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Frontal EEG Asymmetry and Fear Reactivity in Different Contexts at 10 Months

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Abstract

Individual differences in observed and maternal-rated fear behaviors and frontal electroencephalogram (EEG) asymmetry were examined in normally developing 10-month-old infants. EEG was recorded during resting baseline, as well as during stranger approach, mask presentation, and toy spider presentation. Mothers completed the Infant Behavior Questionnaire. For mask presentation, baseline and task right frontal EEG asymmetry as well as maternal ratings predicted fear behavior during the mask task. For stranger approach, task-related right frontal EEG asymmetry predicted fear behavior during stranger approach after controlling for baseline asymmetry. There was a trend for task-related right frontal EEG asymmetry to predict fear during presentation of a toy spider after controlling for baseline asymmetry. Maternal report of temperament only added unique variance to the prediction of one fear task after controlling for baseline and task EEG. Assessing fear in multiple situations revealed context-specific individual differences in infant fear.

Keywords

Frontal Asymmetry; Fear; EEG; Infancy; Context; Temperament

Newborns exhibit a startle response to stimuli that display loud noises (Scarr & Salapatek, 1970). With normal development, infants become less driven by these startle reflexes and begin to show a range of fear behaviors in response to various types of novel stimuli (Rothbart, 1986). Because infants are regularly confronted with unfamiliar stimuli or situations, examining the manifestation of fear in various contexts is vital to understanding infant emotional development. In this study, we focused on normal variations in infant fear reactivity in different contexts using a temperament framework.

Temperament is the biological basis of individual differences in emotion reactivity and its regulation (Rothbart & Bates, 1998, 2006). Researchers have measured temperament-related fear behaviors using different procedures, a common one being a social fear-inducing task focused on stranger approach (e.g., Andersson, Bohlin, & Hagekull, 1999; Buss et al., 2003; Fox & Davidson, 1987). In this procedure, the child is observed in the unfamiliar research lab while a stranger enters the room, creating a context of increased unfamiliarity. Fear is also measured in non-social contexts with relatively mild and non-intrusive stimuli, such as a mask, animals, or spontaneous moving toys (e.g., Kagan, Reznick, Clarke, Snidman, & Garcia-Coll, 1984; Ricard & Allard, 1993; Losonczy-Marshall, 2008). Measurement of fear

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in the same infants across multiple contexts is critical. Low correlations in fear behaviors have been reported across situations designed to elicit fear (Buss, 2011; Garcia Coll et al., 1984). For example, Buss (2011) reported that 24-month olds identified as showing the highest levels of fear in one context did not always demonstrate the same high level of fear in a different context. Thus, multiple contexts are required to capture the complexities of fear and highlight meaningful individual differences in fear-related behaviors.

In addition to assessments of fear behaviors in the research lab, maternal ratings of infant temperament have been used to assess temperamental fear behaviors in various contexts outside of the laboratory setting. Temperament questionnaires such as the Infant Behavior Questionnaire (IBQ-R; Garstein & Rothbart, 2003) have shown good internal consistency and converge with other similar scales (Matheny, 1997). Both research lab and questionnaire methodologies indicate variability among typically-developing infants in their fear-related behaviors.

The examination of individual differences in infant fear requires not only the consideration of behaviors in a specific context (i.e., stranger approach, masks, toys, animals), but also the biology associated with those behaviors (e.g., Buss, 2011; Buss et al., 2004). In a temperament conceptualization of fear, individual levels of fear reactivity encompass the arousability, responsiveness, and excitability of behavioral as well as neurophysiological systems (Rothbart, 1981; Rothbart, Ellis & Posner, 2004). One of the major functions of the frontal lobe is to deal with new or surprising situations effectively. The frontal lobe exerts control over emotions, modulating the degree to which the amygdala’s output produces emotional responses in different contexts (Kolb & Taylor, 1990). The examination of electrophysiological indicators of fear in particular contexts may have important implications for understanding normal variations in behavioral fear during infancy.

Indeed, infants respond to fearful emotional events with a set of highly integrated neurobiological responses. Brain electrical activity (i.e., electroencephalogram, EEG) correlates of emotion have been noted in the first year of life, suggesting that different types of emotion are associated with different patterns of frontal activation. In a model of differential activation of the left and right frontal cortices, Fox (1994) postulated that frontal EEG asymmetry patterns are indices of individual differences in emotion reactivity and regulation. Measuring resting EEG during a baseline condition may yield important information regarding electrophysiological patterns of normal infant fear behavior. Indeed, the Fox model of frontal asymmetry proposes that activation of the right hemisphere during a resting baseline condition is associated with the tendency to display withdrawal types of behaviors and emotions (e.g., sadness, fear), whereas activation of the left hemisphere is associated with the tendency to exhibit approach types of behaviors and emotions (e.g., joy, surgency, anger). For example, infants who exhibit resting right frontal EEG asymmetry are more likely to cry when separated from their mothers compared to infants who exhibit left frontal EEG asymmetry (Bell & Fox, 1994; Davidson & Fox, 1989; Fox, Calkins, & Bell, 1994; Fox & Davidson, 1987). Likewise, negative emotion reactivity is correlated with EEG activation at right frontal scalp locations during baseline (Fox, Bell, & Jones, 1992) perhaps reflecting an individual’s bias to respond with negative affect to certain stressful situations (Fox, Henderson, Rubin, Calkins, & Schmidt, 2001). Thus, patterns of resting frontal EEG asymmetry may serve as a marker of an underlying disposition.

Frontal EEG asymmetry can serve as an indication of a current emotional state, as well. Infants’ right frontal EEG asymmetry is thought to influence behavioral expression of fear, anxiety, or shyness (Fox, 1997; Fox et al. 2001). Fox and Davidson (1987; 1988) tested 10-month-old infants during approach of mother, approach of stranger, and maternal separation. They found that when infants exhibited behaviors reflecting approach (reaching with hands, positive vocalization, facial expressions of joy), there was greater relative left-frontal activation (i.e., left frontal asymmetry) during those behaviors. When those same infants displayed behaviors reflecting active withdrawal (distress, gaze aversion), there was greater relative right-frontal activation. Buss and colleagues (2003) also reported greater right frontal EEG asymmetry during stranger approach when infants demonstrated fear and sadness. Thus, in addition to serving as a marking of underlying disposition toward positive or negative responsivity, frontal EEG asymmetry is also correlated with patterns of emotion behavior reactivity *during* an emotion-eliciting situation. As can be seen from these examples, however, the elicitation of normal variations of fear in infant frontal EEG asymmetry studies typically involves social contexts (i.e., stranger, mother). Although a recent behavioral study measured fear across six contexts in 24-month-old toddlers (Buss, 2011), little is known about normal fear responsivity and frontal EEG asymmetry in non-social contexts during the first year.

Although context effects have been a focus in animal models of fear (Kalin, Shelton, & Takahashi, 1991), context is much less prominent in studies of human fear reactivity. Researchers have argued for the role of context in the expression of fear-related behaviors (Buss, Davidson, Kalin & Goldsmith, 2004; Davidson, Jackson, & Kalin, 2000; Dennis, Buss, & Hastings, in press), but work thus far has focused on infants with extreme fear or extreme behavioral inhibition temperaments (e.g., Buss et al., 2004; Fox et al., 2001). However, the study of normal variations of fear may also be informed by observing fear behaviors under different situations (Buss et al., 2004). The biological sensitivity to context theory states that relations between physiological reactivity and behavior vary across different contexts (Boyce & Ellis, 2008). Thus, we focused on individual differences in observed and maternal-rated fear behaviors and frontal EEG asymmetry in different situations designed to induce fear in normally developing infants.

The Current Study

We recruited a sample of 10-month-old infants and mothers to participate in our study of infant frontal EEG asymmetry associated with fear responses in different contexts. Our efforts were focused on 10-month-olds for two reasons. First, fear behaviors show increases between 4 and 9 months, and again from 9 and 19 months (Denham, Lehman, Moser, & Reeves, 1995). Second, functionalist theorists note that fearful reactions are most adaptive once infants are mobile and capable of seeking help and avoiding potential danger (Campos, Barrett, Lamb, Goldsmith, & Stenberg, 1983; Campos, Frankel, & Camras, 2004), which typically occurs sometime in the second half of the first year. Unlike most studies of temperament-based negative affect (e.g., Buss et al., 2003; Fox, et al., 2001; Perez-Edgar et al., 2010), we did not select for infants who were high in behavioral reactivity in order to examine more typical infant fear responses. Using a temperament-based theoretical framework, we hypothesized that baseline frontal EEG asymmetry, as well as fear task frontal EEG asymmetry, would uniquely account for variance in normal infant fear reactivity measured behaviorally. We also expected maternal report of infant fear responses (i.e., temperament questionnaire) to account for significant variance in infant fear behaviors during the tasks. Although we measured fear in three different situations (social and nonsocial), we had no basis to predict that infants would react with more fear in one context than another. Thus, our hypotheses focused on the ability of baseline and task EEG and maternal temperament rating to predict fear behavior in the three separate contexts. A potential outcome from our study would be the efficacy of frontal EEG asymmetry to predict fear behaviors in specific fear-related situations.

Method

Participants

Participants included 50 10-month-old infants (24 male, 26 female; 38 Caucasian, 4 African American, 4 Asian American, 4 Hispanic) and their mothers from 3 small towns surrounding a research university in the mid-Atlantic region. Infants were born within 2 weeks of their expected due dates, experienced no prenatal or birth complications and had no neurological diagnoses. Infants were seen in the research lab within two weeks after their 10-month birth dates. All infants were born to parents with a high school diploma; 89% of mothers and 73% of fathers had a college degree. At the infant's birth, mothers were approximately 29 years of age (range 17–38) and fathers were approximately 31-years-old (range 18–45). Infants and mothers were recruited through a departmental database of mother names and addresses, advertisements on the university website, e-mails to the university Working Moms list serve, and flyers to the community.

Procedures

Upon arrival at the research lab, infant and mother were greeted by a research assistant who explained the study procedures and obtained signed consent from the mother. After a brief warm-up period, the infant sat on mother's lap and was distracted with toys in order to situate the EEG Electro-cap on the infant's head. EEG was recorded during baseline and fear tasks and the EEG record was event marked by a research assistant in an adjacent room. The session was digitally recorded for later behavioral coding.

All the fear tasks from Lab-TAB (Version 3.1; Goldsmith & Rothbart, 1999) were used: stranger approach, mask presentations, and toy spider. The fear tasks were counterbalanced during each infant's visit to control for order effects and tasks are described in further detail below. Infants were only assessed if they were calm and displayed no distress before starting each of the temperamental fear tasks. If infants cried continuously for more than 15 seconds during a task, the task was stopped and mothers were asked to comfort their infants until they returned to a calm state. After each fear task, mothers were instructed to interact with their infants as they normally would at home for two minutes during a free play session. The free play session allowed infants to return to a quiet baseline state, if needed, and limited any carryover effects of the fear tasks. Memory tasks, not part of this report, were also part of the protocol. The entire procedure lasted approximately 45 minutes.

EEG recording and analysis—Upon arrival to the research laboratory, the EEG cap (Electro-Cap, Inc.; Eaton, OH) was placed on the infant's head. Recordings were made from 16 left and right scalp sites [frontal pole (Fp1, Fp2); medial frontal (F3, F4); lateral frontal (F7, F8); central (C3, C4); temporal (T7, T8); parietal (P3, P4, P7, P8); and occipital (O1, O2) referenced to Cz during recoding]. Baseline EEG was recorded for 1 minute while the infant sat on the mother's lap and watched a research assistant manipulate a toy containing brightly colored balls on top of the testing table, 1.1 m in front of the infant. This procedure quieted the infant and yielded minimal eye movements and gross motor movements, thus allowing the infant to tolerate the EEG cap (Bell, 2001). Mothers were asked not talk to infants during the EEG recordings and tasks, unless they needed to comfort their infants after a specific fear task.

Recommended procedures regarding EEG data collecting with infants were followed (Pivik et al., 1993). Specifically, a small amount of abrasive gel was placed into each recording site and the scalp gently rubbed. Next, conductive gel was placed in each site and the scalp gently rubbed. Electrode impedances were measured and accepted if they were below 10K ohms. The electrical activity from each lead was amplified using separate SA

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Instrumentation Bioamps (San Diego, CA) and bandpassed from 1 to 100 Hz. Activity for each lead was displayed on a monitor of an acquisition computer. The EEG signal was digitized on-line at 512 samples per second for each channel so that the data were not affected by aliasing. The acquisition software was Snapshot-Snapstream (HEM Data Corp., Southfield, MI) and the raw data were stored for later analyses.

EEG data were examined and analyzed using EEG Analysis System software developed by James Long Company (Caroga Lake, NY). First, the data was re-referenced via software to an average reference configuration. The average reference EEG data were artifact scored for eye movements and gross motor artifact. These artifacts scored epochs were eliminated from all subsequent analyses. One infant (a boy) had no artifact-free baseline data and his data were removed from all analyses. All infants underwent the three fear tasks. Artifact in infant EEG, for different infants for each task, necessarily made the final sample size different for each task. The EEG data were then analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-second width and 50% overlap. Power was computed for the 6 to 9 Hz frequency band, as infants at this age have a dominant frequency between 6 and 9 Hz (Bell & Fox, 1994; Marshall, Bar-Haim, & Fox, 2002). This particular frequency band is thought to approximate the alpha band in adults and has been used in previous studies of infant frontal asymmetry (e.g., Bell & Fox, 1994; Buss, et al., 2003; Fox et al., 1992; Fox et al., 2001; Smith & Bell, 2010). For the current study, EEG power was expressed as mean square microvolts and the data transformed using the natural log (ln) to normalize the distribution.

Frontal EEG asymmetry scores, especially those associated with F3/F4 medial frontal scalp locations, have been used as evidence of the associations between brain electrical activity and observed emotion-related behaviors (Fox, 1994; Fox et al., 2001; Davidson & Fox, 1989; Dawson, Panagiotides, Klinger & Hill, 1992). Buss and collogues (2003) provided evidence that these emotion-asymmetry associations were observed at other frontal locations as well. In their study, greater frequency of withdrawal-related behaviors was not associated with baseline asymmetry but with right frontal activation at the most anterior site of Fp1/Fp2 during stranger approach. Therefore, for the current study, frontal asymmetry scores were calculated at frontal electrodes Fp1 and Fp2 by subtracting ln left frontal power from ln right frontal power (ln right − ln left = frontal asymmetry). In the EEG literature, brain activation is indicated by lower EEG power values in the alpha frequency band (Lindsley, 1936). Thus, negative asymmetry scores reflect greater relative activation in the right hemisphere compared to the left.

Stranger approach—After the baseline EEG recording, the infant was placed in a highchair and remained there throughout each of the fear tasks. Mother was instructed to keep her chair slightly behind the infant and refrain from speaking for the duration of the tasks. At the start of the strange approach task, the experimenter exited the room and a novel female research assistant (i.e., the stranger) entered, saying nothing for 10 seconds and standing at the far corner of the room. The stranger walked halfway across the room toward the infant and paused for 10 seconds. Then, she continued walking and stopped directly in front of the highchair for another 10 seconds. The stranger then made motions as if to pick up the infant and stayed in the position for an additional 10 seconds. Throughout the stranger approach, the stranger looked directly at the infant but refrained from smiling and speaking.

Mask presentations—The experimenter positioned a table covered by a black cloth in front of the infant. Five masks on a wig stands (evil queen, old man, vampire, gas mask, and gorilla) were placed under the table out of sight of the infant. Four of the masks were from Lab-TAB and the fifth mask (gorilla) has been used in studies of behavioral inhibition

(Kagan et al., 1984). Gorilla mask behavioral fear was not significantly different than fear elicited by the other four masks (all p's >.24). The experimenter sat on the floor behind the table out of sight of the infants. The task began when the infant's attention was focused on the table. The experimenter then placed one mask at a time on top of the table 63.5 cm away from the infant. Each mask was shown for 10 seconds with a 5 second interval between each mask presentation.

Toy spider—This task involved presenting the infant with a small jumping spider toy. The experimenter sat on the floor behind a cloth-draped table and out of sight of the infant. The task began when the infant's attention was focused on the table. The experimenter then placed the spider on top of the table 63.5 cm away from the infant. The experimenter manipulated the toy spider, making it jump and move toward the infant for 60 seconds.

Behavioral Coding

Lab-TAB guidelines were used to code each fear task (Goldsmith & Rothbart, 1999). A fear score was obtained by rating the intensity of five specified behaviors:

1. Intensity of facial fear (0–3): Three facial regions were the focus of fear coding: forehead/brow region (raised brows drawn together, faint horizontal furrows), eyes/nose/cheeks region (raised eyelids that make the eyes appear wide with a tense appearance), and mouth/lips/chin region (lip corners drawn straight back making the mouth appear less than wide open). Using Lab-TAB guidelines, if the infant demonstrated none of these indications of facial fear they were coded as a zero. If only one facial region showed fear, the infant was identified as low intensity fear and received a one. When two facial regions showed codable fear or when the infant's fear expression was very clear in one region, the infant received a two. A score of three was given to those infants that demonstrated an appearance of fear in all three facial regions (Goldsmith & Rothbart, 1999).
2. Intensity of distressed vocalizations (0–5): Ranging from no distress to long whining or low-intensity cry with extended or rhythmic quality.
3. Intensity of bodily fear (0–3): Degree, if any, of freezing or trembling.
4. Intensity of escape (0–3): Degree of mild fleeting behavior to full-body movements.
5. Startle: Reflex or alarm reaction at first presentation.

Latency, in seconds, from the start of the trial to the first definite fear response (facial, vocalic, bodily fear or escape behaviors) was also measured. Average inter-rater reliabilities were acceptable: stranger approach (.89), mask presentations (.76) and toy spider (.79). Table 1 provides summary scores for each behavioral fear variable for each task. The sample means demonstrate that this group of infants showed relatively low levels of fear. The sample range, however, shows that there was variability in the intensity of fear behaviors.

Maternal Report of Temperament

Prior to the laboratory visit, mothers were asked to complete the Infant Behavior Questionnaire-Revised (IBQ-R; Gartstein & Rothbart, 2003). The IBQ-R is a 191-item questionnaire assessing 3- to 12-month old infants' emotional and behavioral responses across a number of situations, measuring 14 domains of infant temperament. Although all IBQ-R temperament subscales were collected, the Fear subscale was of particular interest in the current study. This 16 item scale has high internal consistency (α = .87; Gartstein & Rothbart, 2003). Forty-six of the 50 mothers returned the IBQ-R.

Results

Prior to analyses, data were examined for outliers. The Lab-TAB behavioral variable *startle* was dropped from consideration due to its lack of occurrence. A separate behavioral composite fear score (excluding latency) was created for each of the three fear tasks (Rothbart & Bates, 1998). Individual fear behaviors were z-scored for each respective task and then summed; the task composites were not intercorrelated. However the mask fear composite was negatively correlated with maternal ratings of fear (see Table 2).

Correlations among fear behavior composites, baseline and task-specific frontal EEG asymmetries, and maternal IBQ-R ratings of fear, are shown in Table 3. Baseline and task-specific frontal EEG asymmetries were negatively correlated with the masks fear behavior composite, indicating that infants exhibiting greater levels of fear during the masks had right frontal asymmetry during baseline as well as during the masks task.

Baseline frontal EEG asymmetry was not correlated with either the stranger fear behavior composite or the toy spider fear behavior composite. However, for both stranger approach and toy spider, the task-specific frontal EEG asymmetry was negatively correlated with the corresponding fear behavior composite, indicating that infants exhibiting greater levels of fear during the stranger and toy spider tasks exhibited right frontal asymmetry during each of those tasks as well.

A series of stepwise regression analyses were conducted with infant frontal EEG asymmetry (baseline, task) and maternal fear ratings as predictors of the behavioral fear composites. The regressions were done separately for each fear task. Only infants with complete data were used in each task's analysis. Fox (1994) has proposed that patterns of resting frontal EEG asymmetry may serve as a marker of an underlining disposition. Therefore, baseline frontal Fp1/Fp2 asymmetry was entered in Step 1. Task-related frontal EEG asymmetry may be indicative of current emotional state (Davidson & Fox, 1989; Dawson et al, 1992). Thus, frontal Fp1/Fp2 asymmetry during the fear task was entered in Step 2. Lastly, maternal ratings of fear were entered in Step 3. Mothers observe their infants in a variety of contexts and may provide additional variance to the fear score above and beyond the child's frontal EEG asymmetries.

Results of these regression analyses for the mask presentations are presented in Table 4 (top). Baseline frontal EEG asymmetry, task-related frontal EEG asymmetry, and maternal ratings of fear together accounted for 43% of the variance in the fear behavior composite during mask presentation, $F(3, 41) = 10.24$, $p < 0.001$. The model with all three predictors confirmed that task frontal EEG asymmetry significantly predicted behavior fear displays, accounting for 8.7% of the variance. The negative beta values for baseline and task EEG asymmetry indicate that as the infants become more right frontal in their EEG asymmetry (i.e., the asymmetry index becomes more negative in value), the level of fear behavior also increases. Additionally, maternal ratings of fear significantly predicted fear, explaining an additional 6.5% of the variance. Baseline asymmetry scores were not a unique predictor of behavior fear during mask presentation in the final model, after including both task asymmetry and IBQ.

To determine the utility of baseline frontal EEG asymmetry, task-related frontal EEG asymmetry, and maternal ratings of fear in predicting fear behavior during the toy spider presentation, a similar step-wise regression was also performed. Predictors were entered in the same order as in the previous analysis. The results of these analyses are shown in Table 4 (middle) and reveal a marginally significant contribution from task frontal EEG asymmetry in the second model, accounting for 8.7% of the variance in fear behavior during the toy spider task, $F(2, 40) = 1.91$, $p = .06$. The addition of maternal ratings of fear in the final model did not change the amount of variance accounted for by the regression equation.

Finally, to determine the value of these same three variables in predicting fear behavior during stranger approach, another step-wise regression was performed. Predictors were entered in the same order as in previous analyses (see Table 4, bottom). Baseline and task frontal EEG asymmetry together accounted for 10% of the variance in fear behavior during stranger approach, $F(2, 38) = 2.08$, $p = .05$. The model confirmed that task-related frontal EEG asymmetry was a significant predictor of behavior fear for the social fear task, uniquely accounting for 9.8% of the variance. Including maternal report of fear in the final model did not significantly change the amount of variance.

Similar analyses were performed to look at the predictive value of physiology and maternal ratings of fear on infant latency to exhibit a fear response during these social and nonsocial fear tasks. However, these variables were not significant unique predictors of behavior fear latency (all *p*'s >.35).

Discussion

Our study investigated normal variations in fear behaviors across different contexts: social (stranger approach) and nonsocial (masks, toy spider). We hypothesized that the infants' frontal EEG asymmetry during baseline and tasks, as well as maternal ratings of fear, would predict fear behaviors in each task. However, not all of these associations were found for each fear context.

Fear behaviors across the different contexts were not correlated. Other studies have shown only small correlations across fear tasks (Buss, 2011; Garcia Coll et al. 1984). However, infant electrophysiology predicted behavioral manifestations of fear during every task. Although baseline, as well as task-related frontal EEG asymmetry predicted fear behavior during the presentation of the masks, only task-related frontal EEG asymmetry, after accounting for baseline EEG asymmetry, predicted infant fear behavioral reactivity during stranger approach and toy spider fear tasks ($p = .06$ for spider task). We had hypothesized that greater right frontal EEG asymmetry during the tasks would be associated with concurrent higher levels of fear behaviors. This hypothesis was confirmed and verifies the efficacy of task-related frontal EEG asymmetry as an indicator of fear emotion even when the behavioral expression of that emotion is quite low.

Our data suggest that infants may be more likely to demonstrate dispositional bias to some fearful situations but not others. Baseline frontal EEG asymmetry was related to later fear behaviors only in the mask presentation task. This resting right frontal EEG pattern is typically associated with the tendency to display negative emotions (Fox, 1994). It also has been used to indicate activation of the motivational system associated with withdrawal behaviors coupled with the experience and expression of fear (Fox, Henderson, Marshall, Nichols, & Ghera, 2005). Our prediction that infants with higher levels of task fear would also exhibit right frontal EEG asymmetry during baseline was based in part on the behavioral inhibition literature that does report this effect during baseline (e.g., Calkins, Fox, & Marshall, 1996; Fox et al, 2001; Fox et al, 2005). The infants in those studies, however, were screened and selected as being high on negative reactivity and motor movements (potential infant indicators of later behavioral inhibition) and thus may have been more likely to exhibit right frontal EEG asymmetry during baseline.

The infants in our study were unselected for temperament traits, much like the infants in other stranger approach and maternal separation studies (i.e., Bell & Fox, 1994; Davidson & Fox, 1989; Dawson et al., 1992; Fox & Davidson, 1987, 1988). In those studies with unselected infants, the EEG focused on baseline asymmetry (except for Fox & Davidson, 1987, 1988) and the infants' likelihood of crying to either maternal separation or stranger approach. The findings are consistent that distress in either of those situations is correlated with right frontal EEG asymmetry during baseline. However, those studies did not code specifically for fear behaviors, as we did using LAB-Tab coding guidelines. Thus, it may be that the previous stranger approach studies the infants cried for reasons other than fear, such as sadness or anger.

Maternal ratings of infant fear did not uniquely account for variance in normal infant fear reactivity during two different fear contexts, after accounting for baseline and task frontal EEG asymmetries and was in the opposite direction in another fear context. Parental ratings of infant temperament may be the product of not just infant behavior but also of parental perceptions of these behaviors (Bates, 1980). For instance, certain behaviors such as an infant crying in the sight of novelty may be interpreted as a fearful reaction (Goldsmith & Rothbart, 1999). However, parents may vary in the degree to which they find this infant behavior as fearful. Research has indicated that parental ratings of infant temperament are influenced by variation in objectively measured infant behavior patterns and by antecedent parental behavior patterns (Anderson et al.,1989; Crockenberg & Acredolo, 1983). Furthermore, there is some evidence that maternal temperament has a modest but significant contribution to maternal reports of early temperament (Matheny, Wilson, & Thoben, 1987). One viable and interesting next step would be to extend this experimental protocol to investigate mother's perception of her own temperament and examine correlations with her infant's fear behaviors.

This study is not without its limitations. Infants may have varied in previous exposure to strangers, masks, and toy spiders. Because we did not access previous exposure to these contexts, we cannot account for individual differences in fear due to familiarity. Furthermore, infants were predominately Caucasian and from highly educated families. Future studies should examine ethnic and culture differences in fear. Studies have indicated differences in temperament across distinct ethnic group in various Eastern and Western cultures (Ahadi, Rothbart & Ye, 1993; Windle, Iwawaki, & Lerner, 1988). Culture is an important factor in understanding individual differences, as it may influence the development or maintenance of certain behaviors.

In sum, this group of infants was not selected on any specific behavioral or physiological criteria and exhibited low fear behaviors during three tasks designed to be fear-inducing for infants. Fear behaviors across contexts were not correlated. Yet, the behavioral fear during three very different tasks (social and nonsocial in context) was associated with right frontal EEG asymmetry during the tasks. These data suggests that the examination of brain electrophysiology in typically developing infants may reveal critical information regarding normative fear development.

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References

Ahadi SA, Rothbart MK, Ye R. Child temperament in the U.S. and China: Similarities and differences. European Journal of Personality. 1993; 7:359–378.

Anderson LT, Garcia Coll C, Vohr BR, Emmons L, Brann B, Shaul PW, et al. Behavioral characteristics and early temperament of premature infants with intracranial hemorrhage. Early Human Development. 1989; 18:273–283. [PubMed: 2702952]

Andersson K, Bohlin G, Hagekull B. Early temperament and stranger wariness as predictors of social inhibition in 2-year-olds. British Journal of Developmental Psychology. 1999; 17:421–434.

Bell MA. Brain electrical activity associated with cognitive processing during a looking version of the A-not-B object permanence task. Infancy. 2001; 2:311–330.

Bell, MA.; Fox, NA. Brain development over the first year of life; Relations between electroencephalographic frequency and coherence and cognitive and affective behaviors. In: Dawson, G.; Fischer, KW., editors. Human behavior and the developing brain. New York: Guilford; 1994.

Buss KA. Which fearful toddlers should we worry about? Context, fear regulation and anxiety risk. Developmental Psychology. 2011; 47:804–819. [PubMed: 21463035]

Buss KA, Malmstadt J, Dolski I, Kalin N, Goldsmith H, Davidson R. Right frontal brain activity, cortisol, & withdrawal behavior in 6 months old infants. Behavioral Neuroscience. 2003; 117:11–20. [PubMed: 12619903]

Buss KA, Davidson RJ, Kalin NH, Goldsmith HH. Context-specific freezing and associated physiological reactivity as a dysregulated fear response. Developmental Psychology. 2004; 40:583–594. [PubMed: 15238045]

Calkins SD, Fox NA, Marshall TR. Behavioral and physiological antecedents of inhibition in infancy. Child Development. 1996; 67:523–540. [PubMed: 8625726]

Campos, J.; Barrett, K.; Lamb, M.; Goldsmith, H.; Stenberg, C. Socioemotional development. In: Haith, M.; Campos, J., editors. Infancy and developmental psychobiology. Vol. II. Handbook of child psychology. New York: Wiley; 1983.

Campos J, Frankel C, Camras L. On the nature of emotion regulation. Child Development. 2004; 75:377–394. [PubMed: 15056194]

Crockenberg S, Acredolo C. Infant temperament ratings: A function of infants, of mothers, or both? Infant Behavior and Development. 1983; 6:61–72.

Davidson RJ, Fox NA. Frontal brain asymmetry predicts infants' response to maternal separation. Journal of Abnormal Psychology. 1989; 98:127–131. [PubMed: 2708653]

Davidson RJ, Fox NA. Asymmetrical brain activity discriminates between positive and negative affective stimuli in human infants. Science. 1982; 218:1235–1237. [PubMed: 7146906]

Davidson RJ, Jackson DC, Kalin NH. Emotion, plasticity, context, and regulation: Perspectives from affective neuroscience. Psychological Bulletin. 2000; 126:890–906. [PubMed: 11107881]

Dawson G, Panagiotides H, Grofer Klinger L, Hill D. The role of frontal lobe functioning in the development of infant self-regulatory behavior. Brain and Cognition. 1992; 20:162–176.

Denham SA, Lehman EB, Moser MH, Reeves S. Continuity and change in emotional components of infant temperament. Child Study Journal. 1995; 25:289–308.

Dennis TA, Buss KA, Hastings PD. Physiological measures of emotion from a developmental perspective: State of the science. Monographs of the Society for Research in Child Development. in press.

Ellis BJ, Boyce WT. Biological sensitivity to context. Current Directions in Psychological Science. 2008; 17:183–187.

Fox NA. Dynamic cerebral processes underlying emotion regulation. The development of emotion regulation: Biological and behavioral considerations. Monographs of the Society for Research in Child Development. 1994; 59(2–3):240.

Fox NA, Bell MA, Jones NA. Individual differences in response to stress and cerebral asymmetry. Developmental Neuropsychology. 1992; 8:161–184.

Fox NA, Calkins SD, Bell MA. Neural plasticity and development in the first two years of life: Evidence from cognitive and socioemotional domains of research. Development and Psychopathology. 1994; 6:677–696.

Fox NA, Davidson RJ. Taste-elicited changes in facial signs of emotion and the asymmetry of brain electrical activity in human newborns. Neuropsychologia. 1986; 24:417–422. [PubMed: 3736825]

Fox NA, Davidson RJ. EEG asymmetry in ten-month-old infants in response to approach of a stranger and maternal separation. Developmental Psychology. 1987; 23:233–240.

Fox NA, Davidson RJ. Patterns of brain electrical activity during facial signs of emotion in ten month old infants. Developmental Psychology. 1988; 24:230–236.

Fox N, Henderson H, Marshall P, Nichols K, Ghera M. Behavioral inhibition: Linking biology and behavior within a developmental framework. Annual Review of Psychology. 2005; 56:235–262.

Fox NA, Henderson HA, Rubin KH, Calkins SD, Schmidt LA. Continuity and discontinuity of behavioral inhibition and exuberance: psychophysiological and behavioral influences across the first four years of life. Child Development. 2001; 72:1–21. [PubMed: 11280472]

García, Coll CT.; Kagan, J.; Reznick, JS. Behavioral inhibition in young children. Child Development. 1984; 55:1005–1019.

Gartstein MA, Rothbart MK. Studying infant temperament via the Revised Infant Behavior Questionnaire. Infant Behavior and Development. 2003; 26:64–86.

Goldsmith, HH.; Rothbart, MK. The Laboratory Temperament Assessment Battery (Locomotor Version 3.1). Madison, WI: University of Wisconsin—Madison; 1999.

Kagan J, Reznick J, Clarke C, Snidman N, Garcia-Coll C. Behavioral Inhibition to the unfamiliar. Child Development. 1984; 55:2212–2225.

Kalin NH, Shelton SE, Takahashi LK. Defensive behaviors in infant rhesus monkeys: Ontogeny and context-dependent selective expression. Child Development. 1991; 62:1175–1183. [PubMed: 1756661]

Kolb, B.; Taylor, L. Neocortical substrates of emotional behavior. In: Stein, NL.; Leventhal, B.; Trabasso, T., editors. Psychological and biological approaches to emotion. Hillsdale, NJ: Erlbaum; 1990.

Lindsley DB. Brain potentials in children and adults. Science. 1936; 84:354. [PubMed: 17782580]

Marshall PJ, Bar-Haim Y, Fox NA. Development of the EEG from 5 months to 4 years of age. Clinical Neurophysiology. 2002; 113:1199–1208. [PubMed: 12139998]

Matheny AP. Convergence between temperament ratings in early infancy. Journal of Developmental and Behavioral Pediatrics. 1997; 18:260–263. [PubMed: 9276833]

Matheny AP, Wilson RS, Thoben AS. Home and mother: Relations with infant temperament. Developmental Psychology. 1987; 23:323–331.

Pérez-Edgar K, Bar-Haim Y, McDermott JM, Chronis-Tuscano A, Pine DS, Fox NA. Attention biases to threat and behavioral inhibition in early childhood shape adolescent social withdrawal. Emotion. 2010; 10:349–357. [PubMed: 20515224]

Pivik R, Broughton R, Coppola R, Davidson J, Fox N, Nuwer MR. Guidelines for the recording and quantitative analysis of electroencephalographic activity in research contexts. Psychophysiology. 1993; 30:547–558. [PubMed: 8248447]

Ricard M, Allard L. The reaction of 9- to 10-month-old infants to an unfamiliar animal. The Journal of Genetic Psychology: Research and Theory on Human Development. 1993; 154:5–16.

Rothbart MK. Measurement of temperament in infancy. Child Development. 1981; 52:569–578.

Rothbart MK. Longitudinal observation of infant temperament. Developmental Psychology. 1986; 22:356–365.

Rothbart MK. Temperament and the development of the inhibited approach. Child Development. 1988; 59:1241–1250. [PubMed: 3168640]

Rothbart MK. Temperament, development, and personality. Current Directions in Psychological Science. 2007; 16:207–212.

Rothbart, MK.; Bates, JE. Temperament. In: Eisenberg, N.; Damon, W., editors. Handbook of child psychology: Vol. 3. Social, emotional, and personality development. 5. New York: Wiley; 1998. p. 105-176.

Rothbart, MK.; Bates, JE. Temperament. In: Eisenberg, N.; Damon, W.; Lerner, RM., editors. Handbook of child psychology: Vol. 3, Social, emotional, and personality development. 6. Hoboken, NJ, US: John Wiley & Sons Inc; 2006. p. 99-166.

Rothbart, MK.; Ellis, LK.; Posner, MI. Temperament and self-regulation. In: Baumeister, RF.; Vohs, KD., editors. Handbook of self-regulation: Research, theory, and applications. New York: Guilford Press; 2004. p. 357-370.

Scarr S, Salapatek P. Patterns of fear development during infancy. Merrill-Palmer Quarterly, Behavior & Development. 1970; 16:53–90.

Schaffer HR. The onset of fear of strangers and the incongruity hypothesis. Journal of Child Psychology and Psychiatry. 1966; 7:95–106. [PubMed: 5969990]

Smith CL, Bell MA. Infant frontal asymmetry as predictor of toddlerhood internalizing and externalizing behaviors. Developmental Psychobiology. 2010; 52:158–167. [PubMed: 20175143]

Windle M, Iwawaki S, Lerner R. Cross-cultural comparability of temperament among Japanese and American preschool children. International Journal of Psychology. 1988; 23:547–567.

Table 1

Summary Scores for the Temperamental Fear Variables for Each Task

Stranger Approach	**M**	**SE**	**Range**
Facial	.78	.11	0 – 2.25
Vocal	.36	.17	0 – 5
Bodily	.28	.06	0 – 1.75
Escape	.96	.12	0 – 2.50
Latency to first response (sec.)	3.32	.28	0 – 7.25
Mask Presentations	M	SE	Range
Facial	.66	.06	0 – 2.3
Vocal	.29	.06	0 – 1.75
Bodily	.19	.05	0 – 1.80
Escape	.43	.05	0 – 1.63
Latency to first response (sec.)	3.81	.31	0 – 9
Toy Spider	M	SE	Range
Facial	.73	.09	0 – 2.33
Vocal	1.01	.18	0 – 4.33
Bodily	.15	.05	0 – 2
Escape	.84	.12	0 – 3
Latency to first response (sec.)	19.88	2.16	0 – 60

Note: n = 50 for each variable

Table 2

Correlations among Temperamental Fear Composite Scores and IBQ Fear

	1 Mask	2 Stranger	3 Spider	4 IBQ
1 Mask Composite	-			
2 Stranger Composite	.07	-		
3 Spider Composite	.04	.13	-	
4 IBQ-R Fear scale	−.39**	.09	.07	-

** $p \leq .01$

Note: $n = 46$ for each variable

Table 3

Correlations between Behavior Composite Measures of Temperament Fear and Infant Frontal EEG Asymmetry

Fear Task	Baseline Asymmetry at Fp1/Fp2	Task-specific Asymmetry at Fp1/Fp2
Masks	−.46***	−.52***
Toy Spider	.18	−.30*
Stranger Approach	.21	−.30*
IBQ Fear	.37*	-

** $p \leq .01$;

* $p \leq .05$

Table 4

Summary of Regression Analysis Predicting Task Fear from Infant Frontal EEG Asymmetry and Maternal Rating of Fear

Mask Presentation (n=45)	**b**	**SE b**	**β**	**t**	**p**	**sR²**
Step 1						
Baseline Asymmetry	−1.13	.28	−.53	−4.06	<.001	.28
Step 2						
Baseline Asymmetry	−.72	.32	−.34	−2.29	.03	.08
Task Asymmetry	−.56	.23	−.35	−2.39	.02	.09
Step 3						
Baseline Asymmetry	−.50	.32	−.23	−1.57	.12	.03
Task Asymmetry	−.56	.23	−.35	−2.49	.02	.09
IBQ Fear	−.14	.06	−.27	−2.16	.04	.06

Toy Spider (n=43)	**b**	**SE b**	**β**	**t**	**p**	**sR²**
Step 1						
Baseline Asymmetry	−.06	.33	−.03	−.17	.87	.001
Step 2						
Baseline Asymmetry	.43	.40	.21	1.07	.29	.03
Task Asymmetry	−.66	.34	−.37	−1.95	.06	.09
Step 3						
Baseline Asymmetry	.46	.44	.21	1.02	.32	.02
Task Asymmetry	−.66	.34	−.38	−1.92	.06	.09
IBQ Fear	−.01	.08	−.02	−.095	.93	.002

Stranger Approach (n=42)	**b**	**SE b**	**β**	**t**	**p**	**sR²**
Step 1						
Baseline Asymmetry	.03	.32	.02	.10	.92	.002
Step 2						
Baseline Asymmetry	.23	.32	.11	.70	.49	.01
Task Asymmetry	−.38	.19	−.33	−2.04	.05	.10
Step 3						
Baseline Asymmetry	.10	.37	.05	.27	.79	.002

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Stranger Approach (n=42)	b	SE b	β	t	p	sR^2
Task Asymmetry	−.36	.19	−.31	−1.87	.07	.08
IBQ Fear	.06	.08	.14	.78	.44	.01

Note. Step 1 R^2 = .28, p<.001; Step 2 ΔR^2 = .09, p= .02; Step 3 ΔR^2 = .06, p= .04

Note. Step 1 R^2 = .001, p=.87; Step 2 ΔR^2 = .09, p=.06; Step 3 ΔR^2 = .000, p=.93

Note. Step 1 R^2 < .001, p=.92; Step 2 ΔR^2 = .10, p=.05; Step 3 ΔR^2 = .02, p=.44