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Maternal Sensitivity and Infant Response to Frustration: The moderating role of EEG asymmetry

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Abstract

Two hundred and thirty-three 5-month-old infants and their mothers participated in a study designed to examine the influence of maternal sensitivity and infant neurophysiology, as well as interactions between these, on infants' regulatory behavior and reactivity to emotional challenge. Maternal sensitivity was measured during two mother-child free-play episodes prior to the challenge task. Infant neurophysiology was derived from a measure of resting EEG asymmetry collected during a baseline episode. Infant regulatory behaviors (mother orienting and distraction) and reactivity to challenge (negative affect) were assessed during an arm restraint procedure. Maternal sensitivity predicted mother orienting behavior for all infants, regardless of baseline EEG asymmetry. Maternal sensitivity also predicted more distraction behaviors for infants with left frontal EEG asymmetry at baseline. In contrast, maternal sensitivity predicted more negative affect for infants with right frontal EEG asymmetry at baseline. These findings lend support for the hypothesis that maternal sensitivity and infant neurophysiological functioning interact to predict regulatory behavior and reactivity and are discussed in terms of the significance for understanding infant regulatory development in the first year of life.

Keywords

Maternal Sensitivity; emotion regulation; reactivity; EEG asymmetry; Infancy

Although infants acquire a wide range of skills in the first year of life that will continue to develop over the course of early childhood, emotional reactivity to the environment and an ability to regulate emotional responses are considered two of the most important predictors

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of later adaptive social-emotional and psychological functioning (Fox & Calkins, 2003; Propper & Moore, 2006). Research has demonstrated that the expression and regulation of emotion in infancy and early childhood are powerful mediators of interpersonal relationships and socioemotional adjustment, including behavioral self-control (Calkins, 1994; Cicchetti, Ganiban, & Barnett, 1991; Malatesta, Culver, Tesman & Shephard, 1989; Rothbart, 1989; Thompson, 1994), and are associated with behavioral outcomes such as compliance, effortful control, and inhibitory behavior in later childhood (Fox & Calkins, 2003; Henderson, Fox, & Rubin, 2001; Stifter, Spinrad, & Braungart-Rieker, 1999). Thus, understanding the factors that influence the development of emotion regulation and reactivity in the first year of life is important for predicting both concurrent and future child functioning. Separate lines of research have demonstrated that environmental factors such as parenting, and intrinsic factors such as infant neurophysiology, predict emotional reactivity and regulatory behavior in infancy and early childhood. However, relatively little work has considered parenting and neurophysiology in combination, despite the fact that theoretical approaches suggest that intrinsic and extrinsic influences likely interact to influence child development (e.g. Fox and Calkins, 2003). To address this gap in the literature, the current study examines the influence of maternal sensitivity and infant neurophysiology, as well as interactions between these, on infants' regulatory behavior and reactivity to emotional challenge.

1.1 The development of regulatory behavior in the first year

From very early, infants show individual differences in a predisposition for when and how they respond to cues in their environment; this reactivity style is thought to be present at birth and reflect a relatively stable characteristic of the infant (Calkins, Fox, & Marshall, 1996; Rothbart, Derryberry & Hershey, 2000). By three months of age, primitive and rapidly developing attentional self-regulatory mechanisms begin to assist in simple control of behavioral state and emotional reactivity (Eisenberg, Smith, Sadovsky & Spinrad, 2004) perhaps because of the solidification of biologically based processes (e.g. sleep-wake cycles and eating and elimination) into more predictable and stable patterns and an increasing ability to voluntarily control arousal (Calkins, 2008). This depends largely on attentional control mechanisms and the development of simple motor skills (Rothbart, Ziaie, & O'Boyle, 1992; Ruff & Rothbart, 1996), and leads to coordinated use of attention engagement and disengagement to regulate the infant, particularly in contexts that evoke negative affect.

Rothbart and colleagues (Rothbart, Posner, & Boylan, 1990) were among the first to observe that attentional control, and particularly voluntarily control of visual attention, was related to decreases in negative affect in infants. These authors also demonstrated that by six months of age infants are capable of engaging in self-initiated distraction, and of moving attention away from the source of negative arousal to more neutral stimuli as a means of regulating their own arousal (Posner & Rothbart, 1998). Others have also found that distraction strategies may assist the child in managing early frustration and fear responses in situations where the control of negative emotions is required (Stifter & Braungart, 1995; Calkins, Smith, Gill & Johnson, 1998). However, there are considerable individual differences in the development of these abilities that have been shown to have important implications for

psychosocial adaptation and the acquisition of important developmental achievements (Calkins, 1994, 2008; Calkins et al., 1998; Posner & Rothbart, 1998; Rothbart & Derryberry, 1981; Sroufe, 1996).

Intrinsic child factors and extrinsic environmental factors may account for some of the individual differences in the development of young children's emotion regulation capabilities over time (Calkins, 2004; Cicchetti & Rogosch, 1996). For example, both neurophysiological functioning and experience with a sensitive caregiver have been found to be powerful predictors of regulatory development in the first year of life (e.g., Dawson, Panagiotides, Klinger, & Hill, 1992; Condradt & Ablow, 2010). Theories of emotion regulation suggest that although each of these may have an independent contribution to the development of regulatory behavior, they also likely interact with one another to influence patterns of behavior that emerge with development (e.g. Fox and Calkins, 2003; Posner & Rothbart, 1998).

1.2 Maternal influences on development of regulatory behavior in infancy

The rapid development of regulatory skills and abilities during the infant and toddler years has been described as a process in which the infant progresses from predominately relying on caregivers for regulation to increasingly more and more independent self-regulation (Calkins, 1994; Kopp, 1982; Sroufe, 1996). In infancy, success at regulation depends heavily on the parent's awareness, flexibility, and responsivity to the infant's emotional expression and need for intervention (Calkins, 2008). Indeed, infants' state control in the first few months of life is considerably aided by caregivers' social interactions and routines and it is in the context of these interactions that infants first learn about regulating their own emotions (Kopp, 1982, 1989).

According to current models of caregiving, sensitive caregivers, who recognize infant coping signals (e.g., looking away or protesting), and who respond to them in an appropriate manner, have infants who develop a sense that they can help to regulate the dyadic exchange and, eventually, themselves (Gianino & Tronick, 1988; Tronick, 2007). The ultimate goal of early mother–infant face-to-face interactions is to achieve mutual regulation, or a state of reciprocity, which acts as an important foundation for the infant's development of effective self-regulation. That is, when infants are able to elicit caregiver interaction through the use of affective signals, and experience appropriate and sensitive responding to these signals, they begin to develop self-regulatory skills needed to cope with longer periods of frustrating or emotionally challenging episodes (Gianino & Tronick, 1988; Tronick, 2007).

Empirical evidence has demonstrated that regulatory behaviors observed in infants and toddlers during a challenge episode are related to sensitive maternal responses in previous interactive episodes (Kogan & Carter, 1996; Rosenblum, McDonough, Muzik, Miller, & Sameroff, 2002). For instance, mothers who were more sensitive in interactions that took place prior to a still-face episode had infants who showed more attention seeking behaviors (e.g., looking to her, smiling, reaching) and greater positive affect during a still-face episode (Kogan & Carter, 1996; Mesman, van Ijzendoorn, & Bakermans-Kranenburg, 2009). Negative maternal behavior, over-control and intrusiveness across a variety of contexts have

been found to be negatively related to the use of distraction and sustained attention in a sample of toddlers (Calkins et al., 1998). Together, these data suggest that the infants of more sensitive mothers may display more mother orienting behaviors in an attempt to use her as an external source of regulation during times of challenge and threat. Because sensitive caregiving is thought to serve as a foundation for the development of infants' self-regulation, infants of more sensitive mothers may also be more likely develop and employ more independent self-regulatory distraction behaviors.

1.3 EEG asymmetry and regulatory behavior

Despite the importance of sensitive parenting behaviors for helping to shape the developing regulatory behaviors of the infant, the infant brings his or her own contribution to this process in the form of biological processes. Developmental psychophysiological work emphasizes that certain underlying physiological processes and functioning may play an important role in the etiology of early regulatory behaviors and predict later functioning (Fox, 1994; Fox, Rubin, Calkins, Marshall, Coplan, Porges, Long, & Stewart, 1995; Fox & Card, 1999; Porges, 1991, 1996). Activation within the prefrontal cortex in particular, as measured by electroencephalogram (EEG) methodology, has been found to be an important mechanism through which more sophisticated and effortful regulatory behaviors develop (Fox, 1989, 1994; Davidson, 1993). The EEG is a measurement of scalp-recorded brain electrical activity that represents the synchronized activity of large numbers of cortical pyramidal neurons firing together. This synchronization of activity leads to a dominant frequency of oscillation that is measureable at electrode sites placed at specific scalp locations (e.g. Kagan, Snidman, Kahn, & Towsley, 2007). One reason activity of the frontal lobe may underlie emotion expression and regulation is that the frontal region receives input from every cortical area, as well as from the motor areas of the neocortex (Nauta, 1971). Further, the prefrontal cortex has important and well-mapped-out reciprocal connections with the amygdala (Kelly & Stinus, 1984), which is known to play a definitive role in the basic behavioral-emotional responses to fearful and otherwise negative stimuli (LeDoux, 1987; Fox, 1994).

The prefrontal cortex also plays a functional role in the deployment of attention and in the processing and regulation of emotion, cognition, and behavior as part of the effortful regulation of behavior via the Anterior Attention System (Posner & Rothbart, 1994; 1998). The Anterior Attention system is guided by the Anterior Cingulate Cortex (ACC), which governs cognitive, attentional, and emotional processes using reciprocal connections between the prefrontal cortex and structures of the limbic, autonomic, visceromotor, and endocrine systems (Lane & McRae, 2004; Luu & Tucker, 2004; Davis, Bruce, & Gunnar, 2002; Davidson, Putnam & Larson, 2000). Emotion regulation strategies such as self-initiated distraction and orienting behaviors rely heavily on attentional control are typically effective in the regulation of distress (Fox & Calkins, 2003; Grolnick, Bridges, & Connell., 1996; Kopp, 2002; Silk, Shaw, Skuban, Oland, & Kovacs, 2006). The involvement of attentional control in emotional regulation strategies is facilitated by the overlap in the neural circuitry involved in both emotion regulation and sustained attention, particularly via the ACC and the orbitofrontal cortex (Beauregard, Levesque, & Paquette, 2004; Ernst, Liebenauer, King, Fitzgerald, Cohen, & Zametkin, 1994; Rubia, Hilari, Smith, Mohammed,

Scott, Giampietro, Taylor, & Brammer, 2008; Smith, Taylor, Brammer, Toone, & Rubia, 2006). Thus, activation within frontal cortex, as measured by EEG, may play a particularly important role in development of infant regulatory behaviors.

A large body of research has focused on resting levels of frontal EEG asymmetry to explain important sources of variation in both trait predispositions to respond to emotional stimuli as well as changes in emotional state (Coan & Allen, 2003a, for a review). Thus, baseline EEG measures of frontal cortex activity are theorized to provide a relatively noninvasive way to gain insight about an individual's predisposition toward certain aspects of emotional expression, experience, and regulation (Davidson, 2000). One way to quantify individual differences in frontal asymmetry is to measure the pattern of resting frontal EEG power in the alpha frequency; a frequency that is present throughout the lifespan, although its specific values have been shown to change with development. Difference scores are computed between homologous left and right hemisphere scalp electrodes such that frontal EEG asymmetry provides a measure of the difference in the degree of activation between left and right frontal regions (e.g. Henderson et al., 2001; Vuga, Fox, Cohn, Kovacs & George, 2008; Miskovic & Schmidt, 2010).

Empirical work using measures of EEG asymmetry has established that the frontal region plays a unique and significant role in the regulation of emotional behaviors in development. In an early series of studies using EEG methodology, Fox (1989, 1994) and Davidson (e.g. Davidson, 1993) demonstrated that the frontal lobes of the brain are differentially specialized for approach versus avoidance and that these tendencies influence the behaviors that children engage in when emotionally and behaviorally aroused (Davidson & Fox, 1982; Davidson, 1992; Fox, 1991, 1994, Henderson et al., 2001). Specifically, activation of the right frontal region has been consistently associated with behaviors facilitating withdrawal from novel or stressful stimuli such as gross motor movement, autonomic reactivity, and the expression of negative affect (Fox & Davidson, 1984; Calkins et al., 1996). In contrast, greater left frontal activation is associated with behaviors facilitating approach such as fine motor behavior, language, and the expression of certain positive emotions (Fox & Davidson, 1984). One possible explanation proposed in the literature is that approach-withdrawal tendencies act as a potential bias for an individual's interactions with their environment leading them to preferentially initiate or withdraw from stressful situations or unfamiliar social exchanges (Henderson et al., 2001). These biases may then influence later behavioral functioning. For example, in a sample of infants characterized as showing more negative reactivity at 9 months of age, those displaying left frontal EEG asymmetry were less likely to exhibit behavioral inhibition later in childhood compared to those exhibiting right frontal EEG asymmetry. This led to a hypothesis that infants exhibiting left frontal EEG asymmetry may have access to more adaptive attention and inhibitory strategies that are important in the control of negative affect (Henderson et al., 2001).

1.4 EEG Asymmetry × Maternal Sensitivity

Depending on individual patterns of neurophysiological functioning, environmental factors known to influence regulatory development may not function in the same way for all infants. And indeed, developmental theories have suggested that children's intrinsic biological

characteristics may impact the way in which environmental influences relate to developmental outcomes (Boyce & Ellis, 2005; Belsky & Pluess, 2009). Although relatively little work has examined potential interactions between child intrinsic factors and extrinsic environmental factors on the development of emotion regulation in early life, theoretical work has suggested that integrative approaches to the study of the development of self-control of emotion will be most fruitful if investigations examine the interplay among internal and external factors over time (Fox & Calkins, 2003). Previous theoretical work has also suggested that the development of self-regulation seems to hinge on both the infant's own capacity for utilizing necessary regulatory strategies and the parent's sensitivity in meeting the regulatory needs of the infant (Calkins, 1994).

Examining both maternal sensitivity and infant's neurophysiology allows for a greater understanding regarding the way in which extrinsic factors from the environment, such as caregiver behavior, may interact with children's intrinsic biological characteristics to shape infants' regulatory capacities. The role of maternal sensitivity on regulatory development may vary based on the infant's neurophysiological functioning. For example, right frontal baseline EEG asymmetry has been associated with increased negativity and a tendency to withdraw from challenging situations. Therefore, maternal sensitivity may be especially important for infants who demonstrate right frontal asymmetry at baseline as they may have an increased need for extrinsic sources of regulatory support in the absence of internal resources. In contrast, for infants who display left frontal asymmetry at baseline, maternal sensitivity may not have as strong an influence on regulatory behaviors, as left frontal asymmetry by itself is associated with more positive behavior and tendency to approach and engage in situations. It may be especially important to examine interactions between intrinsic and extrinsic factors influencing regulatory development in the period before the rapid change in regulatory abilities occurs from 6 to 10 months of age; from a developmental perspective earlier experience shapes later development. Thus, the current study aimed to examine the influence of maternal sensitivity and infant baseline EEG asymmetry at 5 months, as well as interactions between these two factors, on infant regulatory behavior and reactivity to challenge, reflecting the multi-level, psychobiological model that pervades current theories of emotion regulatory development (e.g. Proppper & Moore, 2006).

Hypotheses

H1: Maternal sensitivity would be related to infant regulatory behavior and reactivity to frustration, such that infants with more sensitive mothers would show more self-regulatory behavior and less negativity.

H2: EEG asymmetry at baseline would be related to infant regulatory behavior and reactivity to frustration, such that infants with left frontal baseline asymmetry would show more self-regulatory behavior and less negativity than infants with right frontal baseline asymmetry.

H3: Maternal sensitivity would interact with infant baseline EEG to predict infant regulatory behavior and reactivity. Specifically, we hypothesized that infants with right frontal baseline asymmetry would benefit more from maternal sensitivity; infants with right frontal baseline

asymmetry and sensitive mothers would show more regulatory behaviors and less negativity than infants with right frontal baseline asymmetry and less sensitive mothers. Infants who exhibited left frontal baseline asymmetry were hypothesized to show more regulatory behaviors and less negativity during frustration, regardless of maternal sensitivity.

Methods

2.1 Participants

Participants in the current study are part of an ongoing longitudinal study examining psychobiological processes in cognitive and emotional development. Data were collected from 233 healthy, full-term infants (125 female, 108 male) and their mothers who participated in the arm restraint task at a 5 month laboratory visit. Study participants were recruited by two research locations (XXXX, and XXXX), with each location recruiting half of the total sample. Of the 233 infants, 181 were Caucasian, 26 African American, 23 multiracial or other, one Asian and two did not report; 17 were Hispanic. Mothers and fathers were, on average, 29 and 32 years old ($SD = 6$ and 7 years), respectively, when the infants were born; 65% of mothers and 56% of fathers had a college education or higher. Infants were recruited via commercial mailing lists, flyers and newspaper advertisements, and word of mouth. All infants were born within 15 days of their calculated due dates and were healthy at the time of testing. Infants' mean age (in days) was 162 ($SD = 8$) at the 5 month visit. Parents were paid for each laboratory visit.

2.2 Procedures

The experimental protocol was approved by the University Institutional Review Boards at each research location (XXXX; XXXX). Data were collected in both research locations using identical protocols. Research assistants from both locations were trained together on protocol administration and psychophysiological editing and scoring by the last author. To ensure that identical protocol administration was maintained between the labs, the XXXX site periodically viewed DVD recordings and psychophysiology files collected by the XXXX site. To ensure that identical coding criteria were maintained between labs, the XXXX site coded all behavioral data collected by both labs and provided reliability coding of artifact screening for psychophysiology data collected by the XXXX site.

Upon arrival at the research laboratory, 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 while a researcher situated the EEG Electro-cap (Electro-Cap, Inc.) on the infant's head. The EEG record was event marked with the start and end times of tasks by a research assistant in an adjacent room who viewed the session via video feed from two wall mounted cameras. The session was digitally recorded for later behavioral coding.

2.2.1 Measures

Observed infant regulation and reactivity: Infant regulation and reactivity was observed during an arm restraint procedure (Calkins, Dedmon, Gill, Lomax, & Johnson, 2002; Stifter & Braungart, 1995; Stifter & Spinrad, 2002), which reliably produces short-term distress

and frustration in infants and is prominently used as a challenge task in the developmental literature (Calkins et al., 2002). Mothers were asked to face their infants and instructed to gently hold their infant's arms down at the infant's sides so that their arm movements would be restricted. Mothers were also instructed to maintain a neutral facial expression and use no vocalizations with their infant for a total duration of up to two minutes. However, experimenters were instructed to terminate the procedure if necessary after 10 seconds of hard crying by the infant.

Two regulatory behaviors, mother orientation and distraction, were scored in 10 second epochs during the arm restraint task. Mother orienting was coded when the infant was looking, vocalizing, or otherwise attempting to engage with the mother. Distraction was coded when the infant was visually attending to or attempting to manipulate an object other than the mother. Final scores for mother orienting and distraction behaviors were calculated as the number of epochs on which the behavior occurred out of the total number of epochs for the task, which yielded a proportion score for each measure. Infant negative affect was coded on a 0 to 5 scale during 10 second epochs, with zero indicating no negative affect present and five indicating escalated crying with at least one shriek. Final scores for negative affect on the task were created by summing scores across epochs and dividing by the number of epochs to create an average score.

Reliability coding was accomplished on 30% of the sample. The ICCs between each pair of coders were examined and determined to be acceptable for the regulatory behaviors and negative affect: mother orienting (.93), distraction (.95) and infant negative affect (.95).

Observed maternal sensitivity: Maternal sensitivity was observed during two sequential mother-child interaction tasks that occurred prior to the frustration task. For each task, the mother was asked to move her chair or turn so that she was facing her infant and to interact with him or her as she normally would. During the first interaction task mothers were given two age appropriate infant toys and asked to play with her infant for two minutes. This was followed immediately by a peek-a-boo task in which mothers were instructed to play peek-a-boo with their infant for an additional two minutes using their hands or a washcloth provided.

Maternal Sensitivity was coded in 30 second epochs during the mother-child interaction tasks using a coding scheme adapted from previous work (Fish, Belsky, & Stifter, 1991; Shapiro & Mangelsdorf, 1994; Calkins, Hungerford, & Dedmon, 2004). Mother sensitivity was rated on a 1 to 4 scale on each epoch according to how skillfully and appropriately the mother facilitated the infant's response to an object or the peek-a-boo game and/or how well she followed and contingently responded to the infant's attention and behavior. A score of 1 on an epoch indicated that the mother showed very low or no facilitation of the infant's attention to the task or objects in the task and did not respond to the infant's attention and spontaneous behaviors. A score of 4 indicated that the mother showed repeated instances of appropriate and well-timed facilitative behaviors, sensitive and contingent responding to the infant, and adapted her own behavior according to the infant's spontaneous behavior. Final scores for maternal sensitivity on each task were created by summing scores across epochs and dividing by the number of epochs to create an average score for the task. Since maternal

sensitivity on the two interaction tasks was significantly positively correlated ($r = .37, p < .001$) an average maternal sensitivity score was created by averaging the scores for the two tasks.

Reliability coding for maternal sensitivity was accomplished on 36% of the sample. The Inter class correlations (ICCs) between each pair of coders were examined and determined to be acceptable for each task (.74 for both).

2.2.2 EEG recording—Infants' EEG was recorded for one minute while they were seated on their mother's laps and watched a research assistant manipulate a toy containing brightly colored balls on a testing table 1.1 meters in front of them. This baseline procedure is common in the field because it quiets the infant and yields minimal eye movements and gross motor movements and allows the infant to tolerate the EEG cap (e.g. Bell, 2001, 2012; Diaz & Bell, 2011; Fox, Henderson, Rubin, Calkins & Schmidt, 2001, Henderson et al., 2001). Mothers were instructed not to talk or interact with their infant during the baseline task.

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), medial parietal (P3, P4), lateral parietal (P7, P8), and occipital (O1, O2). All electrode sites were referenced to Cz during recording. EEG was recorded using a stretch cap (Electro-Cap, Inc.) with electrodes configured in the 10/20 system (Jasper, 1958; Pizzagalli, 2007). After the cap was placed on the infant's head, recommended procedures regarding EEG data collection with infants were followed (Pivik, Broughton, Coppola, Davidson, Fox, & Nuwer, 1993). Specifically, a small amount of abrasive paste was placed into each recording site and the scalp gently rubbed. Following this, conductive gel was placed in each electrode site. Electrode impedances were measured and accepted if they were below 10 Kohms.

The electrical activity from each lead was amplified using separate SA Instrumentation Bioamps (San Diego, CA) and bandpassed from .1 to 100 Hz. Activity for each lead was displayed on the 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 were re-referenced via software to an average reference configuration (Lehmann, 1987). Average referencing, in effect, weighted all the electrode sites equally and eliminated the need for a noncephalic reference. Active (F3, F4, etc.) to reference (Cz) electrode distances vary across the scalp. Without the re-referencing, power values at each active site may reflect interelectrode distance as much as they reflect electrical potential. The average reference configuration requires that a sufficient number of electrodes be sampled and that these electrodes be evenly distributed across the scalp.

The re-referenced EEG data were artifact scored for eye blinks using Fp1 and Fp2 (Myslobodsky, Coppola, Bar-Ziv, Karson, Daniel, van Praag, & Weinberger, 1989) and for gross motor movements; these artifact-scored epochs were eliminated from all subsequent analyses. The data then were analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-second width and 50% overlap. Power was computed for the 6–9 Hz frequency band which is the dominant frequency for infants this age (Bell & Fox, 1992; Marshall, Bar-Haim, & Fox, 2002). The infant 6–9 Hz frequency band is thought to approximate the alpha band in adults and has been used by infant EEG researchers to investigate both cognitive and emotional processing in infancy (Bell, 2001, 2002, 2012; Fox et al., 2001; Orekhova, Stroganova, & Posikera, 2001) and in studies of infant frontal asymmetry (e.g., Bell & Fox, 1992; Buss, Schumacher, Dolski, Kalin, Goldsmith, & Davidson, 2003; Fox, Bell, & Jones, 1992; Fox et al., 2001; Smith & Bell, 2010). Power was expressed as mean square microvolts and the data were transformed using the natural log (ln) to normalize the distribution. Frontal EEG asymmetry scores are most often calculated at the medial frontal scalp locations F3 and F4 in the literature and have been used as evidence of the associations between brain electrical activity and observed emotion-related behaviors (Davidson & Fox, 1989, Dawson et al., 1992, Fox, 1994; Fox et al., 2001). Therefore, for the current study, frontal asymmetry scores were calculated at medial frontal electrodes F3 and F4 by subtracting ln left frontal power from ln right frontal power (ln F4–ln F3 = frontal asymmetry score). 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 and vice versa.

Results

Preliminary analyses included examining descriptive statistics of all study variables; the mean, standard deviation, range, and skew for each variable can be seen in Table 1. Simple correlations among the primary study variables as well as EEG usability status and amount of artifact free baseline EEG were run. EEG usability was not related to any of the study variables suggesting there was no systematic difference between infants who provided useable baseline EEG data, versus those who did not, on any of the study variables. However, amount of artifact free baseline data was significantly correlated with Mother Orientation behavior during the arm restraint task ($r = .19, p < .01$). This correlation suggests that infants who provided more artifact free baseline EEG data also oriented more to their mother during the arm restraint task. Simple correlations among the primary study variables are displayed in Table 2. Given that only 10% of data were missing, single imputation was implemented to account for missingness. Maternal education, child race, infant age in days, and child sex were examined as possible covariates. However, none of these variables were correlated with the independent or the dependent variables in the current study and were therefore excluded from subsequent analyses.

Hierarchical regression was used to test three separate models examining the moderating role of infants' EEG baseline asymmetry in the association between maternal sensitivity and infant regulatory behaviors during the arm-restraint task. An additional model was examined to test the moderating role of infants' EEG baseline asymmetry in the association between

maternal sensitivity and negative affect. Interaction effects were calculated by centering and then multiplying baseline EEG asymmetry and maternal sensitivity. In each model, baseline EEG asymmetry and maternal sensitivity were entered in the first block, and the interaction term was entered in the second block.

3.1 Mother Orientation

Examination of direct effects revealed a significant and positive association between maternal sensitivity and mother orientation behaviors such that more maternal sensitivity was associated with infants engaging in more mother orientation behaviors in the arm restraint task (see Table 3). However, there was no significant interaction between baseline EEG asymmetry and maternal sensitivity in relation to mother orientation behaviors. This finding suggests that maternal sensitivity was associated with more orientation behaviors for infants with both left frontal and right frontal baseline EEG asymmetry.

3.2 Distraction

There were no direct associations between maternal sensitivity or baseline EEG asymmetry and infants' distraction behaviors. However, there was a significant interaction between baseline EEG asymmetry and maternal sensitivity in relation to distraction (see Table 3). Follow-up tests of simple slopes (Aiken & West, 1991) revealed maternal sensitivity predicted greater distraction behaviors for children with higher values of baseline EEG asymmetry ($\beta = .23$, $p = .02$), indicating that for children with more left frontal resting activation, greater maternal sensitivity was associated with infant distraction behavior during frustration. Maternal sensitivity was not significantly associated with mother orientation behaviors for children with lower values of baseline EEG asymmetry (i.e. more right frontal resting activation) (see Figure 1).

3.3 Negative Affect

There were no direct associations between maternal sensitivity or baseline EEG asymmetry and infants' negative affect. However, there was a significant interaction between baseline EEG asymmetry and maternal sensitivity in relation to negative affect (see Table 4). Follow-up tests of simple slopes (Aiken & West, 1991) revealed maternal sensitivity predicted greater negative affect for children with lower values of baseline EEG asymmetry ($\beta = .23$, $p = .03$), indicating that for children with more right frontal resting activation, greater maternal sensitivity was associated with greater negative affect during frustration. Maternal sensitivity was not significantly associated with negative affect for children with higher values of baseline EEG asymmetry (i.e. more left frontal resting activation) (see Figure 2).

Discussion

The goal of this paper was to examine the moderating role of 5-month-old infants' neurophysiological functioning, measured as EEG asymmetry during a baseline episode, in the association between maternal sensitivity and infant regulatory behavior and reactivity during a frustrating arm-restraint task. Our results indicated that more maternal sensitivity measured during mother-infant interaction predicted greater mother orientation for infants with both left and right frontal baseline asymmetry. However, maternal sensitivity only

predicted infant distraction behaviors for infants with greater values of baseline EEG asymmetry, indicative of more left frontal resting activity. With regard to negative reactivity during the arm restraint task, we found that more maternal sensitivity during mother-infant interaction predicted greater negative affect for children with lower values of baseline EEG asymmetry, indicative of more right frontal resting activity, but was not significantly associated with the expression of negative affect for infants with left frontal baseline asymmetry. Although different from what we had hypothesized, this interesting pattern of findings lends some support for the hypothesis that maternal sensitivity and infant neurophysiological functioning interact to predict regulatory behavior and reactivity in the first year of life.

We hypothesized that maternal sensitivity would be especially important for developing regulatory behaviors for infants who displayed a pattern of right frontal EEG asymmetry at baseline, as this pattern of neural activity has been associated with more negative reactivity in infants (Calkins et al., 1996), higher basal and stress-induced salivary cortisol concentrations in 6-month-olds (Buss et al., 2003), and more withdrawal motivation across early development (Fox et al., 2001; Hane, Fox, Henderson, & Marshall, 2008). The rationale behind this hypothesis was that infants with right frontal baseline asymmetry may need to rely more heavily on caregivers to regulate increased negativity and distress given fewer neurophysiological regulatory resources. Contrary to our hypothesis, maternal sensitivity was associated with mother orientation behaviors during frustration for all infants. By 5 months of age infants have an accumulation of experience with caregivers with regard to whether they can expect effective caregiver assistance in times of distress (Sroufe, 1996). Infants with caregivers who are sensitive to their cues and are able to effectively assist them in regulating their behavior and affect are more likely to orient towards their mothers during times of distress in an attempt to facilitate co-regulation of negative arousal (Gianino & Tronick, 1988; Tronick, 2007); this is likely because they have previous experience with a caregiver successfully helping them regulate. Regulatory capacities at 5 months of age are still relatively immature (Kopp, 1982). Thus, although infants with left frontal baseline asymmetry are thought to have greater intrinsic regulatory resources than infants with right frontal baseline asymmetry, our results suggest that they still attempt to utilize their mother as a resource for reducing negative arousal.

EEG asymmetry did moderate the association between maternal sensitivity and infant distraction behaviors. Similar to mother orientation behaviors, it was hypothesized that maternal sensitivity would be more strongly related to distraction behaviors for infants with right frontal baseline asymmetry. However, the opposite pattern was found such that maternal sensitivity was predictive of more time spent engaging in distraction behaviors for infants with higher left frontal baseline asymmetry. Left frontal asymmetry has been found to be associated with approach behaviors (Fox & Davidson, 1984), and it may be that infants with approach tendencies initiate more interactions with the environment that afford sensitive caregivers more frequent opportunities to help infants regulate their emotional responses, thus facilitating more rapid development of independent self-regulatory strategies. Infants with right frontal baseline asymmetry, on the other hand, may avoid or withdraw from emotionally charged situations, consequently reducing the number of opportunities for caregivers to promote infants' self-regulatory abilities. The arm restraint

procedure used in this study involves the mother administering the challenge and not responding to the infant's cues of distress. It is possible that infants with left frontal asymmetry who experience sensitive caregiving have developed more independent self-regulatory strategies and were therefore able to employ distraction behaviors when maternal orientation behaviors were not effective at reducing arousal. In sum, infants of highly sensitive mothers with left frontal baseline asymmetry appeared to attempt to initiate more interaction with their mother by orienting to her, but were also better able to engage in distraction behaviors and direct their attention elsewhere in order to independently reduce their arousal when their mother did not respond. Indeed, it is important to note that the correlation in Table 2 demonstrates that distraction behaviors were negatively correlated with negative affect, suggesting that distraction behaviors did serve a regulatory function and decreased distress during the arm restraint procedure for the infants in this sample. This is also likely why we found an interaction between maternal sensitivity and both distraction behaviors and negative affect.

This pattern of results was not present for infants of highly sensitive mothers who had right frontal baseline asymmetry. Instead, this specific combination of neurophysiology and maternal sensitivity resulted in infants who displayed more negative affect during the arm restraint challenge. Although this may seem counterintuitive at first, it may be that these infants are signaling a need for regulatory help with more negative affect, rather than distracting themselves elsewhere as was observed for infants with left frontal baseline asymmetry. If infants with right frontal asymmetry have not yet developed or begun to use more independent self-regulatory behaviors such as distraction, and have a history of their mother effectively aiding them in the modulation of negative arousal, it is likely that an unresponsive mother may elicit increased negative affect. This fits with the previous work demonstrating that right frontal asymmetry is associated with more negative affect and withdrawal from challenging situations (e.g. Fox and Davidson, 1994, 1997). Therefore, infants with right frontal asymmetry at baseline may be at a regulatory disadvantage or delay, and less able to actively engage in regulatory behaviors independently. From this viewpoint, engaging in negative affect may be a useful strategy to enlist the help of an external source when infants are unable to rely on their own internal resources. Indeed, others have noted that the expression of negative affect creates opportunities for external intervention (Tronick, 1989; Kochanska, 1997; Maccoby, 1992).

An alternative explanation of our findings comes from emerging work (Fortier, Can Lieshout, Waxman, Boyle, Saigal, & Schmidt, in press) which suggests that resting frontal EEG asymmetry may be a biological factor indexing sensitivity to developmental context; essentially conceptualizing frontal asymmetry in terms of the differential susceptibility to environment theory (Belsky, Bakermans-Kranenburg, & Van IJzendoorn, 2007; Belsky & Pluess, 2009; Ellis et al, 2011). Fortier and colleagues found that adults who exhibited left frontal asymmetry and were born with extremely low birth weight (their measure of early developmental context) exhibited the highest levels of attention problems in adulthood, while adults with left frontal asymmetry who were born with a normal birth weight displayed the lowest levels of problem behaviors. Adults who exhibited right frontal asymmetry displayed a moderate amount of problem behavior regardless of birth weight. These authors interpreted their findings as evidence that left frontal asymmetry might be a

biological sensitivity factor to developmental context and may help explain why left frontal asymmetry has been associated with both positive and negative outcomes, while right frontal asymmetry is more consistently associated with negativity and withdrawal behavior. This interpretation is applicable to our findings as well, and suggest that in the presence of positive environmental context (high maternal sensitivity in our case), left frontal asymmetry was associated with more regulatory behavior during a challenging episode, while right frontal asymmetry was not. In contrast, in the presence of positive environmental context, right frontal asymmetry was associated with more negativity; consistent with previous work in which right frontal asymmetry reliably characterizes negative affectivity (e.g. Schmidt, 1999; Fortier et al., in press).

Our findings suggest an advantage for infants who have both left frontal baseline asymmetry *and* a sensitive mother in the transition to early forms of self-regulation. However, the current work is not without limitations. Maternal sensitivity, infant behavior, and EEG data were all collected when infants were 5 months of age. Thus, it was not possible to examine the direction of effects in this study and interpretation of our results as related to developmental processes is limited. However, as almost no work has examined these questions and relations between these constructs, this was an important first step and makes a critical contribution to the literature and suggests avenues for future research. It will be important for future work to look longitudinally at the relations between maternal sensitivity and infant baseline EEG asymmetry on infant regulatory development to further examine how early experience and neurophysiological functioning may predict later regulatory functioning and associated outcomes as emotional reactivity and regulatory behavior becomes increasingly sophisticated and self-regulated. In addition, it will be important for future work to examine these questions in different samples of infants and mother-infant dyads. Although the current sample was a relatively diverse sample, the majority of mothers in our sample had a college education or higher (65%). An important goal for future work will be to recruit mothers with more variability in education level and/or income, as both of these have consistently been associated with maternal sensitivity in a variety of other work (e.g. Mills-Koonce, Propper, Gariepy, Blair, Garrett-Peters & Cox, 2007; NICHD Early Child Care Research Network, 2004). Finally, these data were not designed to address questions of maternal mental health or parenting style, but both of these factors are known to influence maternal sensitivity and parenting behavior. Maternal depression in particular has been shown to influence both maternal behavior during interactions with their infant (e.g. Cohn & Tronick, 1989; Cohn, Campbell, Matias, & Hopkins, 1990; Field, Sandberg, Garcia, Vega-Lahr, Goldstein, & Guy, 1985) as well as measures of infant electrical brain activity (e.g. Dawson, Frey, Panagiotides, Yamada, Hessler, & Osterling, 1999; Field, Fox, Pickens, & Nawrocki, 1995). Therefore, maternal depression is an important variable that should be included in future work further pulling apart associations between maternal behavior, infant EEG, and infant regulatory development.

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Highlights

- Maternal sensitivity predicted mother orienting during frustration for all infants.
- Sensitivity predicted more distraction in infants with left frontal EEG asymmetry.
- Sensitivity predicted more negativity in infants with right frontal EEG asymmetry.
- Mother behavior and infant asymmetry interact to influence frustration response.

Figure 1.
Interaction of EEG baseline asymmetry and maternal sensitivity in the prediction of infant distraction behaviors during arm restraint.

Figure 2. Interaction of EEG baseline asymmetry and maternal sensitivity in the prediction of infant negative affect during arm restraint.

Table 1

Descriptive Information of Study Variables

	M	SD	Range	N	Skew (SE)
Baseline Asymmetry	.08	.35	-1.10 – 1.57	233	.09 (.16)
Maternal Sensitivity	3.46	.45	1.38 – 4.00	233	1.18 (.16)
Mother Orientation	.39	.32	.00 – 1.00	233	.53 (.16)
Distraction	.47	.36	.00 – 1.00	233	-.01 (.16)
Negative Affect	2.24	1.42	.00 – 1.00	233	.06 (.16)

Table 2

Pearson Correlations among Study Variables

	2	3	4	5
1. Baseline Asymmetry	-.03	-.00	.03	.08
2. Maternal Sensitivity		.16*	.05	.05
3. Mother Orientation			-.23**	.14*
4. Distraction				-.60**
5. Negative Affect				

*
 $p < .05$.

**
 $p < .01$.

Table 3
Hierarchical Regression Models of Mother Orientation and Distraction Behaviors

Predictors	Mother Orientation			Distraction		
	<i>B</i> (<i>SE</i>)	β	<i>R</i> ²	<i>B</i> (<i>SE</i>)	β	<i>R</i> ²
<u>Step 1</u>						
Maternal Sensitivity	.11 (.05)	.16*	.03	.04 (.05)	.05	.01
Baseline EEG Asymmetry	.00 (.06)	.00		.03 (.07)	.03	
<u>Step 2</u>						
Baseline EEG Asymmetry × Maternal Sensitivity	.28 (.16)	.12	.04	.41 (.18)	.15*	.03
			<i>R</i> ² = .01			<i>R</i> ² = .02*

* *p* < .05

Table 4

Hierarchical Regression Model of Negative Affect

Predictors	Negative Affect		
	<i>B</i> (<i>SE</i>)	β	<i>R</i> ²
<u>Step 1</u>			.01
Maternal Sensitivity	.15 (.20)	.05	
Baseline EEG Asymmetry	.31 (.27)	.08	
<u>Step 2</u>			.03
			<i>R</i> ² = .02*
Baseline EEG Asymmetry $\times$ Maternal Sensitivity	-1.53 (.70)	-.14*	

*
 $p < .05$.