Infants were seated at a feeding table while they were exposed to several stimulus situations, including the approach of her mother followed by maternal separation. After a standardized approach sequence, the mother was instructed to leave the room. The duration of this period was 60 s unless the infant was judged by the experimenter to be extremely upset, at which time the period was terminated by having the mother re-enter the subject room and comfort her baby. Prior to the initiation of the approach sequences, a 30-s baseline recording of EEG was obtained. The baseline measures were taken while the mother was in the room with her infant. She was instructed not to interact with her infant during this period. During all periods of the experiment, infant behavior was videotaped.

Apparatus and Recording Procedure

The EEG was recorded from the left and right frontal and parietal scalp regions (F3, F4, P3, and P4) referred to a common vertex (Cz) during the 30-s baseline period (see Davidson, 1988b, for a discussion of methodological issues in the recording of EEG asymmetry). EEG was recorded with a lycra stretchable cap that permitted rapid and reliable attachment of electrodes. Each of the four EEG leads was amplified on a Grass Model 7 polygraph, with the output of each channel recorded on separate channels of a Vetter Model D Instrumentation Recorder for subsequent off-line analysis. Behavioral (i.e., from videotape) and physiological data were synchronized by placing event markers coincident with the onset and offset of each event on both the instrumentation recorder and the videotape.

The EEG was low-pass filtered at 44 Hz (48 db/octave cutoff) to prevent aliasing and then digitized off-line on a PDP 11/34A computer at 125 samples/s. All epochs confounded by movement, muscle, or eye movement artifact were eliminated prior to further analysis. If artifact was present in any channel, the data from all of the remaining channels were also eliminated so that all between site comparisons reflect the identical points in time. The EEG was Fourier transformed using a chunk size of 2.05 s. Chunks were overlapped by 75% and averaged across all artifact-free data within an epoch. We required a minimum of 4 chunks of artifact-free data during the 30-s epoch to retain the subject for analysis. Power density (in squared microvolts per hertz) was computed for the 6–8 Hz frequency band since this band has been described as the precursor in infants 10–12 months of age to adult alpha activity (e.g., Lairy, 1975; Mizuno et al., 1970). In addition, decreased power in this band has been used as an index of activation in our previous research with infants of this age (Fox & Davidson, 1987). The power values were log-transformed to normalize their distributions.

The videotapes were coded by two observers blind to the experimental hypotheses. The observers used Izard's (1979) Maximally Discriminative Facial Action Coding System (MAX), which allowed coding of the presence of nine primary discrete facial expressions of emotion (anger, fear, distress/pain, joy, sadness, interest, disgust, surprise, and

[1] Like our study, most of these studies used Cz as a reference site (Amocheav & Salamy, 1979; Ehrlichman & Wiener, 1979; Fein, Galin, Yingling, Johnstone, & Nelson, 1984; Tomarken & Davidson, 1988a), including those studies that specifically examined the reliability of indices of asymmetry (Amocheav & Salamy, 1979; Ehrlichman & Wiener, 1979; Tomarken & Davidson, 1988a).

shame) plus blends. In addition, coders noted the presence or absence of crying during the maternal separation condition. Interrater reliability for the coding of positive affect (joy and interest) was 0.88 and for the coding of the negative expressions, 0.80. The validity of this facial coding system for discriminating between different affect elicitors in infants has been established in both our laboratory (e.g., Fox & Davidson, 1986, 1987) as well as in others (e.g., Shiller et al., 1986).

Results

We coded the infants response to the maternal separation challenge. Of the 13 infants who had sufficient usable EEG during the baseline period, 6 were coded as criers and 7 as noncriers during the maternal separation period. This classification was made dichotomously. An infant was classified as a noncrier only if she showed no evidence of crying for the entire duration of the maternal separation episode. The classification of an infant as a crier or noncrier was done prior to any EEG analysis and was therefore completely blind.

The essential question we posed in this study was whether these groups which differed in their response to maternal separation could be discriminated on the basis of resting brain electrical asymmetry. We specifically predicted that the criers would show greater relative right frontal activation during the preceding baseline period. The amount of artifact-free data we extracted from the baseline period was 14.2 s for the criers (SD = 3.9) and 16.1 s for the noncriers (SD = 3.1).

An analysis of variance (ANOVA) with group (crier/noncrier), hemisphere (left/right) and region (frontal/parietal) as variables was performed on the log-transformed 6–8-Hz band power. The two groups were equivalent on overall power across region and hemisphere as revealed by the complete absence of any main effect for group, $F(1, 11) = .09$. As predicted, a highly significant Group × Hemisphere × Region interaction was obtained, $F(1, 11) = 12.85, p = .004$. This interaction is displayed in Figure 1. As can be seen from this Figure, the differences between groups are pronounced in the frontal region. This is supported by the significant Group × Hemisphere interaction for the frontal region, $F(1, 11) = 8.15, p < .02$. No significant effects were obtained for parietal 6–8-Hz power. In the frontal region the noncriers had more left frontal activation (i.e., less 6–8-Hz power) than did the criers (p < .06), and the criers had more right frontal activation than did the noncriers (p < .01). In addition, the noncriers showed significant (p < .05) left-sided frontal activation (i.e., less power in the left vs. right lead), whereas the criers showed significant (p < .01) right-sided frontal activation (i.e., less power in the right vs. left lead).

To examine the consistency of this effect on an individual subject basis, we derived a single metric to capture the asymmetry of 6–8-Hz power in the frontal leads for each subject. This metric was a laterality difference score (log right power − log left power). Every one of the criers fell below the mean score for the noncriers and every one of the noncriers fell above the mean score for the criers. Moreover, all but one of criers had absolute right-sided frontal activation.

In light of the apparent opposite pattern of asymmetry in the frontal and parietal regions for both groups (see Figure 1), we computed correlations between the laterality index for each of the two regions across all subjects. No significant relation between frontal and parietal asymmetry was found (r = .10).

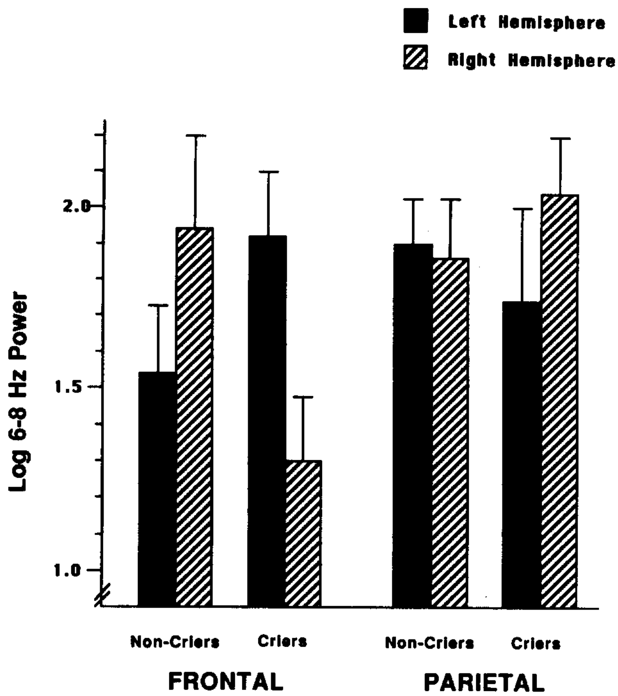

Figure 1. Mean log 6-8–Hz power for the resting baseline period in the left and right frontal and parietal regions for criers (N = 6) and noncriers (N = 7). (Decreases in 6-8–Hz power are indicative of increases in activation. Error bars indicate standard errors of the mean.)

We next addressed the question of whether our two groups of infants differed in their pattern of emotional expressivity during the baseline period when the EEG data were collected. If we found differences between the groups in the incidence and duration of particular facial signs of emotion, the baseline EEG effect we report might conceivably be a function of phasic differences in emotional state between the groups. Accordingly, we coded the infants' facial behavior during the resting baseline period and compared the duration of different facial signs of emotion for the criers and noncriers during this period. Table 1 presents these data split by group. As can be seen, there were no differences in the duration of any of the emotion expressions coded during baseline between the criers and noncriers.

Discussion

These findings indicate that infants' distress response to separation can be predicted from prior measures of baseline frontal activation asymmetry. Those infants who showed right-sided frontal activation during rest were more likely to cry upon maternal separation. Of the 6 infants who cried in this situation, only one did not show absolute right frontal activation during the baseline period (i.e., less 6–8-Hz power in the right vs. left frontal lead). Consistent with a large body of previous evidence (for reviews, see Davidson, 1984; Tucker & Frederick, in press), the effect reported here is specific to the frontal region. No reliable group differences were obtained in measures of parietal asymmetry recorded from the same points in time.

It is noteworthy that no main effect for group was obtained

Table 1
Facial Signs of Emotion During the Baseline Period

Facial sign	Criers	Noncriers
Interest		
M	9.5	11.3
SD	8.6	7.8
No expression		
M	17.0	15.1
SD	8.2	8.9
Joy/surprise		
M	2.4	3.2
SD	2.9	3.2
Negative affect		
M	0.5	1.4
SD	0.9	1.3

Note. Mean duration in seconds of facial affect for criers ($N = 6$) and noncriers ($N = 7$) during the baseline period. The no expression category represents the mean number of seconds during which no facial signs of emotion were present. The negative affect category represents the mean number of seconds during which facial signs of any of the negative emotions (anger, fear, distress, sadness, and disgust) were expressed.

on EEG power. The lack of any group main effect indicates that the two groups did not differ in overall EEG activation, but only in the pattern of activation between the two hemispheres. This lack of any group main effect is important because it suggests that the groups did not differ in overall arousal.

One limitation of the current study is that it is based on only that subset of infants from whom artifact-free data was obtainable. It is conceivable that these subjects differ in some as yet unmeasured way from those that had to be excluded because of excessive movement artifact. In future studies, it would be advisable to include several 30-s baseline periods to increase the number of subjects who show a sufficient amount of artifact-free data to analyze.

It might be argued that the difference in frontal asymmetry between the criers and noncriers simply reflects phasic mood differences between these groups during the baseline period. According to this view, the infants who subsequently cried in response to maternal separation might have entered the lab in a more dysphoric mood state and our EEG measures during the baseline period might simply have reflected these phasic mood differences between the groups. Our measures of facial behavior during the baseline period revealed no differences between groups. This finding argues against the notion that these groups of infants differed in phasic mood at the start of the experiment. If such differences existed, they would most likely have been reflected in the baseline period facial behavior.

It is also possible that the asymmetry between criers and noncriers reflects the infants' response to the laboratory procedure (i.e., electrophysiological recording). Some subjects might be more affected by this procedure than others. Whether the subjects who were more affected were also those with greater resting right frontal activation is not possible to answer in this single experiment.

The view of the frontal asymmetry difference between groups presented here is consistent with recent research on relations between individual differences in frontal asymmetry and reactivity to affective elicitors in adults. Tomarken and Davidson (1988b) have found in two separate studies that baseline eyes-open frontal activation asymmetry is correlated with the intensity of self-reports of fear and disgust in response to negative affective film clips. Specifically, the greater the right-sided frontal activation during rest, the more intense the self-reports of these negative emotions in response to the film. Recordings of parietal asymmetry from the same points in time during the baseline period are unrelated to subsequent self-reports of emotion in response to the film clips. Whatever the specific mechanism ultimately is found to be for the bias in affective responding found among subjects with relative right frontal activation, when this pattern is present the threshold for experiencing negative affect in response to an appropriate elicitor is lowered.

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