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Maternal Behavior Predicts Infant Neurophysiological and Behavioral Attention Processes in the First Year

Margaret M. Swingler, Nicole B. Perry, and Susan D. Calkins
University of North Carolina at Greensboro

Martha Ann Bell
Virginia Tech

We apply a biopsychosocial conceptualization to attention development in the 1st year and examine the role of neurophysiological and social processes on the development of early attention processes. We tested whether maternal behavior measured during 2 mother−child interaction tasks when infants (N = 388) were 5 months predicted infant medial frontal (F3/F4) EEG power and observed attention behavior during an attention task at 10 months. After controlling for infant attention behavior and EEG power in the same task measured at an earlier 5-month time point, results indicated a significant direct and positive association from 5-month maternal positive affect to infant attention behavior at 10 months. However, maternal positive affect was not related to medial frontal EEG power. In contrast, 5-month maternal intrusive behavior was associated with infants' task-related EEG power change at the left frontal location, F3, at 10 months of age. The test of indirect effects from 5-month maternal intrusiveness to 10-month infant attention behavior via infants' EEG power change at F3 was significant. These findings suggest that the development of neural networks serving attention processes may be 1 mechanism through which early maternal behavior is related to infant attention development in the 1st year and that intrusive maternal behavior may have a particularly disruptive effect on this process.

Keywords: attention, infancy, EEG power, maternal behavior, neural networks

Infant visual attention has a long history as an early measurement tool for studying development across a number of domains and has been shown to be a predictor of childhood socioemotional skills, cognitive competencies, intellectual and language outcomes, and academic achievement (Colombo, 2002; Colombo & Salley, 2015; Cuevas & Bell, 2014; Perry, Swingler, Calkins, & Bell, 2016; Posner & Fan, 2008; Sarver et al., 2012). Attention development in early infancy is dominated by an emerging ability to maintain an alert state and orient to sensory events in the environment (Posner & Fan, 2008). By the second half of the first year, however, attentional flexibility and the capacity to effortfully control, manipulate, and sustain attention become increasingly prevalent (e.g., Rothbart, Posner, & Rosicky, 1994; Ruff & Rothbart, 1996). Despite extensive documentation of the rapid emergence of more sophisticated volitional attention beginning toward the end of the first year, relatively little empirical work has examined early factors that may influence this process.

Biopsychosocial theories of development posit that neurophysiological, behavioral, and social processes become elaborated and integrated over time to shape subsequent functioning (e.g., Calkins, 1994, 2008; Thompson & Goodvin, 2007; Thompson, Lewis, & Calkins, 2008). The development of attention, specifically, has strong biological underpinnings but is also influenced by transactions between the child and his or her social environment (e.g., Blair, 2002; Calkins, 2011; Colombo & Salley, 2015; Colombo & Saxon, 2002; Swingler, Perry, & Calkins, 2015). Indeed, human neuroplasticity research has revealed that neurocognitive systems like those involved in attention are characterized by a great deal of plasticity in early development (e.g., Sanders, Stevens, Coch, & Neville, 2006; Stevens & Neville, 2013), when interaction with caregivers dominates the infants' social environment. Thus, caregiver behavior may contribute to individual differences in the emergence, maturation, and consolidation of rapidly changing neural systems underlying attention behavior (Cicchetti & Dawson, 2002; Luthar, Cicchetti, & Becker, 2000; Posner, Rothbart, Sheese, & Voelker, 2014). To better understand

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Margaret M. Swingler and Nicole B. Perry, Department of Human Development and Family Studies, University of North Carolina at Greensboro; Susan D. Calkins, Department of Psychology, University of North Carolina at Greensboro; Martha Ann Bell, Department of Psychology, Virginia Tech.

Susan D. Calkins is now at the Department of Human Development and Family Studies, University of North Carolina at Greensboro.

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Correspondence concerning this article should be addressed to Margaret M. Swingler, UNCG- 248 Stone Building. PO Box 26170, Greensboro, NC 27402. E-mail: mmswingl@uncg.edu

the impact of caregiving behavior on the early development of attention processes, we examined whether two specific maternal behaviors, positive affect and intrusiveness, predicted neurophysiological and behavioral attention processes in infants from 5 to 10 months of age.

Importance of Attention Behavior in Early Development

The development of attention in the first year has been of particular interest to researchers aiming to better understand precursors to adaptive functioning because it has been associated with mechanisms for resolving conflict among thoughts, feelings, and behavioral responses (Rueda, Posner, & Rothbart, 2005). In particular, control of attention is thought to contribute to the regulation of emotional reactivity, resulting in more socially appropriate and adaptive behavior in infancy and early childhood. Indeed, emotion regulation in the first year has been largely described and defined in terms of attentional and motoric control mechanisms that emerge early in development and operate primarily to regulate distress (Posner & Rothbart, 2000; Rothbart & Bates, 1998).

By the end of the first year, infants are able to employ organized sequences of behavior in emotionally arousing contexts that enable them to disengage, redirect attention, and self-sooth in a flexible manner (Calkins, 2004). The coincident timing of the emergence of more sophisticated sustained and controlled attention behavior with more adaptive emotion regulation abilities in the second half of the first year has been proposed as evidence of an association between the development of attention and emotional functioning in infancy and beyond (Bell & Calkins, 2012). Accordingly, deviations or delays in the development of attention processes and associated regulation likely contribute to maladaptive developmental trajectories associated with poor regulatory abilities. A recent empirical study from our lab provided some preliminary evidence for this; greater observed behavioral attention measured during an attention task at 10 months was associated with less observed behavioral frustration during a challenging task at 3 years of age (Perry et al., 2016). Importantly, in this work neural activity measured during the attention task at 10 months was also associated with later emotion regulation behavior through an association with 10-month attention behavior. Therefore, understanding the development of neural, behavioral, and contextual processes associated with early attentional control is particularly important when aiming to better understand early antecedents of later behavior problems and psychopathology.

Neurophysiological Underpinnings of Attention Behavior

Data from work using electrophysiological and neuroimaging techniques has shown that one function of attention at the neural level is to increase the “gain” or salience of an attended stimuli or event relative to an unattended one (e.g., Hillyard, Vogel, & Luck, 1998). This can occur either as an increase in neural activity associated with the processing of that stimuli or event or a suppression of activity to other irrelevant stimuli or ambient noise (Colombo & Salley, 2015; Neill & Westberry, 1987), with either case making it more likely that neural connections surrounding that stimulus or event are learned or acted upon and that connections between neural areas involved are strengthened (Colombo & Salley, 2015). Thus, one consequence of attention processes at the neural level is a reinforcement of coordinated or synchronous neural activity within and across areas of the brain, which likely facilitates other cognitive and regulatory processes for the infant (Albright, Jessell, Kandel, & Posner, 2000; Colombo & Salley, 2015; Steinmetz et al., 2000). This neural synchrony has been theorized to provide the basis for higher-order cognitive abilities, including the formation of neurocognitive networks which lead to the emergence of new behavior (Bressler & Tognoli, 2006; Fries, 2005). A large body of theoretical and empirical work supports the existence of three neural networks that contribute to attention and whose development mirrors the emergence of increasingly sophisticated attention behavior: the alerting, orienting, and executive attention network or networks (Petersen & Posner, 2012; Posner & Dehaene, 1994; Ruff & Rothbart, 1996). Recent work with resting state functional connectivity using fMRI has shown that extensive development of these networks proceeds rapidly so that adult-like connectivity is present by the end of the first year (Gao, Gilmore, et al., 2013; Gao, Zhu, et al., 2009).

We focus our examination on the executive attention network, whose development is thought to underlie the more purposeful and controlled aspects of attention that allow infants to voluntarily engage and sustain their own attention toward the end of the first year. The more volitional control of attention behavior that defines executive attention is associated with activation of a neural network that includes the anterior cingulate cortex (ACC) in the medial frontal lobe, lateral frontal and prefrontal cortex, and basal ganglia, which help to start and control movement (Posner & Fan, 2008). By 2 years of age, the ACC exhibits strong connectivity to both parietal and frontal areas associated with alerting, orienting, and executive control of attention, making it a central component of neural networks for attention (Gao et al., 2009). Empirical work with noninfant samples has found that one function of the executive attention network is to monitor and resolve conflict at the neural level, including conflict among thoughts, feelings, and behavioral responses (Berger, Tzur, & Posner, 2006; Rothbart et al., 1994; Rothbart, Sheese, & Posner, 2007). This has led to the argument that the ACC and associated areas of midfrontal cortex are central to the emergence of more sophisticated attention and regulatory behavior because they function to monitor, regulate, and resolve conflicting information from other neural networks that might be activated in cognitive and emotional challenges (e.g., Botvinick, Braver, Barch, Carter, & Cohen, 2001).

Despite promising theoretical conceptualizations of the development of attention processes in the brain that underlie attention behavior in infancy, empirical work providing data to support these ideas is limited by methodology practical for use with infants. Attention exerts its influence in the brain by modulating the activity of neural systems involved in information processing such that information processing in the attended channel is facilitated, whereas processing in irrelevant channels in inhibited (Hillyard et al., 1998; Orekhova, Stroganova, & Posikera, 2001; Rueda et al., 2005). Electroencephalogram (EEG) methodology provides a noninvasive measure of neural activity measured at the scalp level during spontaneous behavior and is therefore ideal for developmental work while still providing a direct measure of attention processes in the brain. The EEG signal is a measure of brain electrical activity that is recorded via electrodes on the scalp

and results from summated postsynaptic neuronal potentials firing in synchrony (Davidson, Jackson, & Larson, 2000). 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). From this, measures of EEG power, or the root-mean-square voltage of the EEG signal within a frequency band of interest (Pizzagalli, 2007), can be derived that provide information about extent and location of cortical activity. This activity can be measured at rest and in response to specific situations or stimuli requiring attention and is useful in the study of the development of attention networks in infancy.

Although work with adults and infants has revealed potential associations between attention performance and multiple frequency bands at multiple scalp locations (see Orekhova, Stroganova, & Posikera, 1999, 2001; see also a review by Saby & Marshall, 2012), the vast majority of developmental EEG work has identified the developmental alpha (6 to 9 Hz) frequency band as the dominant frequency in infancy and early childhood and has demonstrated its prevalence during both cognitive and emotional processing in early development (e.g., Bell, 2001, 2002, 2012; Bell & Fox, 1992; Diaz & Bell, 2011; Fox et al., 2001; Marshall, Bar-Haim, & Fox, 2002; Orekhova et al., 2001). In addition, the 6- to 9-Hz developmental alpha band has been suggested to approximate the adult alpha band, which has been associated with attentional modulation of cortical activity in adult work (e.g., Orekhova et al., 2001; Ray & Cole, 1985).

Task-related changes in EEG power (in comparison to baseline) are hypothesized to represent activation of brain areas underlying specific scalp electrodes (Cuevas & Bell, 2011) recruited for task performance and have been used as indicators of cognitive processing during laboratory tasks with infants and young children (e.g., Bell, 2001, 2002; Wolfe & Bell, 2004, 2007) and adults (see Klimesch, 1999 for a review). The 6- to 9-Hz developmental alpha band has been shown to discriminate overall performance (Bell, 2001) and individual correct and incorrect responses (Bell, 2002) on a working memory and inhibitory control task and on overall performance on a sustained attention task (Orekhova et al., 2001) in previous work with infants in the second half of the first year. In general, this work has found that tasks which require cognitive processing and attentional engagement result in increases in EEG power from baseline to task in the 6- to 9-Hz frequency band (e.g., Bell, 2001; Bell & Wolfe, 2007; Orekhova et al., 2001) and that individual differences in baseline to task changes in power are associated with individual differences in task performance (Bell, 2001). In addition, task-related change in 6- to 9-Hz power, and associations with task performance, becomes increasingly localized to frontal lobe locations with age, suggesting a preferential role for activity of the frontal lobe for cognition and attention processes in development (e.g., Bell, 2001, 2002; Orekhova et al., 2001; Wolfe & Bell, 2004, 2007).

Neural activity from medial frontal scalp areas may at least partially reflect activity of the ACC, and is consistently shown to be present in higher order processes of attention regardless of task domain in work with older children and adults (Posner & Rothbart, 1998; Posner & DiGirolamo, 1998). In a recent empirical paper utilizing the same dataset as the current study, we found that medial frontal 6- to 9-Hz EEG activity during an attention task was associated with concurrent observed attention behavior at 10 months of age (Perry et al., 2016). Interestingly, this relationship varied by hemisphere; an increase in right frontal (F4) power was associated with more time spent looking at task stimuli while an increase in power at the analogous left frontal location (F3) was associated with less time spent attending. These findings are consistent with research in adults and older children showing a right hemisphere specialization for attention based performance and that right hemisphere volumes of the ACC and other frontal structures correlate with performance on tasks requiring attention and response inhibition (Casey et al., 1997a, 1997b; Durston et al., 2001). Thus, right frontal activity during attention processes may be an optimal pattern of neurophysiological response from very early in development, which we expect to replicate here, with downstream consequences for attention behavior and associated functioning in development.

Other infant work has demonstrated that larger baseline and task specific 6- 9-Hz EEG power values at frontal locations are associated with better performance on an attention task (Diaz & Bell, 2011) and on working memory tasks that rely on attention shifting (e.g., Bell, 2002; Bell & Wolfe, 2007; Cuevas & Bell, 2011). Taken together, these results suggest that neural activity within the frontal cortex may play a particularly important role in the development of infants' observed attention behavior. EEG methodology utilizing attention task related change in EEG power at medial frontal scalp locations (F3/F4) may be one way to examine an association between neural activity potentially linked with the executive attention network and change in observed attention behavior.

The Role of Caregiving on Behavioral Attention Processes

Behavioral changes in attention in the first year have been well documented and there is clear theoretical, and emerging empirical, support for a neural basis for this change. However, relatively little work has examined factors in the infant's environment that may influence this relationship in the first year. Applying a biopsychosocial perspective to the development of attention emphasizes the importance of including both intrinsic biological factors (e.g., functioning of neural systems for attention outlined above) as well as extrinsic environmental factors (e.g., caregiver behavior). Because of the increased plasticity during early development (e.g., Sanders, Stevens, Coch, & Neville, 2006; Stevens & Neville, 2013), interactions with caregivers may be a key factor contributing to individual differences in the emergence, maturation, and consolidation of behavioral and neurocognitive systems underlying attentional abilities (Colombo, 2004).

Kopp (1982) and others (e.g., Calkins, 2004; Calkins, 2008; Grossman & Grossman, 1991; Kopp & Neufeld, 2003; Posner & Rothbart, 1998) have theorized that early caregiving has a strong influence on the infant's developing regulatory capabilities, which include attention processes. This is because much of infant behavior develops in the context of an infant-caregiver dyad in which caregivers initially act as external regulators of their infant's behavior (Calkins, 2008; Calkins & Fox, 2002; Kopp, 1982; Sroufe, 2000). Although there is a relatively little work specifically examining the influence of caregiver behavior on attention development in the first year, empirical studies have revealed that caregivers initially regulate their infant's arousal and attention by

being aware of their infant's capacity to receive and use stimulation (e.g., Brazelton, Koslowski, & Main, 1974; Sander, 1975; Stern, 1977). For example, in their extensive work on the regulation of distress, Posner and Rothbart (1998) have noted that by 3 months many caregivers attempt to redirect infant attention by using distraction techniques to bring their infant's attention to a positive or neutral stimuli, a caregiver's effective use of these strategies is thought to shape the infant's developing capacity for using these same strategies independently (Posner & Rothbart, 1998).

Caregiving behavior has rarely been examined in relation to attentional development specifically; however, parental sensitivity, warmth, and positive reinforcement have been associated with a host of later positive socioemotional, cognitive, and academic outcomes in child development (NICHD ECCRN, 1999, 2003; Rimm-Kaufman, Pianta, Cox, & Bradley, 2003). Empirical work on parenting has demonstrated that caregiver behavior is sensitive when it occurs in response to an infant's cues and is modified by the infant's behavior or state; thus, in the context of attentional engagement, a sensitive caregiver responds with stimulation when the infant is under aroused and reduces it when the infant is engaged or overly stimulated. Thus, a sensitive caregiver who shows more positive affect during interactions with their infant may reinforce infant attentional engagement and exploration with positive vocalizations, affect, or behavioral cues while infants are attending, and only intervene and redirect attention when necessary and in response to the infant's signals for a need for such intervention. Because a sensitive and nonintrusive caregiver is able to follow the infant's lead to facilitate and support the infant's own attentional engagement, this may promote the development of fundamental intrinsic processes which support independent attentional engagement for the infant. In contrast, intrusive caregiving behavior is characterized by interventions that are not in response to infants' mood, state, or interest (Jacobvitz & Sroufe, 1987) and are often in direct competition to the infants' own source of attentional engagement and interaction. Thus, intrusive caregiving behavior has the potential to create rapidly shifting and disorienting sources of arousal and stimulation that place external demands on the infant's attention and may disrupt intrinsically controlled attention processes. Indeed, previous work has demonstrated that negative and intrusive caregiving behavior is associated with behavioral, academic, and social adjustment problems in later childhood (Cookston, Harrist, & Ainslie, 2003; Culp, Hubbs-Tait, Culp, & Starost, 2000; Pike & Plomin, 1996; Rubin, Burgess, Dwyer, & Hastings, 2003). Thus, caregiver levels of positive affect and intrusive behavior in the context of routine interactions with the infant may have the ability to facilitate or impede the development of attentional processes at both a behavioral and neurophysiological level.

Influence of Caregiving on Neurophysiological Attention Processes

Emerging empirical work has begun to provide evidence that early relational experiences are closely related to neural development. The theoretical bases for this work comes from the idea that basic neural circuitry established during the first years of life lays the groundwork for later changes (e.g., Propper & Moore, 2006) and is capable of being molded by the social environment (De Bellis, 2001; Gunnar, Fisher, & the Early Experience, Stress, & Prevention Network, 2006; Nelson, 2000; Propper & Moore, 2006). Social experience is thought to be especially salient in the first two years of life when a spurt in brain growth characterized by an overproduction of synapses occurs (Nelson, Thomas, & de Haan, 2006). During this process, environmental experiences are thought to directly influence the synaptic connections that persist and are strengthened, or which are selectively eliminated due to lack of use (Greenough & Black, 1992; Nelson & Bloom, 1997; Singer, 1995). Recent work by our research group (Bernier, Calkins, & Bell, 2016) has provided previously lacking empirical support for the notion that normative variation in caregiving behavior early in development is predictive of individual differences in brain development. Specifically, we found that more maternal positivity during interactions when infants were 5 months of age was associated with greater infant EEG alpha and theta baseline power at 10 and 24 months, and greater increases in baseline power between each age. Importantly, this effect was specific to EEG power measured at frontal locations only; suggesting that development of the frontal lobe, which is associated with emerging attention and executive function abilities, may be especially sensitive to normative variation in caregiver behavior. Thus, caregiver behavior and, in particular, a caregiver's ability to support and facilitate the infant's early use of attention may have long term effects on the structure and function of neural systems associated with attention.

A second area of research has provided evidence that experience with an adult can have a direct effect on brain activity associated with attention processes in development. For example, engagement in joint attention with an adult when viewing an object results in a larger peak amplitude of the Nc component of the event-related potential (indicating greater allocation of "neural attention") in 9-month-old infants compared with a nonjoint attention interaction condition (Striano, Reid, & Hoehl, 2006). The direction of this effect suggests that joint attentional engagement, like that which occurs in sensitive and responsive caregiving, results in *increased* activity of areas of the brain associated with executive attention in development. This suggests that one role of sensitive caregiving behavior early in development may be to increase activity in brain areas associated with neural networks of attention, thereby strengthening connections between these areas and helping to create a neural network for attention processes.

The Current Study

A large amount of theoretical and emerging empirical work suggests that there are biological characteristics that are likely present from birth that underlie the rapid attentional development that occurs in the first year of life (e.g., Posner, Rothbart, & Sheese, 2007; Rueda, Rothbart, McCandliss, Saccamanno, & Posner, 2005). However, these biological underpinnings, including the neural systems underlying attention, are thought to be at least partially modified by environmental input (Bakermans-Kranenburg, van IJzendoorn, Pijlman, Mesman, & Juffer, 2008; Sheese, Voelker, Rothbart, & Posner, 2007; Stevens, Sanders, & Neville, 2006). The caregiving environment is arguably the most important and influential context for infant development and caregiver manipulation of infant attention in the context of regulation of infant distress has been well documented. Caregiver behavior in

the context of typical daily interactions has been less well studied in its potential relation to the infant's developing attention behavior and underlying neural systems. Although caregiver behavior that is positive and sensitive is likely to have a reinforcing impact on the infant's attention development, intrusive caregiver behavior may actively disrupt attention processes for the infant. We examine whether maternal positive affect and intrusive behavior measured at 5 months in the context of two play based interactions predicts infants' attention behavior and associated neural activity at 5 and 10 months. In a recent paper using data from the same sample of infants as the current work, we found that normative variation in caregiver behavior related to developmental change in baseline EEG power from 5 to 24 months (Bernier et al., 2016). Thus, we hypothesize that early maternal caregiving behavior exhibited during regular interaction with the infant may have an effect on the development of infants' attention behavior through its influence on the infant's developing neurophysiological systems supporting attention development. This work provides an important empirical test of the widespread theoretical belief that the expansive influence of quality of caregiving behavior on a wide range of child functioning occurs through children's neural circuity (Belsky & de Haan, 2011; Bernier et al., 2016; Gunnar, 2003).

Method

Participants

As part of a longitudinal study examining individual differences in the development of cognition and emotion across early development, 410 infants were recruited by two research locations (Greensboro, NC and Blacksburg, VA), with each location recruiting half of the total sample. Infants were recruited via commercial mailing lists, newspaper birth announcements, and word of mouth. Of the 410 infants, 22 were reported to have been born with low birth weight (i.e., less than 2,700 g) or were diagnosed with developmental delay and were excluded from the final sample. Therefore, the current study used data from 388 infants (199 girls, 189 boys; 303 Caucasian, 48 African American, 17 multiracial, 2 Asian, 14 other, 4 not reported) who were born within 15 days of their calculated due dates and were typically developing (see Table 1 for final sample size for each variable at each time point). For mothers who reported educational information ($N = 378$), 97% graduated from high school, 6% had a technical degree, 42% had a bachelor's degree, and 22% had a graduate degree. Mothers were, on average, 29 years old ($SD = 6$) when the infants were born. Families who did not return for a 10-month laboratory assessment ($n = 43$) included those who could not be located, moved out of the area, declined participation, or did not respond to phone and letter requests to participate at the 10-month visit. There were no significant differences between families who did or did not participant at both time points in terms of child sex, race, maternal education, or any of the primary study variables.

Procedures

Data were collected at both research locations using identical protocols. Research assistants from each location were trained together by the project's Principal Investigator on protocol administration, as well as on behavioral and psychophysiological data collection and coding. To ensure that identical protocol administration was maintained between the labs, the Blacksburg site periodically viewed DVD recordings and psychophysiology files collected by the Greensboro lab. To ensure that identical coding criteria were maintained between labs, the Blacksburg lab provided reliability coding for behavioral data and verification of artifact screening and data editing for psychophysiology data collected and coded by the Greensboro lab.

Upon arrival at the research laboratory, participants were greeted by a research assistant who explained the study procedures and obtained signed consent from the mother. After a brief warm-up period, infants were fitted with the EEG cap and participated in a variety of behavioral tasks assessing cognitive and emotional development. The start and end times of tasks were marked in the EEG record by a research assistant in an adjacent room who viewed the session via video feed from two wall mounted cameras. The session video feed was digitally recorded for later behavioral coding. Parents were paid $50 for each laboratory visit.

Table 1
Correlations and Descriptive Statistics for Study Variables

Variable	1	2	3	4	5	6	7	8
1. Maternal positive affect (5 m)	—							
2. Maternal intrusiveness (5 m)	$-.14^{**}$	—						
3. EEG power ΔF3 (5 m)	.02	−.10	—					
4. EEG power ΔF4 (5 m)	−.01	−.05	$.43^{**}$	—				
5. EEG power ΔF3 (10 m)	−.04	$.12^{*}$	−.01	.05	—			
6. EEG power ΔF4 (10 m)	−.01	.09	.08	.10	$.55^{**}$	—		
7. Attention behavior (5 m)	$.20^{**}$	$-.16^{**}$	.02	.10	−.03	−.05	—	
8. Attention behavior (10 m)	$.20^{**}$	−.06	.04	$.12^{*}$	$-.12^{*}$	.02	$.35^{**}$	—
M	2.63	1.34	.03	.06	.08	.09	58.94	60.65
SD	.52	.38	.31	.32	.31	.35	17.07	13.22
Minimum	1.38	1.00	−.95	−1.10	−.91	−.94	20.80	27.66
Maximum	4.00	3.25	1.47	1.41	.94	1.02	94.84	94.73
Skew	.52	1.66	.12	.09	−.05	.59	.01	.07
(*SE*)	(.13)	(.13)	(.13)	(.13)	(.13)	(.13)	(.13)	(.13)
N	357	357	355	355	331	331	370	343

* $p < .05$. ** $p < .01$.

Measures

Neural activity. EEG was recorded during a 1-min baseline and during a visual attention task at 5 and 10 months. The procedure for obtaining baseline EEG was identical at both visits; infants sat on their mothers' laps and watched a research assistant manipulate a toy containing brightly colored balls on a testing table, 1.1 m in front of them. This baseline procedure quiets the infant, yields minimal eye 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).

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 International, Inc.; Eaton, OH; E1-series cap) with tin electrodes in the 10/20 system pattern. After the cap was placed on the head, a small amount of abrasive gel was placed into each recording site and the scalp gently rubbed. Conductive gel was then added to the recoding sites. Electrode impedances were measured and accepted if they were below 20 kΩ.

The electrical activity from each lead was amplified using separate Bioamps (James Long Company; Caroga Lake, NY). During data collection, the high-pass filter was a single pole RC filter with a 0.1-Hz cut-off (3 dB or half-power point) and 6 dB per octave roll-off. The low-pass filter was a two-pole Butterworth type with a 100 Hz cut-off (3 dB or half-power point) and 12-dB octave roll-off. Activity for each lead was displayed on the monitor of the acquisition computer. The EEG was digitized online at 512 samples per second for each channel to eliminate the effects of aliasing. The acquisition software was Snapshot-Snapstream (HEM Data Corp.; Southfield, MI) and the raw data were stored for later analyses. Prior to the recording of each subject a 10-Hz, 50-uV peak-to-peak sine wave was input through each amplifier. This calibration signal was digitized for 30 s and stored for subsequent analysis. To ensure that the EEG data being collected was as clean as possible, a visual inspection of the incoming data from each electrode was performed by a trained experimenter viewing the data on a computer in a control room adjacent to the testing room. This experimenter also viewed the testing session via camera and inserted event marks in the EEG data at the start and finish of the baseline and attention tasks while the data was being collected. These event marks were later used to segment the baseline and attention task portions from the ongoing EEG record for data analyses.

EEG data were examined and analyzed using EEG Analysis software developed by James Long Company. Data were first re-referenced via software to an average reference configuration (Lehmann, 1987). The average reference EEG data were artifact scored for eye movements using a peak-to-peak criterion of 100 uV or greater, and for gross motor movements using a peak-to-peak criterion of 200 uV or greater. Segments of EEG data that were scored as containing artifact were eliminated from all subsequent analyses. No artifact correction procedures were used. The data were then analyzed with a discrete Fourier transform (DFT) using a Hanning window of 1-s width and 50% overlap. Across infants, the mean number (and proportion) of artifact-free DFT windows during the baseline and attention tasks was 76.2 (.60) and 57.9 (.51), respectively, for the 5-month assessment; 57.07 (.46) and 61.28 (.50), respectively, for the 10-month assessment. Differences in artifact-free DFT windows available for analyses between ages were primarily due to increases in gross motor artifact as infants became increasingly physically active and mobile (baseline) and longer task times as infants' sustained attention increased (attention task) between 5 and 10 months.

Power was computed for the 6- to 9-Hz developmental alpha frequency band, which is the dominant frequency for infants and young children (Bell & Fox, 1992; Marshall, Bar-Haim, & Fox, 2002) and is used by infant EEG researchers to investigate both cognitive and emotional processing (Bell, 2001, 2002, 2012; Diaz & Bell, 2011; Fox et al., 2001; Orekhova et al., 2001), and attentional modulation of cortical activity (e.g., Orekhova et al., 2001; Ray & Cole, 1985). Therefore, the 6- 9-Hz frequency band was both developmentally appropriate, and the most likely to reveal associations with differences in attention behavior in our infant sample. Power was expressed as mean square microvolts and data were transformed using the natural log (ln) to normalize the distribution. We derived a measure of task-related neural activity at medial frontal scalp locations by subtracting baseline EEG power from EEG power during the attention task at the medial frontal electrode sites (F3 and F4). We chose to only examine these medial frontal sites because of the well-established role of the frontal cortex for attention processes (Posner & Fan, 2008) and previous work from our research group using data from the same sample of infants and mothers demonstrating that an effect of maternal behavior on infant and toddler EEG alpha power was specific to frontal electrode locations only (Bernier et al., 2016).

Attention behavior. At the 5- and 10-month laboratory visit infants sat on their mothers' laps 1.1m from the edge of the testing table (90 cm [L] × 60 cm [W] × 75 cm [H]) and were presented with a glove puppet adorned with facial features on the palm of the glove and small bells attached to each fingertip (Cuevas & Bell, 2014; Diaz & Bell, 2011; Perry et al., 2016). The glove puppet was presented until the infant looked at the glove four separate times, with each look separated by at least 3 s during which the infant looked away (procedure and criteria adapted from Diamond, Prevor, Callender, & Druin, 1997). Although this procedure ensured that each infant was given multiple opportunities to direct their attention to the stimuli, it resulted in different task times for each participant (Cuevas & Bell, 2014). Thus, a proportion score of time looking at the glove puppet in relation to the total task time was used as the measure of infant attention. In the current study, a greater proportion of time spent attending to the puppet was indicative of greater behavioral attention.

Looking data were coded offline to determine proportion of time looking. A video camera was placed behind and above the experimenter's head and focused to maintain a close-up split-screen view of the glove and the infant's face. A research assistant coded each infant's look duration from a video recording of the laboratory session using the Video Coding System software developed by James Long Company (Caroga Lake, NY). An additional independent observer coded at least 20% of the recordings to confirm reliability of coding. Intraclass correlations exceeded .91 for proportion of looking at each age at each study site.

Observed maternal behavior. Maternal behavior was observed at the 5-month laboratory visit during two sequential play

based interaction tasks with the mother and infant. For each task, the mother was asked to turn so that she was facing her infant and to interact with him or her as she normally would. During the toy free-play task mothers were given two age appropriate infant toys and asked to play with the 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 provided washcloth.

Maternal behavior was coded in 30-s epochs during the mother−child interaction tasks using a coding scheme adapted from previous work (Fish, Stifter, & Belsky, 1991; Shapiro & Mangelsdorf, 1994; Calkins, Hungerford, & Dedmon, 2004). Maternal behavior across the epoch was rated on a scale ranging from 1 (*no evidence of the behavior*) to 4 (*consistent, high levels of the behavior*). The current analyses examined two dimensions of maternal behavior during mother-infant interaction: maternal positive affect and maternal intrusiveness.

Maternal positive affect during the toy free play and peek-a-boo tasks was defined as positive affect the mother expressed either through tone of voice such as infant directed speech with positive intonation and tone, facial expressions such as smiling or laughing, or a combination of the two. Maternal intrusiveness was defined as insensitive, overcontrolling behavior during which the mother ignored or overrode the infant's behavioral cues and initiations of play or interaction in favor of her own behavioral agenda during the toy free-play or the peek-a-boo game. Examples of intrusive behaviors were failing to modulate her own behavior in response to the infant turning away, pulling away, or expressing negative affect toward the mother, a toy, or activity; overwhelming or overstimulating the infant with a continuous barrage of toys or play instead of letting the infant pace the play or interaction; ignoring or interrupting the infant's interest in a toy or activity by introducing a different toy or activity, taking a toy or object away from the infant when the infant was playing with it, or not allowing the infant to touch a toy the mother was holding. Maternal behavior was also scored as intrusive if mothers physically manipulated the infant's hands or face to make them perform an action or manipulation, especially if the infant was objecting to maternal interference or was already independently playing.

Final scores for maternal behavior on each task were created by summing scores across epochs and dividing by the number of epochs to create an average maternal positive affect and maternal intrusiveness score for the task. Since maternal behavior on the two interaction tasks was significantly positively correlated ($r = .45$, $p < .001$ for positive affect; $r = .30$, $p < .001$ for intrusiveness) average maternal positive affect and intrusiveness scores were created by averaging the scores for the two interaction tasks. Reliability coding for maternal behavior was accomplished on at least 20% of the sample for each task (range of 22% to 30%). The interclass correlations (ICCs) between each pair of coders were examined and determined to be acceptable for each task (range = .82−.96).

Results

A path analysis was conducted to examine the associations between maternal behavior, infant attention behavior, and medial frontal EEG activity utilizing Mplus (Version 7; Muthén & Muthén, 2015). Full information maximum likelihood (FIML) was used to handle missing data; all data were missing at random. Maternal education was included as a covariate; as expected based on previous work (e.g., Bernier et al., 2016; Mills-Koonce et al., 2007; NICHD Early Child Care Research Network, 2004) it was associated with our observed measures of maternal positive affect ($\beta = .19$) and intrusiveness ($\beta = -.13$) here as well (see Figure 1). Moreover, because baseline EEG power is used in the calculation of EEG power change and may also be individually associated with attention behavior, baseline EEG power values at 5 and 10 months were entered into the model as control variables. Finally, given our interest in examining whether maternal behavior predicted changes in medial frontal EEG activity from 5 to 10 months, and whether these changes were subsequently related to *changes* in infant's attention behavior from 5 to 10 months, 5-month EEG power change and 5-month observed behavioral attention during the attention task were also controlled for in the model. Descriptive statistics and bivariate correlations for the primary study variables are provided in Table 1.

The hypothesized model fit well, χ^2 (40, $N = 388$) = 65.437, $p = <.01$, CFI = .96, RMSEA = .04 [CI = .02, .05] (unstandardized coefficients are presented in Table 2 and standardized coefficients are presented in Figure 1). Below, we walk through specific model pathways that directly reflect our primary research questions. First, we sought to address whether changes in medial frontal EEG activity (as indexed by EEG power change from baseline to task at medial frontal scalp locations F3 and F4) were associated with changes in infant attention behavior during the glove puppet attention task at 10 months. After controlling for 5-month EEG power change and 5-month attention behavior, baseline to task increases in EEG power at medial frontal locations F3 and F4 at 10 months were associated with the amount of time infants spent attending to the glove puppet at 10 months, although the specific pattern of association varied by hemisphere (see Figure 1). An increase in EEG power change from baseline to task at 10 months at the right frontal medial location, F4, was associated with more time spent looking at the puppet during the attention task. In contrast, an increase in EEG power change from baseline to task between 5 and 10 months at the left frontal medial location, F3, was associated with less time spent looking at the puppet.

An additional aim of this work was to examine whether maternal positive affect and intrusiveness at 5 months predicted changes in infants' attention processes from 5 to 10 months. With regard to changes in attention behavior, the direct path from maternal intrusiveness at 5 months to the percentage of total time spent looking at the glove puppet during the attention task at 10 months was not significant. However, higher levels of maternal positive affect at 5 months was directly associated with greater time spent attending at 10 months after controlling for time spent attending at 5 months, suggesting that more maternal positive affect at 5 months is associated with greater increases in infants observed attention behavior in this task from 5 months to 10 months (see Figure 1).

We also sought to examine associations between maternal positive affect and intrusiveness and changes in infant's medial frontal EEG activity from 5 to 10 months during the attention task. Maternal positive affect was not directly related to infants' baseline to attention task change in EEG power values at either medial frontal location. Maternal intrusiveness at 5 months was associated positively with infant's 10-month baseline to attention task change in EEG power values at the left frontal midline location, F3, after

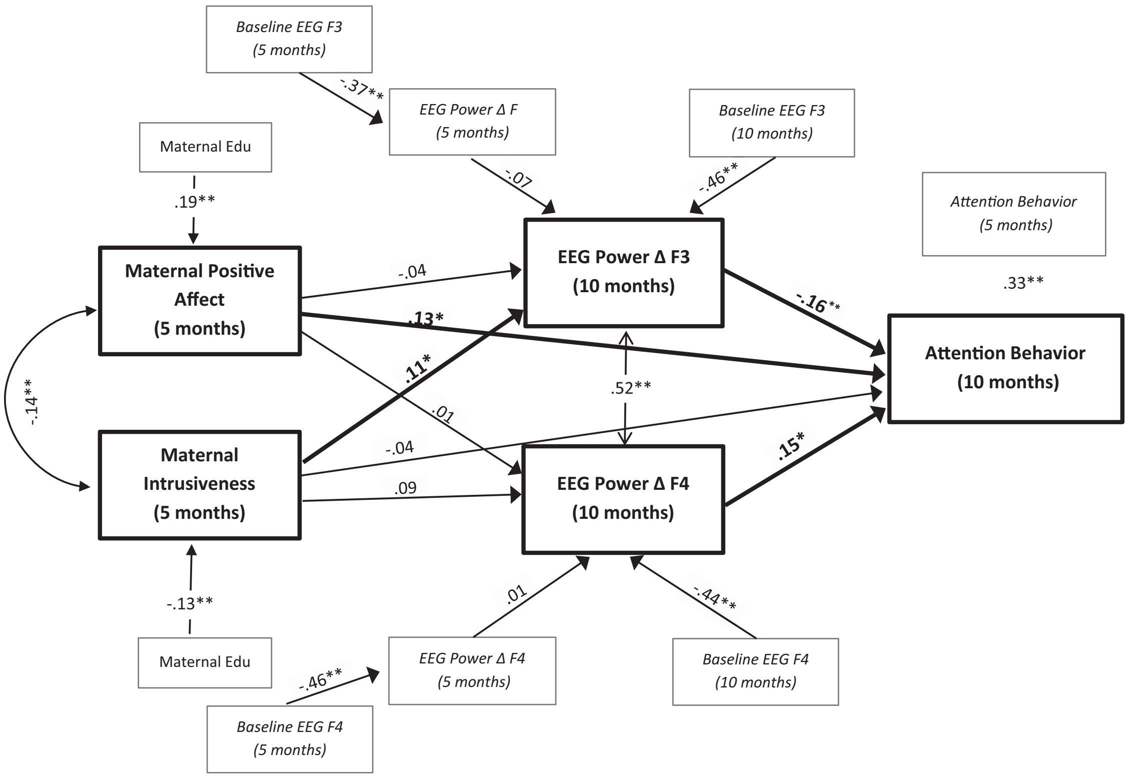

Figure 1. Standardized estimates for the indirect effects model predicting 10-month attention behavior. Italicized wording delineates variables included for the purposes of controlling for previous levels. Bold pathway delineates significant associations among primary variables of interest. * $p < .05$. ** $p \leq .01$.

controlling for 5-month baseline to task change in EEG power at this location (see Figure 1). This suggests that greater maternal intrusiveness during interactions at 5 months is associated with greater increases in attention-related power change at the left medial frontal location F3 from 5 months to 10 months. In contrast, intrusiveness was not associated with infants' baseline to attention task change in power values at the right medial frontal location, F4.

Finally, we aimed to assess whether maternal positive affect and intrusiveness were indirect predictors of infant attention behavior via 5- to 10-month change in infants' medial frontal EEG activity during the attention task. Although it was hypothesized that early maternal positive affect may be indirectly related to 10-month observed attention through an effect on changes in neural activation from 5 to 10 months, maternal positive affect at 5 months was not significantly associated with medial frontal neural activity at either electrode location at 10 months (see Figure 1). Thus, the indirect effects could not be considered. Maternal intrusiveness at 5 months was not associated with infant's baseline to task EEG power change at the right medial frontal location, F4, but was positively associated with EEG power change at the left medial frontal location, F3 (see Figure 1). Therefore, only the indirect effect from maternal intrusiveness at 5 months to infant observed attention at 10 months via 10-month change in neural activity at the left medial frontal electrode site F3 (controlling for 5 month levels of both) was tested. To test this indirect effect, a bias-corrected bootstrapping procedure (10,000 draws) was performed. This approach has been shown to generate the most accurate confidence intervals for indirect effects, reducing Type I error rates and increasing power over other similar tests (MacKinnon, Lockwood, & Williams, 2004). The indirect path was significant (unstandardized estimate $= -.61$, 95% BC bootstrap [CI -1.9, $-.02$]), indicating that greater maternal intrusiveness when infants were 5 months was associated with less time spent attending to the glove puppet task stimulus at 10 months, through its association with an increase in neural activation at 10 months at the left medial frontal location during the attention task.

Discussion

We examined the role of maternal behavior during interaction with their infants at 5 months of age on the infants' developing neural and behavioral attention processes in the second half of the first year of life. We proposed that maternal behavior may have a direct effect on infant's developing attention behavior, but that it may also have an indirect effect on attention behavior through an effect on infants' neural attention systems which rapidly develop to adult-like connectivity and functioning by the end of the first year (Gao et al., 2009, 2013). Thus, we hypothesized that we might find an effect of maternal behavior measured in interactions at 5 months on infants' neural systems for attention, measured as neurophysiological responses to an attention task at 10 months of age.

Table 2
Unstandardized Model Estimates

	Estimate	*SE*	*p*
Covariance			
Maternal Positive Affect (5m) ↔ Maternal Intrusiveness (5m)	−.03	.010	.007
Baseline EEG F3 (5m) ↔ Baseline EEG F4 (5m)	.23	.019	.000
EEG Power ΔF3 (5m) ↔ EEG Power ΔF4 (5m)	.04	.005	.000
Baseline EEG F3 (10m) ↔ Baseline EEG F4 (10m)	.22	.020	.000
EEG Power ΔF3 (10m) ↔ EEG Power ΔF4 (10m)	.05	.006	.000
Covariate			
Maternal Edu (5m) → Maternal Positive Affect (5m)	.09	.024	.000
Maternal Edu (5m) → Maternal Intrusiveness (5m)	−.04	.017	.012
Baseline EEG F3 (10m) → EEG Power ΔF3 (10m)	−.27	.028	.000
EEG Power ΔF3 (5m) → EEG Power ΔF3 (10m)	−.07	.049	.167
Baseline EEG F3 (5m) → EEG Power ΔF3 (5m)	−.21	.029	.000
Baseline EEG F4 (10m) → EEG Power ΔF4 (10m)	.38	.153	.608
EEG Power ΔF4 (5m) → EEG Power ΔF4 (10m)	.01	.051	.861
Baseline EEG F4 (5m) → EEG Power ΔF4 (5m)	−.27	.028	.000
Attention Behavior (5m) → Attention Behavior (10m)	.25	.041	.000
Focal path			
Maternal Positive Affect (5m) → EEG Power ΔF3 (10m)	−.02	.032	.477
Maternal Positive Affect (5m) → EEG Power ΔF4 (10m)	.01	.036	.893
Maternal Positive Affect (5m) → Attention Behavior (10m)	3.14	1.367	.022
Maternal Intrusiveness (5m) → Attention Behavior (10m)	−1.21	1.993	.545
Maternal Intrusiveness (5m) → EEG Power ΔF3 (10m)	.09	.050	.049
Maternal Intrusiveness (5m) → EEG Power ΔF4 (10m)	.09	.053	.098
EEG Power ΔF3 (10m) → Attention Behavior (10m)	−6.67	2.495	.008
EEG Power ΔF4 (10m) → Attention Behavior (10m)	5.36	2.197	.015

We found that change in task-related medial frontal EEG activity was related to time spent attending during the attention task at 10 months of age even after controlling for prior levels of attention behavior and EEG in the same task at 5 months. Our findings indicated that the direction of this relationship varied by hemisphere. A baseline to task increase in EEG power at the right frontal location (F4) was associated with more time spent attending during the task at 10 months. In contrast, an increase in power from baseline to task at the analogous left frontal location (F3) was associated with less time spent attending. Because this sample was used in our previous work addressing the role of behavioral and neural attention processes for the development of emotion regulation, it is not surprising that we found the same pattern of results at 10 months with regard to hemispheric differences (Perry et al., 2016).

These findings are consistent with both clinical and developmental research that has shown a right hemisphere specialization for attention based performance and demonstrated that volumes of the right anterior cingulate of the ACC and other structures of the right frontal cortex correlate with performance on tasks requiring attention and response inhibition in middle childhood and early adolescence (Casey et al., 1997a, 1997b; Durston et al., 2001). These results also demonstrate that although greater right frontal activity is associated with greater proportion of time spent attending, greater left frontal activation during an attention task is related to less time spent attending and may suggest a potential disadvantage for left frontal activation during attention processes in infancy. We interpret these findings to suggest that right frontal activity during attention processes is an optimal pattern of neurophysiological response from very early in development and that deviations in this pattern of neural response may have downstream consequences for attention behavior and for other areas of functioning that rely on attention development.

In our prior work, we have demonstrated that attention behavior in infancy predicts later emotion regulation abilities and that there is an indirect effect linking early neurophysiological functioning during attention processes to later emotion regulation abilities through early attention behavior (Perry et al., 2016). Given the link between the early development of attention processes and the later development of more sophisticated emotional and cognitive abilities (e.g., Posner et al., 2014), a better understanding of environmental factors that may facilitate or impede attention development at both the biological and behavioral levels is important. Thus, our primary goal in the current article was to extend our previous work and examine specific caregiving behaviors in the first year that may influence the development of attention behavior as well as associated neurophysiological functioning.

Our results indicate that maternal positive affect at 5 months had a direct positive effect on infant attention behavior at 10 months, even after controlling for infants' 5-month attention behavior. Thus, maternal positivity during interactions early in development seems to have a facilitative effect on infants' developing attention capabilities; infants who have experienced more positivity during interactions with their mother earlier in development show more evidence of independent attentional engagement and visual exploration toward a new stimulus at 10 months of age. One interpretation for this finding is that infants who have experienced high levels of positivity during early interactions with their mother may be inclined to look at and engage more with a new stimulus as a result of a history of interactions in which new stimuli are often paired with positive vocal and facial cues from the mother. With this positivity, mothers may be signaling to their infants that these

new objects are safe and interesting and should be attended to and explored. In addition, infant attentional engagement has likely been consistently met with positivity and reinforcement from the mother, thereby promoting the likelihood of infant attentional engagement in the future.

Although maternal positive affect at 5 months was significantly associated with infants' attention behavior at 10 months, positive affect did not show a significant association with infant medial frontal EEG activity during the attention task at 10 months. This result was contrary to our original hypothesis that maternal positivity would be related to differences in neural activity associated with attention processes in early development. However, this finding has led us to consider an alternative hypothesis that a history of maternal positivity during interactions may have a reinforcing effect on the developmental progression of attention processes that occur in a common fashion across individuals in typical development. That is, the ability to sustain attention and independently engage and disengage attention is naturally increasing during this developmental period in general, and this is theorized to be at least partially a result of normative development of neural networks associated with attention processes. Thus, mothers who show more positivity during interactions with infants early in development may be creating more opportunities for the infant's attention to be engaged and pairing this engagement with reinforcing positive stimulation and feedback. These increased opportunities for attentional engagement, as well as an established association between attentional engagement and positive or rewarding social stimulation, may lead to increased attentional engagement behavior, but may not change the natural development of neural networks for attention that is occurring during this time. Thus, mothers who are more positive may reinforce a natural proclivity to engage with and attend to new stimuli, resulting in differences in infant attention behavior but not in the neural activity specifically associated with this behavior. In fact, recent work from our lab has shown that maternal positive affect may be associated with increases in baseline frontal EEG power between 5 and 10 months (Bernier et al., 2016). Thus, maternal positive affect may influence the activity of the frontal lobe in this period of development, but this may not extend to activity specifically associated with attention processes.

In contrast to positive affect, we did not find a direct effect of maternal intrusiveness at 5 months on infant attention behavior at 10 months. However, higher levels of maternal intrusiveness during the 5-month interaction were significantly associated with greater activity at the left medial frontal electrode location (F3) during performance of the attention task. Intrusive caregiving behavior is characterized by unsolicited assistance or intervention and attempts to change the child's behavior, which can often lead to distress or avoidance and shutting down to avoid overstimulation and protect from an overload in information processing and overarousal (e.g., Ainsworth, Blehar, Waters, & Wall, 1978; Belsky, Rovine, & Taylor, 1984; Tronick, 1989). Because intrusive caregivers do not appear to be sensitive to infant attentional engagement and arousal needs, they may often interrupt or interfere with the infant's own attention processes to impose their own. During the first year of life, when rapid change in the neural processes supporting attention development is occurring, these interventions may have long-reaching consequences for the development of neural connections that support the emergence of more sophisticated and complex attention behavior in development.

Given that maternal positive affect was not significantly associated with EEG power change at either medial frontal location, we could not examine a potential indirect association with attention behavior. However, the indirect effect from maternal intrusiveness to observed attention behavior via neurophysiological attention processes was significant. Specifically, higher levels of maternal intrusiveness during interactions when the infant was 5 months was associated with less attention behavior during the attention task at 10 months through its relationship with greater left medial frontal (F3) activity during the task. Although this is a preliminary finding that will require systematic follow-up in future work, this is an intriguing result that suggests that intrusive maternal behavior early in development may have a disruptive effect at the neural level on developing attention processes that leads to measurable differences at the behavioral level.

Neural networks that subserve attention processes and give rise to change in attention behavior are rapidly developing during this period and may follow a typical pattern of development such that increased neural connections lead to the emergence of more complex, sophisticated, and nuanced attention abilities. Experience using these more sophisticated attention abilities in turn leads to increased specialization and connection of neural areas for attention. However, factors in the environment that disrupt the infant's attention experience may have the ability to alter or impact the neural development processes. By consistently interrupting and disrupting their infant's attentional engagement and experience, intrusive mothers may be preventing the environmental input necessary for the development of neural specialization and connections associated with attention processes in the brain. A second, but not mutually exclusive, alternative is that intrusive mothers may actually be altering the pattern of neural activity that occurs in the context of attentional engagement by interfering with the infant's attention and creating additional demands in which the infant has to abandon their own attentional engagement or goals in favor of the mother's external demands on the infant's attention. In either case, accumulated experience with intrusive caregiving appears to be related to the infant's own attentional abilities by the second half of the first year, and an effect on infant's neural activity during attention appears to be one mechanism through which this occurs.

Although these findings are intriguing and provide important preliminary evidence for theories regarding factors in the caregiving environment that may shape the development of behavioral and neural attention processes, these data were collected as part of a longitudinal study examining multiple aspects of early cognitive and emotional development and associated psychophysiology. Future work designed to systematically and carefully examine the role of early maternal interactive behavior on infants' developing attention abilities and associated neural development is necessary to more formally test these hypotheses. For example, we examined maternal behavior in the context of two free-play interaction episodes; future work should examine maternal behavior across multiple contexts, including those designed specifically to engage infant attention and elicit maternal control of infant attentional processes across the first year. Similarly, we examined infant attention behavior during the presentation of a novel stimulus designed to elicit interest and looking in infants. However, future studies should examine infant attention abilities more rigorously in tasks designed to

examine multiple dimensions of attention, which may be mapped specifically to underlying neural activity associated with the development of neural networks.

It will also be important for future work examining these questions to utilize different samples of infants and mother-infant dyads. Although the current sample was relatively diverse, the majority of mothers in our sample had a college education or higher (65%). As education level and income have both been associated with maternal sensitivity in a variety of other work (e.g., Bernier et al., 2016; Mills-Koonce et al., 2007; NICHD Early Child Care Research Network, 2004) and were related to our measures of maternal positive affect and intrusiveness here, an important goal for future work will be to recruit mother−infant dyads with more variability in these measures.

In addition, these data were not designed to examine factors that may predict maternal sensitivity and parenting behavior. Some of these factors may lie within the mother; for example, maternal depression has been shown to predict both maternal behavior during interactions with infants (e.g., Cohn, Campbell, Matias, & Hopkins, 1990; Cohn & Tronick, 1989; Field, Sandberg, et al., 1985) as well as measures of infant electrical brain activity (e.g., Dawson, Frey, Panagiotides, Yamada, Hessl, & Osterling, 1999; Field, Fox, Pickens, & Nawrocki, 1995). Therefore, maternal depression is an important variable that should be included in future work to further pull apart associations between maternal behavior, infant neural activity, and attention development. Moreover, much theoretical and emerging empirical work suggests that parent–child interactions are a result of complex bidirectional and reciprocal influences such that certain child temperaments or biological predispositions may elicit more optimal parenting (e.g., Perry, Mackler, Calkins, & Keane, 2013), which in turn could contribute to biological and neural development influencing child functioning. Future work using longitudinal cross-lagged designs measuring multiple assessments of parent and child functioning, and neural development, will be necessary for testing such hypotheses.

In sum, our work suggests that greater maternal intrusiveness during interactions at 5 months of age is one factor that is associated with a potentially suboptimal pattern of neural activity during attention processes at 10 months, which has negative effects on infant attention behavior at 10 months of age, but may also have cascading negative effects for later development. For example, in our previous work we found that neural activity during our attention task at 10 months was associated with emotion regulation in the preschool years through an effect on attention behavior in infancy. Taken together with our previous work, a pattern of findings emerges in which more right frontal (F4) activity during an attention task at 10 months is associated with greater attentional engagement behavior at 10 months and greater emotion regulation capabilities (less frustration) at 3 years, through its association with greater attentional abilities at 10 months. In contrast, more left frontal (F3) activity is associated less attentional engagement behavior at 10 months and less regulation (greater frustration) at 3 years, through its association with less attentional engagement at 10 months (Perry et al., 2016). Our work here demonstrates that maternal intrusiveness in the first year is one environmental factor that can predict the pattern of neural activity present during the attention task, and that this has implications for attention behavior. Given that right hemisphere dominance for attention related tasks has been found in previous work with older kids and adults we have hypothesized that right frontal activity during attentional engagement at 10 months of age may be an optimal "default" pattern of development, which fosters the emergence of more sophisticated attention behavior by the end of the first year. In contrast, greater left frontal activity may be evidence of a suboptimal, potentially disordered pattern that occurs because of disruption in the environment, like intrusive caregiving, which precludes the strong right hemisphere connections that best serve attention processes and results in less optimal neural responses and concurrent and prospective behavioral attention and regulatory deficits. This is an intriguing and important finding that should be carefully investigated in future longitudinal work.

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