Behavioral and Physiological Antecedents of Inhibited and Uninhibited Behavior[1]

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Abstract:
4-month-old infants were specifically selected for patterns of affective and motoric reactivity that were hypothesized to be associated with later inhibited and uninhibited behavior. Infants were classified as high on motor activity and negative affect, high on motor activity and positive affect, or low on motor activity and affect. Brain electrical activity was assessed in these infants at 9 months of age, and behavior toward novelty was observed at 14 months of age. Infants who were high on motor activity and negative affect exhibited greater right frontal EEC activation at 9 months of age and inhibited behavior at 14 months of age. Infants classified as high motor/high positive at 4 months of age exhibited uninhibited behavior at 14 months of age. No relations were found between frontal asymmetry at 9 months of age and inhibited behavior at 14 months of age. However, greater activation in both the left and right frontal hemispheres was associated with higher inhibition scores at 14 months of age. These findings are discussed in terms of the role that affective and physiological reactivity may play in the development of social behavior during toddlerhood.

Article:
Current theories of infant temperament share at least three assumptions. First, there is general consensus that temperament has a biological and/or genetic basis. The extent to which this issue is stressed in different theoretical/empirical paradigms varies. A number of researchers have identified behavioral style differences between monozygotic and dizygotic twins and have argued that aspects such as sociability or rhythmicity are traits with a strong genetic basis (Plomin & Daniels, 1986; Wilson & Matheny, 1986). Others have investigated physiological differences associated with temperamental behaviors that may imply a strong psycho-physiological link in early infancy. In Rothbart's model, for example, it is presumed that behavioral reactivity is a function of underlying physiological reactivity (Derryberry & Rothbart, 1984; Rothbart & Derryberry, 1981; Rothbart & Posner, 1985). Attempts to assess this dimension of reactivity have focused on patterns of autonomic and central nervous system activity that may be associated with different patterns of affective response. Moreover, this type of research has found links between physiological and behavioral reactivity and regulation, and

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their relation to social and emotional development (see Fox & Calkins, 1994, and Gunnar, 1991, for reviews of this research).

A second point of agreement among current theories of temperament is the emphasis on stability over time in certain patterns of behavioral style. While it is unusual to find stable individual behaviors across the first years of life, a number of reports have identified more macro level concepts (such as the tendency to either approach or withdraw) that seem to exhibit some degree of stability during infancy and early childhood (Broberg, Lamb, & Hwang, 1990; Kagan, Reznick, Snidman, Gibbons, & Johnson, 1988). The continuity in the display of certain temperamental traits may be more a function of similarities across age in clusters of behaviors that may cohere, as opposed to stability in terms of individual behaviors.

A third point of agreement among temperament theorists is the notion that one can understand patterns of temperament by analyzing the mariner in which emotions are expressed and regulated (Buss & Plomin, 1984; Fox, 1989; Goldsmith et al., 1987; Rothbart & Derryberry, 1981). Among those who articulate a theory of emotion and temperament are Rothbart (1989) and Goldsmith (Goldsmith et al., 1987). Each has described temperamental differences as the manner in which infants and children vary in their emotional reactivity and in their ability to regulate emotional responses. So, for example, infants may differ in their tendency to express either positive or negative emotions to novelty, and they may also vary in their ability to modulate those affect states.

Recent studies of behavioral inhibition serve as an example of research that has attempted to meet each of the three assumptions of current theories of temperament. Kagan and colleagues have used the term "behavioral inhibition" to describe the tendency of some infants and young children to withdraw and show negative affect in response to new people, places, events, and objects (Garcia-Coll, Kagan, & Reznick, 1984). This tendency, Kagan argues, is displayed both behaviorally, in terms of long latencies to approach the unfamiliar, high amounts of time spent in proximity to mother, and facial and vocal displays of negative affect, as well as physiologically, in terms of high and stable heart rate, and elevated cortisol levels (Kagan, Reznick, & Snidman, 1987). Inhibited behavior, Kagan argues, has its roots in the child's threshold for arousal, evident as early as. 4 months of age. Children who display high amounts of negative affect and motor activity in response to novel stimuli, for example, tend to be fearful at 9 and 14 months of age (Kagan & Snidman, 1991). Moreover, these behavioral tendencies are more coherent and stable among the group of infants who fall at the extremes of the behavioral dimensions of irritability and arousal, and thus may represent a distinct temperamental type (Kagan et al., 1988).

Kagan's research suggesting that early patterns of negative reactivity, reflected in high amounts of motor activity accompanied by irritability complements a recent finding of Calkins and Fox (1992) that indicates a relation between early irritability, insecure attachment, and behavioral inhibition in toddlerhood. However, additional findings from this study led to the hypothesis that there may also be a second important type of reactivity, to frustrating events, that is marked by a more outgoing, uninhibited behavioral style during toddlerhood. Fox and Calkins (1993) have recently speculated that these two types of reactivity are marked by distinct profiles of motor activity and affect during infancy that may predispose the child to later types of social behaviors. They further suggest that there are physiological correlates of these behaviors (Stifter & Fox, 1990), and that the social behaviors observed during toddlerhood represent attempts to manage or regulate their emotional reactivity (Fox & Calkins, 1993).

While the notion of temperamental reactivity has been observed behaviorally for some time, more recent attempts to strengthen the physiology-behavior link have begun appearing in the infancy literature. For example, research on brain lateralization and emotion has provided insights into the nervous system components involved in both the expression and modulation of affect. Studies on the relations between patterns of brain electrical activity and emotion in human infants (Davidson & Fox, 1982, 1989; Dawson, Hill, Panagiotides, Grofer, & Levy, 1989; Fox & Davidson, 1986, 1987, 1988) were, in fact, motivated by an attempt to explain variations in emotional reactivity and regulation that were the result of brain injury or surgical intervention (see Fox & Davidson, 1984). This work led to speculation that individual differences in threshold for either negative or positive affects are, in part, a function of the pattern of hemispheric activation, particularly in the frontal region.

In a series of studies Fox and colleagues (Davidson & Fox, 1989; Fox, Bell, & Jones, 1992) have attempted to examine whether individual differences in emotional reactivity were related, as proposed above, to patterns of brain electrical activity. These studies have utilized separation distress as an emotional response for which there may be individual differences in the degree to which an infant will tolerate brief separation. In their initial study, Davidson and Fox (1989) found that infants with greater relative right frontal activation were more likely to cry to maternal separation, while those infants who exhibited left hemisphere arousal were less likely to cry. Differences between infants in frontal activation did not seem to be a function of affective state during the EEG recording. There were no differences in facial expressions of different emotions during the procedure. Rather, there was a strong relation between the pattern of resting frontal EEG and whether the infant would cry or not to separation. This finding could be interpreted to indicate that the pattern of frontal activation reflects a temperamental trait or predisposition/susceptibility to react to mildly stressful events. A follow-up study by Fox (Fox et al., 1992) of infants observed across the 7-12-month period found additional evidence that the pattern of resting frontal asymmetry may mark temperamental differences. Infants who consistently displayed a longer latency to cry to maternal separation displayed greater left frontal activation across age, while a group with a short latency to cry across age displayed right frontal activation.

The data, then, suggest that there are individual differences in infant threshold to respond with negative affect to a mildly stressful event that may be associated with the pattern of frontal activation, and in particular with the pattern of asymmetry with respect to this activation. A recent paper by Dawson (1994) suggests that there may be an additional dimension of affect that is related to observed differences in frontal activation. Her data demonstrate that, while frontal asymmetry may be associated with the tendency to display a particular type of affect, generalized activation across both hemispheres may be associated with the intensity of affect displayed. The intensity dimension of affect reflects the latency to respond to an emotion elicitor as well as the level of emotion evoked. Both dimensions of emotional reactivity are observed across a variety of stressful situations and may be relatively independent of one another (Dawson, 1994).

The recent work that has examined the relations between affect and frontal activation suggests that both the tendency toward negativity, as well as the tendency to react intensely to negative emotion elicitors, is associated with specific patterns of frontal activation. And data from a number of independent laboratories (Calkins & Fox, 1992; Kagan & Snidman, 1991) have indicated that infants who display a high degree of irritability and negative affect during the early part of infancy may be more likely to display insecure attachment relationships with their caregiver and inhibited social behavior as toddlers. If high motor activity/high negative reactivity reflects a temperamental pattern that is predictive of subsequent problems in social development it is possible that infants displaying these behaviors in the first year of life also display right frontal activation. That is, these infants who display a pattern of behaviors (negative reactivity as reflected in high motor activity and irritability) that are the precursors to inhibited behavior may also exhibit greater right hemisphere activation. Frontal activation asymmetry may be a physiological correlate of the predisposition to display behavioral inhibition in the face of novelty. A second important issue concerns the possible physiological correlates and behavioral outcomes of a second type of reactive pattern, high motor activity coupled with positive affect. This pattern of infant behaviors has been hypothesized to be related to uninhibited behavior in toddlerhood (Fox & Calkins, 1993), although this relation has yet to be established empirically.

The current study was an attempt to examine this issue of the physiological and behavioral antecedents of inhibited and uninhibited behavior in a group of infants selected at 4 months of age for the behaviors of high motor activity and either high positive or high negative reactivity. At 9 months of age, brain electrical activity was recorded from these selected subjects. At 14 months of age, each infant was observed in a series of brief episodes designed to elicit inhibited behavior.

Several predictions were made. First, based on previous findings that there may, in fact, be multiple types of reactivity, each marked by distinct behavioral profiles in early infancy, fearful reactivity and frustrated reactivity (Calkins & Fox, 1992; Fox, 1989; Kagan & Snidman, 1991), we attempted to select infants who would be predisposed to each type of reactivity. To replicate the Kagan and Snidman finding, we selected infants who were motorically active and displayed negative affect. It was predicted that these infants would display a pattern of greater right frontal EEG activation and would exhibit behavioral inhibition when faced with novelty during the second year of life. In addition, and as our second goal, we selected infants who were active but displayed a high degree of positive affect. These infants, we predicted, would show a pattern of greater left frontal EEG activation and would be uninhibited in the face of novelty. In examining early displays of reactivity and their physiological correlates, several assumptions were made. First, it was assumed that temperamental or behavioral reactivity reflects underlying physiological reactivity and that both are evident in very early infancy (Rothbart & Derryberry, 1981). As a consequence of this relation, the temperamental disposition to be negatively reactive in early infancy is a function of the pattern of brain electrical activity in the right versus the left hemispheres. Second, the assumption was made that the toddler behaviors to which infant behavioral and physiological reactivity are related represent an adaptation to, or an attempt to regulate, that reactivity as opposed to a continuation of a pattern of behavior. The issue addressed in this study, then, is not temperamental stability. Rather, it is a study of the way that temperamental reactivity, reflected in both behavioral and biological systems, influences subsequent development.

METHOS

Overview

Infants and mothers were selected for participation in a longitudinal study of temperament, psychophysiology, and social development. Infants who displayed high versus low amounts of motor activity, positive affect, and negative affect during an initial screening at 4 months of age were assessed during follow-up visits to the laboratory at 9 and 14 months of age. Table 1 presents the procedures administered and measures assessed at each age, and the variables used in the analyses.

At 9 months of age, infants came to the laboratory, at which time the electroencephalogram (EEG) was recorded. At 14 months of age, infants and mothers were observed in a procedure designed to elicit inhibited versus uninhibited behavior. Groups of infants who displayed different patterns of behavioral and affective reactivity at 4 months of age were compared in terms of their patterns of brain electrical activity and inhibited behavior.

Subjects

A sample of 207 infants {95 males, 112 females) and mothers from the suburban Washington, DC, area were recruited for participation in the study through mailing lists of area births provided by a direct mail marketing company. Families were primarily Caucasian and of middle-class backgrounds. The infants were born within 3 weeks of the expected due date, experienced no pre- or perinatal complications, and had an average birthweight of 4,048 grams (range 2,720-5,6011). All infants were born to two right-handed parents. Handedness was scored using the Edinburgh Handedness inventory (Oldfield, 1971). Mothers were contacted by telephone, and a morning home visit was scheduled within 2 weeks of the infant's 4-month birthday.

Procedures and Measures

Four-month selection.—In order to identify infants who were likely to display inhibited versus uninhibited behavior at 14 months of age, procedures used by Kagan and colleagues (Kagan & Snidman, 1991) were adopted. These procedures included the presentation of visual, auditory, and olfactory stimulation. The visual stimuli were two sets of novel visual stimuli (brightly colored Winnie the Pooh and Mickey Mouse mobiles) that were displayed at the infant's eye level, 12 inches from the face for nine trials of 20 sec each, with an interstimulus interval of 10 sec. The auditory stimuli were two sets of taped nonsense syllables and sentences presented at increasing volume, each trial lasting for a period of 10 see with an interstimulus interval of 10 sec. The olfactory stimulation were dilutions of 60, 80, and 100 ppm butyl alcohol and water presented on a Q-tip held 1/2 inch from the infant's nostrils. These procedures were administered while the infant was in a quiet, alert state.

To obtain measures of motoric and affective reactivity, coding procedures adapted from those used by Kagan and Snidman (1991) were used. The videotapes of the visual, auditory, and olfactory tasks were scored for the frequency of the following behaviors: (1) major activity (arm and leg movements of greater than 45° from resting position, bursts of two or more arm and leg movements, back arches, hyperextension of arms and legs); (2) positive affect (smiling and neutral or positive vocalizing), and (3) negative affect (fussing, fretting, and crying). Intercoder reliability was computed on three occasions, on 10% of subjects, during

TABLE 1

PROCEDURES, MEASURES, AND VARIABLES USED AT 4, 9, AND 14 MONTHS OF AGE

Age	Procedures	Measures	Variables
4 months	Two sets novel visual stimuli Two sets novel auditory stimuli Olfactory stimuli (dilutions of butyl alcohol, H_2O)	1. Motor activity: arm/leg movement, back arching, hyperextension of arms/legs 2. Positive affect: vocalizations, smiles 3. Negative affect: fuss, fret, cry	Reactivity group
9 months	3-min baseline EEG recording Infant Behavior Questionnaire		Ln(left), Ln(right), laterality score Three factor scores
14 months	Free play/stranger presents truck/stranger presents tunnel	Latency to vocalize, approach and touch toys, truck, robot; proximity to mother; negative affect	Inhibition score
	Toddler Behavior Assessment Questionnaire		Three factor scores

data collection. Agreement among coders ranged from .78 to .86 on the three measures during the year-long screening.

The process of subject selection involved choosing infants who were extreme on the dimensions of motor activity and positive and negative affect. Because the infants were scheduled to be assessed for a second time within 2 weeks of their 9-month birthday, and because the process of screening the 207 infants lasted for 1 year, the first 25% of the sample was used to establish criteria for selection on each of the three dimensions. In this way, infants who were seen early in the selection process could still be seen at 9 months, an assessment that would not have been possible had the entire sample been seen before cut-off points on the three dimensions were established.

To select infants who were extreme on the three dimensions, mean scores were used to establish cut points for motor activity, positive affect, and negative affect. The mean frequency scores for the first 25% of the sample were: motor activity, 43.21; negative affect, 27.23; and positive affect, 50.08. For the entire sample, these frequency scores were: motor activity, 46.14; negative affect, 31.26; and positive affect, 48.75. Three groups were selected: (1) those above the mean on motor activity and negative affect, representing 14% of the unselected sample (2) those above the mean on motor activity and positive affect, representing 9% of the unselected sample, and (3) those below the mean on motor activity, representing 15% of the unselected sample.

Clearly, given the three dimensions of motor activity, positive affect, and negative affect, and establishing cut points representing the means on these dimensions, there are eight possible groups that could be examined. We chose to focus on three for a number of reasons. One of our primary goals was to examine the implications of two types of reactivity which present as high levels of motor activity in combination with extreme states of either positive or negative affect. By selecting infants who were extreme on these behavioral dimensions, it was hoped that we could identify additional physiological correlates in the form of brain electrical activity, and examine developing social behavior. The selected infants represent numerically, similar proportions of the population that Kagan has identified in his selected samples and are therefore considered to be extreme groups of infants. The process of selecting only three of eight possible groups allowed us to compare, with a reasonable sample size and within a reasonable period of time, two types of reactive infants with a nonreactive group.

The first problem addressed in examining the data from the 4-month procedures was whether the groups of infants selected at 4 months of age differed significantly on the dimensions of motor activity, positive af-

TABLE 2

MEAN 4-MONTH REACTIVITY SCORES (Motor, Negative, Positive) FOR THREE GROUPS

Reactivity Score	Group 1 High Motor/ High Negative/ Low Positive ($n = 30$)	Group 2 High Motor/ Low Negative/ High Positive ($n = 19$)	Group 3 Low Motor/ Low Negative ($n = 32$)
Motor	63.74	60.43	29.12*
Negative	58.89	18.61	14.03*
Positive	27.99	79.58	39.07*

NOTE:—Group 1 and group 2 > group 3 on motor. Group 1 > group 2 and group 3 on negative. Group 2 > group 3 > group 1 on positive.
* $p < .001$.

feet, and negative affect. These groups are described in Table 2 in terms of their raw scores on the three dimensions.

The first group consisted of infants who displayed high amounts of both motor activity and negative affect, and low amounts of positive affect. This group of infants is similar, then, to the group of infants Kagan and Snidman found to be behaviorally inhibited at 9 and 14 months (Kagan & Snidman, 1991). The second group of infants we were able to identify displayed high amounts of motor activity and positive affect and low amounts of negative affect. The third group of infants displayed low amounts of motor activity, Iow amounts of positive and negative affect. A MANOVA comparing the three groups of infants on these dimensions was significant at the .001 level. Separate ANOVAs and subsequent Newman-Keuls post hoc comparisons among the three groups revealed that group 1 (High motor/High negative) differed from groups 2 (High motor/ High positive) and 3 (Low motor) in terms of negative affect ($p < .001$ and $p < .001$) and positive affect ($p < .001$ and $p < .05$). Group 3 differed from groups 1 and 2 in terms of motor activity ($p < .001$ and $p < .01$, respectively). And, group 3 differed from group 2 in terms of positive affect ($p < .001$). A selected sample of 84 infants was assembled for follow-up assessments. Three of the 84 families relocated from the area; a final sample of 81 subjects was contacted for follow-up visits.

Nine-month EEG data collection.— Eighty-one infants (34 males, 47 females) and mothers came to the laboratory for the 9-month assessment, at which time brain electrical activity was recorded. The choice of the 9-month age for the assessment of EEG stemmed primarily from practical considerations. The goal was to identify EEG differences, particularly in the frontal area, at the earliest possible age given the time constraints of the subject selection process and the finding from past research that at some ages this procedure is more difficult to conduct with infants than it is at other ages. Fox et al. (1992) report that, in assessments of infants who have achieved upright locomotion, the loss of data due to extreme movement artifact is quite significant. In a study of 14- and 24-month-olds, loss of data due to excessive movement was above 50%. Prior studies with infants in the second half of the first year of life did not report such a high subject loss (Bell & Fox, 1992). A second constraint of this study in terms of identifying the appropriate age for assessment of EEG was the assumption of development of the frontal cortex. Chugani and Phelps (1986) report an increase in glucose metabolism in the frontal region during the 8-12month-age period. While this increase was relative to other areas that had shown increases earlier than the frontal area, such increases may reflect maturation of the frontal cortex. For these reasons, then, the age of 9 months was selected as the most viable one for assessing possible EEG relations, particularly in the frontal region, with a minimum of data loss.

The collection procedure took place in a laboratory room equipped for psychophysiological assessment. While the infant sat on the mother's lap an experimenter measured the infant's head circumference and selected a stretch cap of appropriate size•(range: 46-50 cm) for the EEG recording. The cap was placed on the infant's head and secured with an elastic headband. The infant also wore a specially designed vest that contained snaps in the front. Bands attached to the cap were snapped onto the vest, the result of which was to further secure the cap onto the infant's head. A small amount of abrasive cream (Omni-prep) was inserted into each of the six active sites and the reference site on the cap. The area under the electrode was gently abraded with the blunt end of a Q-tip, after which a small amount of EEG gel was applied. Resistances were measured and were accepted if they were less than 5K ohms per site.

The EEG was recorded from the left and right frontal, parietal, and occipital regions (F3, F4, P3, P4, 01, 02), referenced to vertez (Cz). Separate channels for each ear (Al, A2 referenced to Cz) were recorded using Grass ear clip electrodes applied to abraded ear lobes to allow for re-referencing of the EEG off-line via software. In addition, one channel of EOG was recorded using two Beckman mini-electrodes, one placed at the outer canthus and the second placed at the supra orbit position of one eye. The EEG and EOG were amplifed by separate Grass bio-amplifiers (7p511) and digitized on-line using a HEM AID board and acquisition software. Prior to the recording of each subject, a .477 volt rms 10 hertz signal was input into each of the channels, and this amplified signal was recorded. This signal of known frequency and voltage (amplitude) was later used for calibration purposes.

The EEG was recorded while the infant sat on his or her mother's lap. In order to keep the infant still for a suitable duration and to keep infant attention, a metal bingo wheel was placed in front of the infant. An experimenter placed multicolored ping- pong balls in the wheel and the wheel was turned for a duration of 20 sec. There were six 20-sec trials with one, three, or seven ping-pong balls in the wheel for a total of 120 stimulus seconds. Manipulation of the number of ping-pong balls was done to maintain infant interest. Stimulus on-time and interstirnulus interval (varying between 15 and 25 sec) was timed by a second experimenter who signaled the first experimenter to begin and end turning the wheel. This second experimenter also depressed a button switch whose output was fed into one analog/digital channel for later synchronization of stimulus times to the EEG.

Data reduction (for EEG data).—The EEG data were digitized at a rate of 512 hertz. The EEG data were then re- referenced via software so that the data could be analyzed with an average reference configuration. The digitized EEG data were then displayed graphically for artifact scoring. Portions of the EEG record that were contaminated by eye movement or motor movement artifact were eliminated for all channels from the EEG record for subsequent analysis. The elimination of epochs contaminated by eye movement was done using a criterion of 100 uV or greater. The re-referenced artifact-scored EEG data were then submitted to a discrete Fourier transform analysis that utilized a Harming Window with 50% overlap. The result of this analysis was to produce power in picowatt ohms (or micro-volts squared) for each channel for each of the different stimulus conditions (spinning wheel with one, three, or seven balls). A more detailed discussion of the technical aspects of this process may be found in Bell and Fox (1992).

Spectral power data in single hertz frequency bins from 1 to 12 hertz from the three conditions were computed. The choice of the appropriate band width for subsequent analyses was based on two considerations, The first was past research with infants demonstrating that the majority of the spectral power could be found in the range from 3 to 9 hertz (Bell & Fox, 1992; Fox & Davidson, 1991; Mizuno et al., 1970). Second, individual spectra were plotted, and it was deter-. mined that a frequency band from 4 to 6 hertz included the majority of power in the spectral distribution, while little power was evident in the bands below 4 hertz, and some power was evident from 6 to 9 hertz. Power in the 4-6 hertz frequency band was then computed by summing the single hertz bins in these three frequencies and averaging the power data from each condition by weighting the power in each condition (one, three, seven balls) by the number of chunks (discrete Fourier transform windows analyzed) used in the analysis. The result was weighted EEG power in the 4-6 hertz frequency band for the stimulus condition for each lead (F3/F4/P3/P4101/02) for each child from the session. The same procedure was used to compute power values for the 6-9 hertz band. The variables that were used in the analyses included log power for each of the six leads in the 4-6 hertz and 6-9 hertz frequency bands and laterality scores (in right – In left) for each region (frontal, parietal, and occipital). Greater log power in a particular lead reflected less activation in that region of the brain. The laterality score reflected the magnitude and direction of hemispheric asymmetry; a negative score reflected right hemisphere activation while a positive score reflected left hemisphere activation in a particular region. The EEG data were available for 66 of the 81 subjects seen at 9 months. Of the subjects on whom no EEG data were obtained, several (11) were lost due to excessive movement during data collection. A small number of subjects (four) had no usable data due to equipment failure. Of the 15 subjects on whom no data were available, three infants were from the low motor group, nine infants were from the negatively reactive group, and three infants were from the positively reactive group. There was no significant association between 4-month group membership and data loss, although a large number of infants from whom no usable EEG was obtained were from the high motor/high negative group.

To confirm that differences in right frontal activation were not a function of affect experienced during the EEG recording, the infants' facial expressions and vocalizations were scored independently using point scales developed by Thompson and colleagues (Frodi & Thompson, 1985). A five-point scale was used to score facial expressions, while a 13-point scale was used to score vocal expression. High scores on each of the scales reflected greater distress. The infant's affect was scored every 10 sec during the collection procedure.

Fourteen-month inhibition.—At the 14- month assessment, 67 infants (30 males and 37 females) were observed in a playroom for three brief episodes: (1) novel room: 5 min free play with mother in playroom; (2) novel person: stranger enters playroom and presents truck while keeping head down for 1 min, stranger plays with truck for I ruin, stranger invites child to play for 1 min; and (3) novel object: stranger presents electronic robot for 2 min.

The primary measure of interest to us from these laboratory procedures was a measure of inhibited behavior. Inhibition was scored using procedures similar to those used by Calkins and Fox (1992) and by Kagan and colleagues (Kagan et al., 1987; Reznick, Gibbons, Johnson, & McDonough, 1989). A single summary index of inhibition was computed using the sum of standardized scores representing latency to touch the first toy, latency to vocalize, and time spent in proximity to mother during free play; latency to vocalize to and approach the stranger and robot, and time spent in proximity to mother during the stranger presents truck and robot sequences; and frequencies of displays of negative affect during all episodes. The score on this index ranged from –1:98 to 3.40 with a mean of .00. Intercoder reliability on these measures was assessed on 15% of the sample; agreement on the individual measures ranged from .85 to 1.00.

Temperament inventories.—Maternal perception of infant temperament was also assessed at 9 months using the Infant Behavior Questionnaire (Rothbart., 1981) and at 14 months using the Toddler Behavior Assessment Questionnaire (Goldsmith, 1987), Subscores representing maternal perception of fear, anger, and pleasure were used in analyses.

It should be noted that the various analyses presented report differing numbers of subjects. While 81 subjects returned to the laboratory at 9 months, several subjects did not complete the entire procedure. A similar situation occurred for 67 subjects who returned for the 14-month visit, and several mothers did not complete both the IBQ and/ or the TBAQ. All available data are presented for each analysis. Of those subjects who did not return to the laboratory at 14 months, five were in group 1, four were in group 2, and four were in group 3 at 4 months. These families did not participate in the 14-month visit because they had relocated, had a serious illness or death in the family, or were unable to make the time to come in to the laboratory.

RESULTS

To examine the role of behavioral and physiological reactivity in predicting subsequent inhibited behavior, several analyses were conducted. Of interest were 4-month reactivity group differences in (1) brain electrical activity (in terms of asymmetry score reflecting the relation between the left and right power values and in terms of log power in the left and right hemispheres); (2) the tendency to be inhibited versus uninhibited in the laboratory at 14 months of age; and (3) maternal report of temperament at both 9 and 14 months of age. In addition, comparisons were made between measures of brain electrical activity collected at 9 months of age and inhibition at 14 months of age.

Four-Month Reactivity Group Differences

Reactivity group differences in 9-month EEG power.—To test the hypothesis that the 4-month reactivity groups would differ from one another, and from the nonreactive group, in terms of brain electrical activity reflecting activation in the left versus right frontal regions, separate MANOVAs were computed with the log power data for the 4-6 hertz and 6-9 hertz band from each region (frontal, parietal, and occipital) with hemisphere (left/right), band (4-6, 6-9), and group (4-month reactivity group) as within- subjects factors. There was a significant band effect for the frontal, parietal, and occipital regions ($p = .001$ for each region). To explore further these band differences, separate analyses were then conducted for the 4-6 hertz band and 6-9 hertz band for the frontal, parietal, and occipital regions. There was a significant interaction between 4-month group and hemisphere for the frontal region, $F(2, 63) = 3.51$, $p = .04$, but not for either the parietal or occipital regions in the 4-6 hertz band. Post hoc comparisons (Newman-Keuls) used to explore this interaction indicated that the high motor/high negative group displayed significantly less power (greater activation) in the right compared to the left frontal region ($p < .05$). This group also showed significantly less power (greater activation) in both frontal hemispheres compared to the low motor group ($p < .05$). And the high motor/high negative group also showed less power in the right frontal hemisphere (greater activation) than the high motor/high positive group ($p < .05$). These results indicate that the high motor/high negative group showed both a pattern of right frontal asymmetry and a pattern of greater overall frontal activation than the low motor group. These differences can be seen in Figure 1, which presents the raw power scores for the left and right frontal regions for the three groups of infants.

The MANOVA conducted with the log power data for the 6-9 hertz band from the frontal, parietal, and occipital regions with hemisphere (left/right) and group (4-month reactivity group) as factors revealed no significant differences between the left and right hemispheres, nor any group differences within the left and right hemispheres for the frontal, parietal, and occipital regions.

Reactivity group differences in 9-month frontal asymmetry.—Given the finding that group differences in right frontal activation were found in the 4-6 hertz band, and to address further the question of whether infants who may be predisposed to display negative affect would exhibit the pattern of right frontal asymmetry (greater right frontal activation relative to the left frontal region) the frontal asymmetry scores of the infants were examined. Figure 2 presents the mean frontal asymmetry scores for the three 4- month reactivity groups. A one-way ANOVA comparing the three groups in terms of this

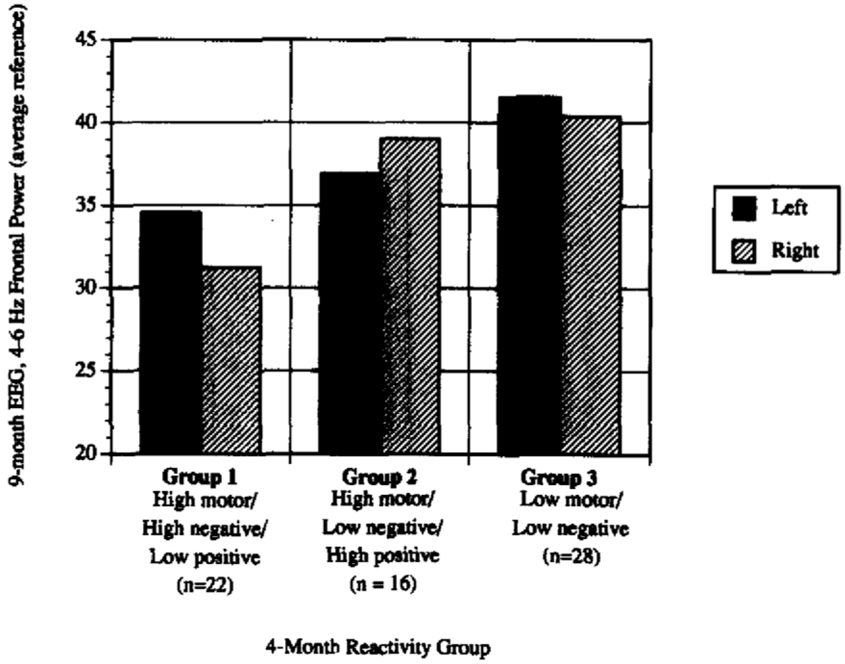

FIG. 1.—Nine-month EEG 4–6 hertz frontal power for the left and right hemispheres by 4-month reactivity group. Higher power scores reflect lower activation in a particular region.

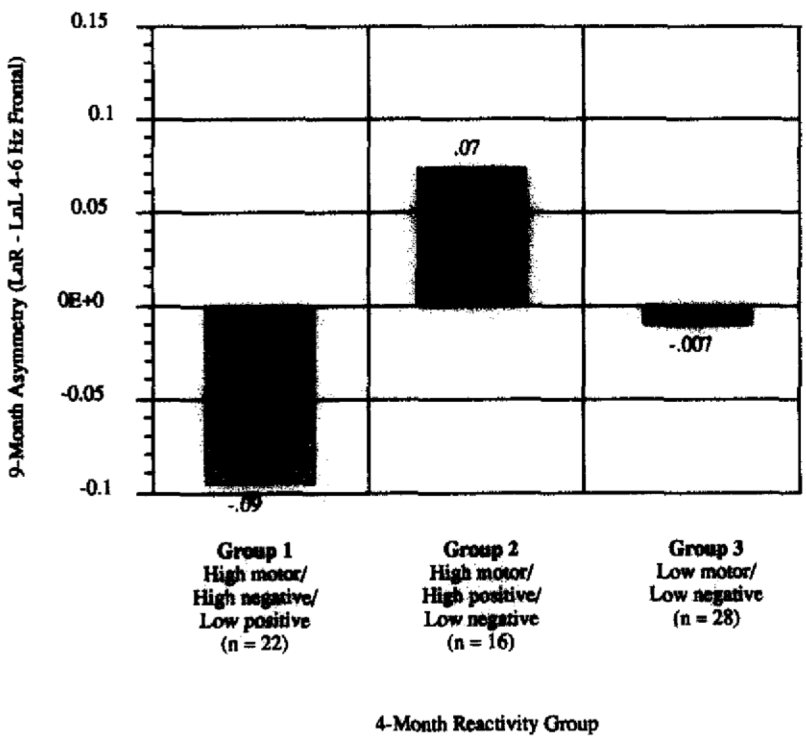

FIG. 2.—Nine-month laterality difference scores by 4-month reactivity group. Positive numbers reflect greater relative left frontal activation while negative numbers reflect greater relative right frontal activation.

score produced a significant group effect, $F(2, 63) = 3.27$, $p = .04$. Post hoc inspection of the means indicated that the high motor/ high negative group displayed greater relative right frontal activation, as reflected in the negative asymmetry score, than the high motor/high positive group (Newman-Keuls, $p < .05$).

The asymmetry and power analyses indicate, then, that the high motor/high negative group displayed a pattern of right frontal asymmetry that was a function of less power (greater activation) of the right frontal brain region than that of the high motor/high positive and low motor infants. Fifteen of the 22 infants in the high motor/high negative group showed this pattern as compared with eight infants in the high motor/high positive group and 14 infants in the low motor group. There was no correlation between asymmetry score and affect ratings during the collection of the EEG data at 9 months.

Reactivity group differences in inhibited behavior at 14 months.—To identify group differences in terms of the tendency to be inhibited versus uninhibited at 14 months, an ANOVA was computed comparing the three 4-month reactivity groups on the index of inhibition. Figure 3 presents the group mean scores on this index.

As the figure indicates, the high motor/ high negative infants displayed significantly more inhibited behavior at 14 months than did the high motor/high positive and low motor infants, $F(2, 59) = 10.60$, p .001, Newman-Keuls, $p < .001$ and $p < .01$. Infants who had displayed, at 4 months of age, high amounts of motor activity and negative affect displayed more proximity to the mother, more negative affect, and long latencies to approach novelty at 14 months than infants who displayed high motor activity and positive affect and infants who displayed low motor activity and low negative affect. In addition, among the high motor/ high negative group, 14 of 21 infants had positive inhibition scores (above the mean of .00), while only three of 15 high motor/ high positive infants group and seven of 26 low motor infants had inhibition scores above the mean of .00, x2(2) = 9.62, $p = .01$. The high motor/high negative group dis-

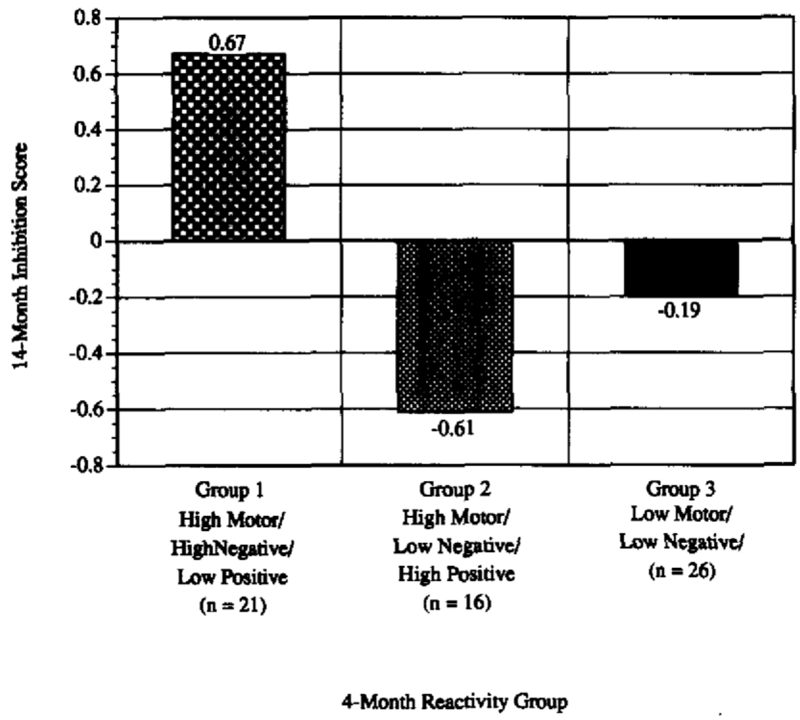

FIG. 3.—14-month inhibition score by 4-month reactivity group. Positive scores reflect inhibited behavior, negative scores reflect uninhibited behavior.

played more inhibited behavior in the laboratory than did either of the other two groups of infants.

Given the hypothesis that the high motor/high positive group of infants would differ from the low motor, or low reactive group, we conducted an exploratory analysis of the three groups in terms of the scores on the index of inhibition at 14 months. For this analysis, we examined those infants who displayed extreme fear at 14 months versus those infants who displayed extreme approach behavior at 14 months. Infants whose inhibition scores at 14 months were one standard deviation or more above the mean of .00 on the index were classified as extremely inhibited, while those whose scores were one standard deviation below the mean of .00 were classified as extremely uninhibited. Of the sample of 62 infants on whom data were available at 14 months, nine infants were classified as extremely inhibited, while eight were classified as extremely uninhibited. The remaining 45 infants were classified as being in the middle of the range. The frequencies of these infants who were members of the three 4- month groups appears in Table 3.

As the table indicates, 88% of the extremely inhibited infants were classifed as high motor/high negative at 4 months, while 67% of the extremely uninhibited infants was classified as high motor/high positive at 4 months, X2 (2) 20.86, p = .001. Very few of the low motor infants could be classified as extremely inhibited or uninhibited. Thus, this analysis indicates that, while both the high motor/high positive and low motor groups of infants had inhibition scores that placed them below the mean of .00, the most extreme of these infants tended to be members of the high motor/high positive group.

Reactivity group differences in maternal assessments of temperament.—To address the issue of whether different patterns of 4-month reactivity would influence maternal assessment of temperament, the three groups were compared on the subscales of the 9-month IBQ and the 14-month TBAQ. Of particular interest were dimensions reflecting positive and negative affect. The summary scores of these dimensions on the 9-month IBQ and the 14-month TBAQ were examined, and the means for each of the three groups are presented in Table 4.

TABLE 3

FREQUENCY OF EXTREMELY INHIBITED AND UNINHIBITED INFANTS IN EACH 4-MONTH REACTIVITY GROUP

14-Month Inhibition	Group 1 High motor/ High negative/ Low positive ($n = 21$)	Group 2 High motor/ Low negative/ High positive ($n = 15$)	Group 3 Low motor/ Low negative ($n = 26$)
Inhibition score < -1.00 (Extremely uninhibited)	1	6	2
Inhibition score $-1.00 \leftrightarrow +1.00$ (middle)	13	9	23
Inhibition score $> +1.00$ (extremely inhibited)................	7	0	1*

*$\chi^2(4) = 20.86$, $p = .0003$.

A series of one-way ANOVAs with Newman-Keuls post hoc analyses was conducted. As the means in Table 4 indicate, the high motor/high negative infants were rated by their mothers as being more distressed to novelty at 9 months ($p < .05$) than the low motor group, and they showed a trend toward displaying more social fear at 14 months ($p < .10$). In addition, infants in the high motor/high positive group were rated by mothers as being more angry at 14 months than the low motor group of infants ($p < .01$).

Relations between 9-Month EEG and I4-Month Inhibition

Nine-month frontal asymmetry and inhibition.—A correlation between 9-month EEG frontal asymmetry score and the index of behavioral inhibition computed from 14-month behaviors revealed no significant relation between the two variables ($r = -.03$). The tendency to be inhibited (above the mean of .00 on the index of inhibition) was not related to the tendency to display greater relative right frontal activation (negative asymmetry score). A chi-square analysis examined the relation between the tendency to be classified as left frontal versus right frontal in terms of EEG asymmetry (positive vs. negative asymmetry score) and the tendency to be inhibited versus uninhibited (above vs. below the mean of .00 on the index of inhibition). This analysis revealed no significant association between asymmetry and inhibition.

Given the observed relations between 4-month reactivity and both asymmetry score and inhibited behavior, an analysis of these two factors in relation to the outcome of 14-month inhibition was conducted. A

TABLE 4

MATERNAL ASSESSMENTS OF FEAR, ANGER, AND PLEASURE AT 9 AND 14 MONTHS OF AGE BY 4-MONTH REACTIVITY GROUPS

	Group 1 High motor/ High negative/ Low positive (n = 27)	Group 2 High motor/ Low negative/ High positive (n = 16)	Group 3 Low motor/ Low negative (n = 30)	$p <$
9-month IBQ:				
Distress to novelty........	3.08	2.90	2.52*	.05
Distress to limits...........	3.29	3.50	3.08	.18
Smiling	5.07	5.16	5.31	.56
14-month TBAQ:				
Social fear......................	4.37	3.67	3.82	.10
Anger	3.84	4.12	3.53**	.01
Pleasure..........................	4.62	4.88	4.88	.28

*Group 1 > group 3.
**Group 2 > group 3.

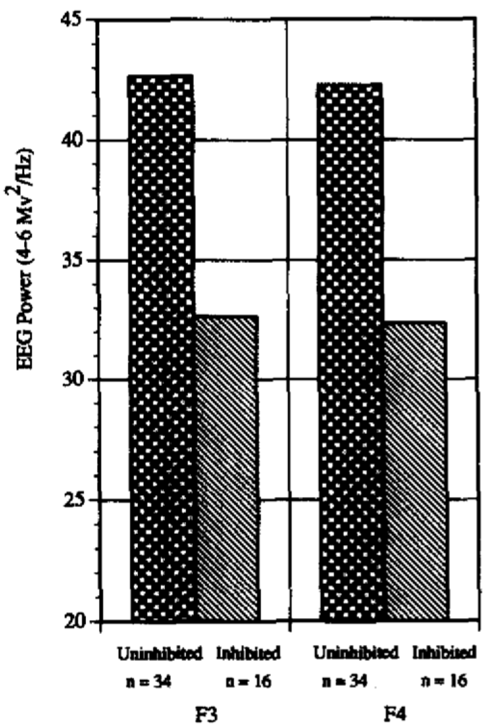

FIG. 4.—Nine-month EEG frontal power (4–6 hertz) for the left and right hemispheres by 14-month inhibition group.

two-way ANOVA with 4-month group and 9-month asymmetry (left/right) as the independent variables and 14-month inhibition score as the dependent measure was conducted. This analysis again indicated that 4-month group was related to inhibition, $F(2, 40) = 9.04$, $p = .001$, but found no association between inhibition and asymmetry, nor an interaction of 4-month group and asymmetry in predicting inhibition at 14 months. Again, the 4-month high negative/high motor group was inhibited, while the other two groups of infants were uninhibited. One difficulty with this analysis concerns the fact that, of the 14-month-old infants on whom no usable EEG data were available at 9 months, eight of the nine infants obtained inhibition scores above the mean of

.00 and would have been classified as inhibited. Clearly these data are critical to a more complete analysis of the relation between EEG and inhibition.

Nine-month frontal power and inhibition.—To examine the hypothesis that left and right frontal power would be associated with intensity of affect, those infants classified as inhibited (above the mean of .00 on the index of inhibition) were compared to those who were classified as uninhibited (below the mean of zero on the index of inhibition) in terms of their frontal power. A MANOVA with left and right frontal power as the dependent measures, inhibition group (inhibited vs. uninhibited) as the grouping factor, and hemisphere as the within- subjects factors indicated a significant group effect, $F(1, 48) = 4.38$, $p = .04$. Separate ANOVAs for each hemisphere revealed a significant difference between the two groups in right hemisphere power, $F(1, 49) = 4.46$, $p = .04$, and a trend toward significance in left hemisphere power, $F(1, 49) = 3.71$, $p = .06$. As Figure 4 indicates, infants who were inhibited showed less power (greater activation) in both hemispheres than those who were uninhibited.

DISCUSSION

One of the goals of the current research was to examine the relations betwen physiological and behavioral reactivity and to explore the role that the two may play in the development of inhibited behavior in early toddlerhood. To examine these relations, infants were selected for particular profiles of behavioral reactivity (as indexed by affective and motoric responses), and subsequent assessments of brain electrical activity and inhibited responses to novelty were con- ducted. It was hypothesized that two distinct behavioral profiles of negative and positive reactivity would be related to particular profiles of brain electrical activity and to different responses to novelty. This idea is consistent with the work of Kagan and colleagues (Kagan & Snidman, 1991) who contend that differential limbic thresholds are reflected in responses to novelty early in infancy. The data indicated that there are individual differences early in infancy in the tendency to display certain reactive profiles consisting of affect and motor behavior. However, the prediction that these profiles are related to particular patterns of brain electrical activity and response to novelty was only partially confirmed.

In examining the relations between behavioral and physiological reactivity, the data from this study suggest that infants selected early in the first year of life for high frequencies of motor activity and negative affect exhibit specific patterns of frontal brain activation. These infants displayed greater relative right frontal activation at 9 months (less power, greater activation in the right frontal region), a pattern of asymmetry which differed significantly from those infants selected for high motor/high positive reactivity. Differences in frontal activation in infants have been associated with infant disposition to exhibit distress in response to brief maternal separation. In three independent studies, Fox (Davidson & Fox, 1989; Fox et al. [studies 1 and 21, 1992) has found relations between right frontal activation and an infant's tendency to cry to separation. The current data extend these findings and suggest that the pattern of frontal asymmetry may be a correlate of a temperamental type distinguished by a low threshold for arousal that is associated with the expression of negative affect.

The findings relating negative affect in infancy to frontal asymmetry parallel work with older children and adults from a number of laboratories. In one study, Davidson and colleagues report that adults with resting right frontal asymmetry are more likely to rate certain video film clips with negative emotions compared to adults with the opposite pattern of resting frontal asymmetry (Tomarken, Davidson, & Henriques, 1990). And, Finman and colleagues (Finman, Davidson, Colton, Straus, & Kagan, 1989) reported that children selected for characteristics of behavioral inhibition (high degree of proximity to mother during a laboratory play session) were more likely to exhibit right frontal asymmetry. Finally, Fox et al. (1995) have recently found that 4-year-olds who display inhibited behaviors in a peer play session exhibited resting right frontal asymmetry. In addition, children exhibiting high degrees of social competency exhibited resting left frontal activation.

What do these differences in frontal asymmetry reflect? A number of researchers have speculated that the two hemispheres are differentially specialized for the expression of emotions associated with either approach or withdrawal (Davidson, 1984; Fox, 1991). Approach-withdrawal is a continuum around which fundamental decisions may be made regarding the valence of stimuli. These decisions involve the activation of motor and autonomic output. In early infancy, responses to stimuli are most probably unipolar: either approach or withdrawal. These responses involve activation of regions within either the left or right hemisphere, and there is probably little communication between hemispheres regarding output. With development, responses increase in complexity as a function of learning, adaptation, and increased interhemispheric communication (Fox, 1991).

The right frontal activation found among the group of high motor/high negative reactivity infants may also reflect heightened reactivity of certain subcortical centers. Kagan and Snidman (1991) have speculated that the behavioral/temperamental pattern exhibited by these infants reflects increased activity in the central nucleus of the amygdala and other centers. Citing both comparative evidence and psychopharmacological data, Kagan argues that infants born with heightened arousal in these subcortical regions may be predisposed to fear, and some may develop patterns of behavioral inhibition. While it is not possible to specify precisely the origins of the EEG activation found in the current study, there are well-known anatomical connections between the frontal region and the amygdala as well as other areas of the limbic system. It is certainly possible, therefore, that the resting right frontal asymmetry of the high motor/high negative affect group could reflect increased limbic activity. Due to methodological constraints, the behaviors indicative of reactivity at 4 months were not assessed at the same time as EEG. It is therefore not possible to claim that one is predictive of the other. Questions of stability in both behavioral and physiological domains also cannot be addressed with this study. Nevertheless, the pattern of relations confirms past affect-EEG findings, and encourages us to hypothesize that the greater relative high frontal activation found in the sample of irritable and active infants may be an important physiological correlate of early infant temperament.

In addition to the asymmetry difference found between the two high motor groups, there was a power difference found between the negative and the low motor groups. Infants selected at 4 months of age for low reactivity displayed greater power (less activation) over both hemispheres than the high motor/high negative group. Dawson's finding (1994) that frontal power is related to individual differences in the intensity of affect experienced suggests that the low rnotor group may be less reactive emotionally than the high motor/high negative infants, a conclusion supported by the behavioral differences observed at 4 months.

By 14 months of age, the three selected groups of infants were displaying differences in their reactions to novelty as assessed both in the laboratory and by mothers. As predicted, infants who were active and negative at 4 months were displaying more inhibited behavior in the laboratory than the other two groups of infants. They spent more time in proximity to mother, took longer to approach the unfamiliar adult and the robot, and fussed and fretted more to these events than those infants who had displayed little negative affect at 4 months of age. And, they tended to be rated by their mothers as displaying more social fear at 9 and 14 months of age than the low motor group of infants. The infants who had been classified as positively reactive at 4 months of age did not appear significantly different from the low motor group in terms of their mean scores on the index of inhibition. However, many of these infants displayed more extreme uninhibited behavior in the laboratory at 14 months of age compared to the low motor infants. They were quick to explore the novel room, approached the stranger with no apparent distress, and spent little time close to their mothers in the laboratory. These infants were rated by their mothers as displaying more anger at 14 months of age than the low motor group, a characterization that may reflect the child's displeasure at the restrictions or boundaries placed on their uninhibited style of play. The low reactive were also displaying uninhibited behavior in the laboratory at 14 months of age. However, their behavior could be characterized as less extreme than that of the high motor/high positive group and would likely be viewed as normal exploratory behavior for a child of this age. In addition, these infants were rated by their mothers as the least angry and least fearful group of infants, a characterization that reinforces the notion that they are less reactive emotionally.

An important issue concerns the lack of observed differences between the two high motor groups in terms of maternal assessment of temperament. The behavioral data collected in the laboratory clearly indicate that there are differences between these groups at both 4 and 14 months, and physiological differences at 9 months. Maternal assessment may fail to capture these differences for two reasons. First, while the two groups of infants may appear to be different based on behavioral observations toward novel stimuli at different ages, these infants may share some characteristics as well. The high motor/high negative infants are likely to be characterized as the more traditional "difficult infant" and thus may pose a challenge for parents across a variety of situations. However, it is important to note that the same may be true for the high motor/ high positive infants. One of the hypotheses of this study was that high motor/high positive infants are likely to develop an uninhibited style of interaction during toddlerhood. This early profile may or may not translate into sociability or positive affectivity at a later age. While these high motor/high positive infants do display negative affect, it is in reaction to different types of events than their high motor/high negative counterparts, and may well be a function of their approach-oriented style of responding to novelty. A second reason that parent report may not have differentiated these two groups is that the maternal report dimensions may be tapping different aspects of behavior than the laboratory assessment. For example, mothers may be rating their children on the dimension of social fear but may not be taking into account behavior in response to nonsocial stimuli such as a novel room or an electronic robot.

While some of the predicted relations between 4-month reactivity and 9-month EEG, and 4-month reactivity and 14-month inhibition were confirmed, others were not. In particular, we could not find a relation between 9-month brain asymmetry and inhibited behavior at 14 months. There are several possibilities for this pattern of data. First, the inhibited behavior observed at 14 months of age most probably reflects both normative fear responses as well as trait- based fear responses. Some infants may display inhibited behavior at this age as a normal developmental response to novelty, while the inhibited behavior of other infants may reflect a lower threshold to novel stimuli that is integral to the profile of the inhibited child. The EEG-behavior relations thus may be confounded by these different types of fear reactions observed at 14 months of age. A second issue which bears on the lack of asymmetry-inhibition relations concerns subjects loss. A number of inhibited subjects did not have usable EEG data. We may not have had the power to find the expected relations. A third hypothesis concerning the lack of asymmetry/inhibition relation is that the pattern of brain electrical activity, while a correlate of some infant temperamental reactivity, is not a direct predictor of behavior at 14 months of age due to some as yet untested environmental influence. A final explanation for the lack of asymrnetry- inhibition relations concerns the power differences that were observed between the inhibited and uninhibited groups of infants. It may be that the type of emotion evoked by the inhibition procedure is the same for all infants—wariness or fear—but that the intensity differs.

The data collected to this point, from both unselected (Calkins & Fox, 1992) and selected longitudinal samples, indicate that there are individual differences in reactivity during the first few months of life that may influence developments in the social- emotional domains of attachment and response to unfamiliar people, objects, and events. Moreover, for at least some types of infants, in particular negatively reactive infants, these differences may be described in terms of (1) patterns of affective and motoric reactivity and (2) brain electrical activity. The physiological and behavioral differences in arousal of either the approach or withdrawal systems observed in this sample of selected infants may have important consequences for social/personality development. These predispositions, by themselves, are not necessarily sufficient to predict social outcome. It is most likely that at least two factors interact in this process. The first factor is parental response to infants with certain extreme patterns of temperament. Caregivers may reinforce, ignore, or intervene in the case of a child who has a low threshold for novelty. Each pattern may produce a different pathway and end point in social development. The second factor is the number of novel or stressful events to which the infant is exposed. Infant negative reactivity may be exacerbated in the case of a child exposed to a high degree of stress or novelty. Thus, differences in frontal asymmetry, of themselves, are not predictive of subsequent social development.

This study represents important steps in the study of behavior-physiology links in early infancy and their consequences for development in toddlerhood. First, the study presents EEG data on a sample of subjects that is sufficiently large to allow a degree of confidence in the reported results. Previous studies of EEG in infancy have been hampered by significant data loss due to the difficulty in testing young subjects (cf. Davidson & Fox, 1989). The present investigation reports that usable data were obtained on 81% of the sample of 81 infants. Second, this study adds important information on the physiological correlates of a temperamental type which Kagan and colleagues have identified as being vulnerable to the development of inhibited behavior in toddlerhood (Kagan et al., 1987). A third important aspect of this study concerns the tentative findings relevant to the group of infants whose early behavior was characterized by high amounts of positive affect and motor activity, and who displayed uninhibited behavior at 14 months of age. The task, then, for future studies of temperamental reactivity should be to examine the multiple types of reactivity and to describe further their behavioral and physiological correlates.

In addition, these studies should be directed at examining the possible interactions of temperamental reactivity and externally induced regulatory strategies that are part of the infant's developing social repertoire. In this way, the relative contributions of early biological/behavioral orientation and environmental influences could be adequately established.

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