Published in final edited form as:

Infant Child Dev. 2020 ; 29(1): . doi:10.1002/icd.2162.

Context of Maternal Intrusiveness During Infancy and Associations with Preschool Executive Function

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Abstract

The relation between maternal behavior and neurocognitive development is complex and may depend on the task context. We examined 5-month-old infant frontal EEG, maternal intrusiveness (MI) evaluated during two play contexts at 5 and 10 months, and a battery of executive function (EF) tasks completed at 48 months to evaluate if MI during infancy and infant neural function interacted to predict later cognition. Infant frontal EEG was a predictor of 4-year EF. MI during structured play at both 5 and 10 months predicted preschool EF, and MI during unstructured did not have a main effect on EF but showed a potential moderating effect of infant EEG on later EF. The pattern changed between ages, with MI during structured play at 5 months showing a positive association with age 4 EF, whereas MI during structured play at 10 months had a negative association with age 4 EF. We demonstrate differences in the context of maternal behavior used to predict childhood EF, highlighting the importance of considering parenting context in EF development.

Keywords

Executive function; maternal intrusiveness; EEG; brain development; infant

Development of executive functions (EF), defined as higher order cognitive abilities required for complex problem solving and goal setting, is facilitated and impeded by multiple factors. One important environmental factor predictive of poor EF development is maternal

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The authors declare no conflicts of interest.

intrusiveness (MI), which is when mothers engage in overly controlling behaviors focused on the maternal agenda (Graziano, Keane, & Calkins, 2010). In addition to the parenting context, individual differences in development of the prefrontal cortex is linked with variations in EF development (Bell & Fox, 1994; Wolfe & Bell, 2007). However, previous work has broadly defined parental behavior, often collapsing the assessment of parenting across different social contexts, and failed to consider the potential combined effects of parenting and neural development. Little is known about if and how the longitudinal association between infant neural patterns and later EF development are affected by early maternal intrusiveness.

EF develops from rudimentary abilities in the second half of the first year, with rapid proliferation of EF abilities between 3 and 5 years of age (Diamond, 2013). During this early childhood period, individual differences in EF stabilize and are predictive of many aspects of later functioning, including academic success, delinquency, and mental health (e.g. Broidy et al., 2003; Gathercole, Pickering, Knight, & Stegmann, 2004; Woodward, Lu, Morris, & Healey, 2017). EF tasks appropriate for use in preschool children assess a variety of skills, including inhibition, set-shifting, and working memory (Carlson, 2005). Inhibition requires children to suppress a dominant response and can be observed during rules-based situations. Set-shifting requires children to use cognitive flexibility to switch frameworks, such as obeying one set of rules in certain conditions and inhibiting a response under another set of conditions. Working memory requires children to update new information to inform their behavior and adapt to new situations. Performance in each of these subdomains represent a unitary construct of EF (Miyake et al., 2000); however, the subdomains can be measured independently by preschool age (Miller, Giesbrecht, Muller, McInerney, & Kerns, 2012; Monette, Bigras, & Lafrenière, 2015; Wiebe et al., 2011).

The prefrontal cortex is primarily responsible for top-down control over cognitive processes and is the brain area most closely linked with EF (Alvarez & Emory, 2006; Diamond, 2002). During prenatal and early postnatal development there is overproduction of neurons and over connection of the neurons (Brown & Jernigan, 2012). As the brain develops through childhood, cortical thinning occurs, and this maturation of the prefrontal cortex coincides with improvement in EF (Gogtay et al., 2004). Brain development can be measured using the electroencephalogram (EEG), which assesses the amount of brain electrical activity measured by electrodes on the scalp. Although the spatial resolution of EEG is relatively poor, frontal EEG power is associated with frontal cortex function (Bell & Cuevas, 2012; Laufs et al., 2003; Schmidt & Trainor, 2001). In infancy, 6 to 9 Hz is the dominant frequency band in the EEG and is commonly referred to as “infant alpha” (Marshall, Bar-Haim, & Fox, 2002). In infancy, higher EEG power values are indicative of increased activity by groups of neurons (Bell & Cuevas, 2012; Nunez, 1981). Higher levels of frontal EEG alpha power measured during infancy are associated with higher performance on an infant EF task (Bell, 2001; Bell & Fox, 1992), as well as increased performance in early childhood EF tasks (Kraybill & Bell, 2013). In general, EEG alpha power is considered a measure of cortical maturity, with higher power indicating more maturity (e.g., Bell & Fox, 1994; Brito, Fifer, Myers, Elliott, & Noble, 2016).

Although cortical maturity as measured by EEG power has a genetic component, EEG power is also influenced by the environment (Bernier, Calkins, & Bell, 2016; Van Baal, De Geus, & Boomsma, 1996). The parenting context is a potent environmental influence and relates to the trajectory of brain development. Experimental work with animal models has demonstrated that the parenting context causes physiological changes in cortical structure and reduction in prefrontal cortex volume, and that the effect of the environment on brain development differs based on age (Teicher, Tomoda, & Andersen, 2006). In humans, there is significant evidence that neglectful parenting and trauma affect brain development in childhood and that children who receive intervention earlier have better outcomes (Curtis & Cicchetti, 2007; De Bellis, 2001; De Bellis & Zisk, 2014; Marshall, Fox, & Bucharest Early Intervention Project Core Group, 2004; Vanderwert, Marshall, Iii, Zeanah, & Fox, 2010). This line of research suggests that the parenting environment has the ability to support or interfere with the pattern of association between neural foundations and later cognitive outcomes. Additionally, specificity in the type of maternal behavior examined is important because different aspects of maternal behavior may relate differently to adverse outcomes.

The caregiving environment has a lasting impact on infant development, affecting attachment, temperament, and cognition (e.g., Rothbart, 2007; Susman-Stillman, Kalkoske, Egeland, & Waldman, 1996; Szabó et al., 2008). Mothers high in intrusiveness often fail to respond to infants' cues and desires for autonomy in sensitive and supportive ways; instead they may engage in behaviors with their infants that are interrupting or overwhelming, often focused on their own goals rather than following infant cues as sensitive mothers do (Ainsworth, 1979; Ispa et al., 2004). Additionally, children whose mothers were high in MI at 6 months during both feeding and free play showed lower academic achievement and more behavioral problems in early elementary school (Egeland, Pianta, & O'brien, 1993).

Comparatively, mothers who are more sensitive to their infants, defined as awareness and interpretation of the infant's signals and appropriateness of the maternal response, create an environment that often leads to better outcomes (Raby, Roisman, Fraley, & Simpson, 2015). Sensitive parenting consists of mothers accurately reading bids from their infants and supporting the infants' needs (Calkins, Hungerford, & Dedmon, 2004). For example, when infants cry, sensitive mothers interpret what is needed by infants and appropriately respond to bids, thus creating reciprocal patterns over time. This type of sensitive parenting facilitates cognitive and self-regulatory development by creating an environment with more socio-emotional scaffolding and appropriate opportunities for autonomy (Bernier, Carlson, & Whipple, 2010). Bernier and colleagues (2010) note that this scaffolding and support for autonomy is the result of mothers being sensitive to children's needs and correctly interpreting children's signals. Infants' needs change throughout development, and mothers high in sensitivity change their behavior to adapt to infants' needs.

We suggest that MI is a multifaceted construct that may be used to scaffold complex behaviors or in ways that overwhelm infants, depending on the goals of the mother-child interaction context. For example, in toddlerhood, maternal behavior during different task contexts (pretend play, structured play, and teaching) that was coded for several aspects of maternal positive guidance and negative control showed different patterns depending on task context (Calkins, Smith, Gill, & Johnson, 1998). Specifically, during the teaching task,

mothers averaged higher rates of guidance and control compared to the other contexts; thus, mothers were changing their parenting strategies to facilitate the task at hand. These changes in parenting strategies are not considered when maternal behaviors during separate task contexts are averaged together.

MI does not occur in a vacuum and different types of parenting behavior can occur within the same interaction. MI is weakly and negatively correlated with maternal positive affect (Bernier, Calkins, & Bell, 2016), suggesting that although the constructs are related, they are not completely incompatible and mothers may display aspects of both sensitivity and intrusiveness, although in varying amounts. It is valuable to consider MI separately from other parenting constructs to understand how maternal behavior can support or interfere with development. Therefore, we chose to examine how MI is associated with EF in two different tasks, and each task context had varying levels of structure (structured game of peekaboo compared to an unstructured free play).

As previously noted, individual differences in parenting are related to brain development. Using data from the current sample of participants, our research group has shown that positive maternal behavior during a free play context at 5 months (i.e., maternal positive affect) predicted the development of EEG alpha power (i.e., 6–9 Hz) at frontal scalp electrodes, but not other locations across the scalp, at 10 and 24 months. In those analyses, we accounted for maternal education, infant sex, and 5-month EEG alpha power (Bernier, Calkins, & Bell, 2016). We also reported that that MI at 5 months was not directly associated with EEG alpha power at 5, 10, or 24 months, but we did not test for interactions between MI and EEG. Other work with one cohort of the current sample has shown that maternal positive affect during free play at 10 months and frontal EEG alpha power in infancy together predicted EF behaviorally at age 4 and via parent-report at age 6 (Kraybill & Bell, 2013). However, our previous research demonstrating associations among maternal behavior, frontal EEG, and later EF within our sample did not focus specifically on MI, nor has it compared maternal behavior across multiple interaction contexts. As suggested above, MI is a multifaceted construct and there may be times when it promotes scaffolding of complex behaviors or times when it is overwhelming to infants and the association may depend on the infants' neural development (Calkins et al., 1998). These complex associations between MI and the context in which parenting is observed may yield different associations between infant frontal EEG, maternal behavior, and preschool EF.

Mother-child relationships are both dynamic and reciprocal, and it is not known how MI and infant cortical maturity relate to each other or if the associations differ as a function of context of the maternal-child interactions. We observed mothers and infants during two social contexts: one was explicitly structured where mothers were asked to play peekaboo and one was a less structured free play. We hypothesized that MI during both task contexts and at both ages would be negatively associated with later child EF, controlling for maternal education, child verbal ability, and child sex. We also recorded infant EEG during a resting baseline and hypothesized that frontal EEG alpha power during infancy would be positively associated with later child EF. Additionally, we hypothesized that MI would moderate the association of infant EEG to child EF, such that infants with mothers high in MI would show a different pattern of association between infant frontal EEG alpha power and preschool EF

compared to mothers lower in MI. Specifically, we expected that infants with mothers low in MI would show an association between infant frontal EEG alpha power and later EF performance, whereas infants with mothers high in MI would not show this association.

Method

Participants

Participants were recruited as part of an ongoing longitudinal investigation on the integration of cognition and emotion across early development. A total of 410 mothers and their healthy 5-month-old infants were recruited from two sites (Blacksburg, Virginia; Greensboro, North Carolina) using mailing lists, media advertisements, and flyers. Blacksburg is a rural area surrounding a research university and Greensboro is an urban area. Each site recruited approximately half of the total sample. When asked about ethnicity, 6.3% of parents reported that their child was Hispanic, 93.4% reported that their child was not Hispanic, and 0.3% declined to answer. Representing the demographics of the population from which the sample was recruited, 0.5% of children were reported to be Asian, 13.7% Black/African American, 76.8% White, 8.0% Other/Multiracial, and 1.0% declined to answer. The education level of the mothers in the sample was varied, with 2.2% of mothers not finishing high school, 25.4% with a high school diploma, 6.0% with an associate's or two-year college degree, 41.6% with a four-year college degree, 21.2% with a postgraduate degree, and 3.6% who declined to answer. On average, mothers were 29 years old ($SD = 5.59$) at their child's birth. By the age 4 lab visit, nine participants had been diagnosed with a developmental disorder and thus were excluded from analyses, leaving a count of 401 children (195 boys and 206 girls) at the 5-month appointment.

Procedures

Data were collected at both sites using identical research lab protocols. Research assistants from each site were trained together by the project's Principal Investigator (the last author) on protocol administration, as well as on behavioral and psychophysiological coding. To ensure that identical protocol administration and coding criteria were maintained between the labs, the Blacksburg site research team periodically viewed video recordings and EEG files collected by the Greensboro team; the Blacksburg lab provided reliability coding for the EF behavioral data coded by the Greensboro lab and verification of artifact screening for EEG data collected by the Greensboro lab. The Blacksburg team coded all mother-child interaction data collected by both labs.

Infant Visits

Infants and mothers visited the lab at 5 and 10 months. When dyads arrived at the laboratory, procedures were explained, and consent was obtained from the mothers. Mothers were asked to fill out a general information questionnaire to report demographic information, including highest level of education obtained. Education level was included as a covariate in analyses as maternal education is correlated with maternal behavior and EF (Hackman, Gallop, Evans, & Farah, 2015). Of the 401 infants included in the original sample, 46 either did not return at 10 months or did not complete both interaction tasks because the child was too fussy.

Maternal intrusive behaviors at 5 and 10 months.—The dyad completed two interaction tasks that lasted two minutes each: first an unstructured free play task and second a structured peekaboo task. For free play, experimenters asked mothers to play with their infants as they normally would with the two age appropriate toys (rattle, keys) that were available. During the peekaboo task, experimenters instructed mothers to play peekaboo with their infants as they normally would, using their hands or a provided cloth. Peekaboo was more structured because there were rules provided, whereas free play did not have any rules and mothers were asked to play freely with their children. For each task, experimenters left the room after giving the instructions. Both interactions were recorded and coded offline by trained research assistants. MI was coded on a 4-point scale in 30-second epochs using a coding scheme previously reported (Bernier et al., 2016) and adapted from Calkins and colleagues (2004). Examples of intrusive behaviors included physical manipulation of infants to complete a goal, forcing toys on infants, or overstimulating infants and not letting infants set the tone and pace of play. A score of 1 was given if there was no evidence of intrusive behavior and a score of 4 was given if there were high levels of intrusive behavior across each 30-second epoch. Scores were then averaged across the 2-minute duration of each task. Reliability was assessed between coders for at least 20% of the sample at 5 months ($ICC = .96$) and 10 months ($ICC = .83$) and was acceptable at both time points.

Infant EEG at 5 months.—Prior to the interaction tasks, baseline EEG was collected at 5 months. Infants were fitted with a stretch cap (Electro-Cap International, Inc.; Eaton, OH; E1-series cap). EEG was collected for 1 minute while the infant sat in the mother's lap and watched the experimenter manipulate a toy with multicolored bouncing balls approximately 1.1 meters in front of them. Of the 401 infants included in this study, 26 did not contribute EEG data because they were too fussy or their movement caused too much artifact for their data to be used.

EEG was recorded from 16 electrodes: 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), referenced to Cz. After the EEG cap was placed on the head, a small amount of conductive gel was placed into each recording site, and the scalp rubbed. Electrode impedances were measured and accepted if they were below 20k. 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 each EEG recording, 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 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 task. These event marks were later used to segment the baseline portion from the ongoing EEG.

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-second width and 50% overlap. Across infants, the mean number of artifact-free DFT windows during the baseline was 84.00 (SD = 22.97), which is approximately 42 seconds of EEG data. Power was computed for the 6–9 Hz infant alpha frequency band, which is the dominant frequency for infants and young children (Bell & Fox, 1992, 1994; Marshall, Bar-Haim, & Fox, 2002). Based on previous findings with this same sample that maternal positive behaviors at 5 months were related to frontal EEG development at 10 and 24 months (Bernier et al., 2016), we focused our attention on EEG power at left and right frontal scalp locations. Specifically, we created a frontal EEG alpha power variable by averaging EEG power across the F3 and F4 electrodes at 5 months.

4-year Visit

At age 4, 263 children returned to the labs, with attrition mainly due to families moving out of the local regions. At the 4-year visit, children completed the Peabody Picture Vocabulary Test (PPVT) as a measure of verbal ability and a battery of EF tasks, including a visual search, dimension change card sort (DCCS), and pig/bull (i.e., Simon-says). These three EF tasks were chosen because of the benefit of using a composite to measure a complex construct like EF (Rushton et al., 1983). Each task taxes different aspects of EF, such as inhibition, set-shifting, and working memory. With respect to behavioral coding, interrater reliability (ICC = .85) was established for at least 20% of the sample.

Visual search.—The visual search task was adapted from the Developmental Neuropsychological Assessment (NEPSY; Korkman, Kirk, & Kemp, 2007) and primarily taxes working memory and executive attention. Experimenter asked children to point out all the bears in a picture with many distracting items. Unique efficiency score was the variable of interest (Espy & Bull, 2005). It was calculated by counting the number of correct points to target bears, rather than distractions or repointing to the same target, and dividing by the total number of attempts.

DCCS.—This task was administered following protocol developed by Zelazo (2006) and is generally considered to involve inhibitory control and set-shifting. Children were first instructed to sort a series of six cards according to one dimension (i.e., color) before being asked to sort the remaining six cards by another dimension (i.e., shape). If children completed four of the six post-switch trials correctly, they were then instructed to sort 12

cards according to one dimension if there was a red border around the card but to sort by the other dimension if there was no border around the card. The borders condition was used because of higher levels of variability and more normal distribution of performance during this condition, compared to the post-switch condition, on which over 50% of children completed every trial correctly. Of the 259 children who attempted DCCS, 140 passed the post-switch condition and completed the borders condition to be included in the DCCS variable. Proportion of cards correctly sorted out of the 12 cards in the borders condition was the variable of interest.

Pig/bull.—This task was administered adapting the bear/dragon protocol detailed by Carlson, Moses, and Breton (2002) and is an inhibition task. After a warm up to ensure that children understood the target actions (e.g., stick out tongue, touch head, etc.), children were presented with two puppets representing a pig and a bull. Children were told to listen to the “nice pig” and not listen to the “mean bull”, similar to the classic Simon-says game. A total of 10 trials were administered, five pig trials and five bull trials. The proportion of correct bull trials over the total number of bull trials was the variable of interest.

Composite EF.—Scores on the three EF tasks were not significantly correlated (Table 1), but each task is a well-validated measure and conceptually is an indicator of an overall construct of EF (Carlson, 2005). It is more reliable to measure a latent construct using a composite rather than individual scores; thus, scores on each of these three tasks were standardized, averaged together, and standardized again to create a composite EF score (Cuevas & Bell, 2014; Rushton et al., 1983). If a participant was missing a score on a single task, the scores of the other two tasks were averaged and standardized to create the composite EF score.

Verbal ability.—We controlled for child verbal ability with the Peabody Picture Vocabulary Test (PPVT) because language is associated with EF (Müller, Jacques, Brocki, & Zelazo, 2009). The PPVT–IV (Dunn & Dunn, 2007) was administered to children to assess verbal comprehension. The PPVT–IV is a nationally standardized instrument and participants’ standardized scores were used in the current study.

Result

All analyses were completed using RStudio 1.1.442. Correlations between all study variables and descriptive statistics can be found in Table 1. Overall, girls had higher frontal EEG power at 5 months, $t = 4.44$, $p < .001$, and scored higher on the EF tasks at 4 years, $t = 2.46$, $p = .015$. There were no differences in MI during either task at either age as a function of infants’ sex. The mean PPVT score was in the high average range (Dunn & Dunn, 2007). Attrition is part of longitudinal research, and we examined patterns of attrition between the 5 and 48-month visit. There were no differences in sex, race, or ethnicity, between children who returned at 48-months and those who did not return. The highest level of education received by the mother was slightly higher in the group that returned to the 48-month visit (2.66 for those who returned and 2.41 for those who did not return, $t = 2.04$, $p = .042$). Little’s Missing Completely At Random (MCAR) Test of our variables of interest was not significant, $\chi^2(65) = 73.30$, $p = .224$, suggesting that the missing data were MCAR (Little,

1988). Listwise deletion is an appropriate statistical technique with data that are MCAR (Schlomer, Bauman, & Card, 2010).

Because of our interest in the task context of MI during mother-infant interactions, we used separate hierarchical regression analyses to predict age 4 EF for each task context (free play, peekaboo). In both regression analyses, step one controlled for maternal education, child sex, and age 4 verbal ability using the PPVT. Step two added 5-month frontal EEG alpha power during baseline and MI during either task context at 5 and 10 months. Step three added the interaction between EEG at 5 months and MI at each age. Variables included in the interaction term were centered before being included in the regression equation. Because moderator effects are difficult to detect in social science research (e.g., McClelland & Judd, 1993; Whisman & McClelland, 2005), we increased the type one error rate to $p < .10$. Raising the type one error rate is a justifiable method for increasing power to detect interaction terms (Diaz et al., 2019; Whisman & McClelland, 2005).

Higher frontal EEG alpha power at 5 months was associated with higher age 4 EF. Specific to MI during the peekaboo task (Table 2), higher MI at 5 months predicted higher age 4 EF; however, higher MI at 10 months predicted lower EF. There was no interaction between EEG and MI during peekaboo.

Specific to MI during the free play task (Table 3), there was an interaction between infant EEG and 5-month MI. Simple slopes analysis at one standard deviation above and below the mean for MI during free play showed the association between infant frontal EEG alpha power and 4-year EF was significant only for infants who had mothers low in MI during free play and not significant for those who had mothers high in MI during free play (Figure 1).

As previously discussed, listwise deletion is an appropriate technique for data that are MCAR; however, due to the raised p-value for interpreting the interaction term, there is a concern for the potential for type I error and the potential need for more power in the interaction analysis. Thus, we reanalyzed both the free play and peekaboo models using multiple imputation to account for missing data. The MICE package was utilized in RStudio 1.1.442 to complete the imputation of all the variables included in both models using predictive mean matching. For the free play model, this resulted in a similar output with only an interaction effect between 5-month EEG and MI being significant ($\beta = -2.11$, $p = .036$). However, when this same pooled imputed dataset was applied to the peekaboo analyses, the main effect for 5-month MI was no longer significant ($\beta = 1.58$, $p = .116$), while the main effect for 10-month MI remained significant ($\beta = -2.286$, $p = .023$). This may be due to the amount of missing data causing instability in multiple imputation analyses and the difficulties of using multiple imputation with longitudinal data (Azur, Stuart, Frangakis, & Leaf, 2011; Jakobsen, Gluud, Wetterslev, & Winkel, 2017).

Discussion

Our results regarding the association between MI during infancy, EEG power, and preschool EF showed a complex pattern that varied depending on task context and infant age. Contrary to our hypothesis, MI within the peekaboo context at 5 months was positively associated

with EF. However, MI at 10 months was negatively associated with EF; the direction of the effect changed as a function of infant age. The main effect of 5-month frontal EEG alpha power on EF at age 4 supported our hypothesis that cortical maturity, as measured by EEG power (Bell & Fox, 1994), in infancy would predict later EF, although the interaction showed that MI during the free play task qualified the main effect of frontal EEG alpha power. Specifically, MI during unstructured play moderated the longitudinal association between infant frontal EEG alpha power and later EF, such that infants with mothers who were less intrusive during free play showed the association in the expected positive direction; infants with more intrusive mothers did not. Although one effect became non-significant after multiple imputation was used to account for the missing data, the overall pattern and direction of effects remained constant in the replication with multiple imputation of missing values.

Infant EEG was as a predictor of preschool EF so that higher frontal alpha power at baseline at 5 months predicted higher levels of EF in preschool. This finding is in the opposite direction as the association reported by Kraybill and Bell (2013) with a small sample of 10-month-old infants but fits with the literature interpreting increased frontal EEG power as an indicator of cortical maturity (Bell & Fox, 1992). The current study is utilizing 5-month EEG whereas Kraybill and Bell (2013) report 10-month EEG. There are significant changes in the pattern of EEG in the first year (e.g., Marshall et al., 2002), and these differences in brain activity are likely due to developmental changes from 5 to 10 months, including advent of self-locomotion and development of the anterior attention system (Bell & Fox, 1994).

Early in the first year of life, infants are altricial and dependent upon the caregiver for both physical and social cues. During early infancy, caregivers help infants to direct and regulate attention through physical cues (Ruff & Rothbart, 1996). As the infant matures and becomes more interactive, mothers' interactions and play style change to adjust to infants' abilities (Crawley et al., 1978). These developmentally appropriate changes in how the mother and infant interact may be the reason for the change in direction of the effect we report between 5-month and 10-month MI during the peekaboo context and later EF. Peekaboo is a structured play context during which intrusiveness may be serving a scaffolding function for very young infants, but not for older infants who are able to engage socially without intrusive prompting. This structured context may be an environment that supports the use of intrusiveness by mothers during early infancy to scaffold infants' cognitive development. In contrast, MI during the peekaboo task at 10 months was associated with EF in the expected negative direction. Infants at 10 months are more capable social partners, and MI at this age during this task context may have been an insensitive interference that negatively predicted EF development in preschool.

MI during a separate free play task, however, yielded a very different pattern of results regarding the relation between MI and later EF development. During this less structured task, there was no main effect of MI on EF. However, the interaction term showed that infants whose mothers were low in MI at 5 months showed the hypothesized association between frontal cortical function and EF development. Comparatively, higher MI disrupted this pattern and attenuated the relation between infant frontal EEG alpha power and preschool EF. Maternal behavior at 5 months interacted with the infants' neural foundation

to predict EF. These results suggest that the caregiving context changes how the infant brain develops to promote EF. Free play context may be a more ecologically valid task that better captures the day-to-day interactions between mothers and infants, which may explain why this finding fits better with the existent literature where MI interferes with development of EF. However, most infants and mothers do engage in structured play in their daily lives, and we have shown that MI behavior during those types of tasks is associated with cognitive development. This finding highlights the importance of considering task context when investigating maternal behavior.

Although MI was correlated across ages and tasks, the association between MI and later EF was different depending on the age of the infant. It may be that mothers who were able to modulate their intrusiveness from early to late infancy during this structured task created the most adaptive environment for EF development. Further studies are needed to tease apart the facets of MI across different contexts at different ages and explore how parenting strategies in different contexts are related to cognitive outcomes. Such studies could observe changes in MI across developmental periods, environments, and task contexts, coding each type of intrusive behavior separately in order to elucidate how different aspects of MI may differentially support or impede cognitive development. Profiles of MI may emerge, for example mothers who use intrusive behaviors to scaffold cognitive development in younger infants or during more structured and complex task contexts and refrain from intrusive behaviors during less structured environments. The coding scheme used in the current study was not able to address the question of specific types of intrusive behaviors were driving the effect of 5-month MI during peekaboo on EF we report.

An additional limitation of the current study is the brief laboratory assessment of MI, during which mothers knew they were being observed and were susceptible to changing their parenting behavior in response to being in the lab. Furthermore, the brevity of the assessment may not have allowed enough time for intrusive behaviors to occur, even if such behavior is common in other environmental contexts. Our measures of MI were slightly positively skewed (Table 1), suggesting that some mothers were not at all intrusive during the observed period. Observing the interactions for a longer period of time or replicating the study with dyads demonstrating higher levels of MI might change the pattern of results. Finally, our EF tasks were not correlated, despite being conceptually strong measures of EF in this age group, which may point to EF not being a unitary construct in this sample of four year old children.

Further affecting the generalizability of these findings is the relatively high verbal ability of the children and high level of education of the mothers in the current sample, as parenting behavior and EF development are associated with these factors. Importantly, we controlled for maternal education and verbal ability in all analyses. A final note is that we interpreted the interaction effect at $p < .10$ in the free play model. As in all null hypothesis testing, there is the possibility of a false positive result, and caution is warranted in the interpretation and application of our findings (Betensky, 2019; Wasserstein & Lazar, 2016). The multiple imputation replication of our results revealed that the main effect of 5-month MI on 4-year EF was not significant in the imputed dataset. Multiple imputation is a powerful tool, but the amount of missing data in the current study, combined with relatively small effect sizes, may

have caused instability in the results (White, Royston, & Wood, 2010). Because one of our original main effects was not replicated with the imputed data, we emphasize the importance of interpreting these exploratory results cautiously and the value of future work to further elucidate them.

Despite these limitations, our findings show neural function and parenting behavior during a structured context were separate predictors of later EF, and that the pattern of early frontal cortex function and parenting behavior on later EF interacted when examining maternal behavior in an unstructured context. These results emphasize that the complex nature of the environment created by mothers through their interactions with infants has the potential to influence directly, as well as coalesce with the infants' neural function, to predict EF. Our results show that the association between MI and EF development may not be exclusively negative but is dependent on context of the interaction, infant age, and infant neural development. Parenting constructs are multifaceted and should be considered on an individualistic basis, and evaluating the developmental time period and social context are important in order to understand the complex infant-mother relationship.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

Acknowledgments

This research was supported by grants R01 HD049878 and R03 HD043057 from the Eunice Kennedy Shriver National Institute of Child Health and Human Development awarded to the fourth author. The authors thank the children and their families who participated in this study.

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Highlights

- The context of maternal behavior is important for its longitudinal implications on cognitive development.
- Level of maternal intrusiveness and infant frontal EEG power predicted preschool executive function in different patterns depending on mother-infant interaction context.
- The associations between maternal intrusiveness and executive function depended on the task context, age at interaction, and neural function of infants.

Figure 1.

Graph of executive function and 5-month infant EEG as a function of 5-month Maternal Intrusiveness (MI) during the free play task showing significant slope for low MI and nonsignificant slope for high MI.

Table 1.

Correlations and Descriptive Statistics.

	1	2	3	4	5	6	7	8	9	10	11	12
1 4y verbal ability	1											
2 Maternal education	.38	1										
3 Sex	-.01	-.07	1									
4 5m EEG power	.04	.02	.22	1								
5 5m MI free play	.00	-.15	.00	.11	1							
6 5m MI peekaboo	.03	-.01	.01	-.03	.27	1						
7 10m MI free play	-.12	-.20	-.09	-.03	.33	.14	1					
8 10m MI peekaboo	-.10	-.01	-.03	-.04	.12	.27	.41	1				
9 4y visual search	.06	.08	.07	.11	.04	-.12	-.06	-.02	1			
10 4y DCCS	.25	.08	.02	.14	.09	.23	-.02	.08	.07	1		
11 4y Simon says	.23	.12	.09	.09	.01	-.00	-.04	-.17	.07	.06	1	
12 4y EF composite	.29	.18	.15	.21	.09	.07	-.05	-.13	.40	.71	.73	1
Mean	111.93	2.56	1.51	2.08	1.40	1.28	1.42	1.22	0.62	0.55	0.85	0
SD	14.05	1.16	0.50	0.51	0.49	0.46	0.51	0.41	0.25	0.15	0.32	1
Skew	-0.11	-0.45	-0.06	0.08	1.51	2.15	1.66	2.79	-0.43	1.43	-1.97	-1.06
SE	0.88	0.06	0.03	0.03	0.03	0.02	0.03	0.02	0.02	0.01	0.02	0.06
N	257	387	401	375	384	370	355	354	222	140	251	258

Notes. Pearson correlation coefficients with $p < .05$ are bolded. All values are prior to centering. Maternal education was scored on the following scale: 0 = did not complete high school, 1 = high school diploma, 2 = technical school, 3 = college degree, 4 = graduate degree. Sex was coded 1 for boys and 2 for girls. Verbal ability: standardized score on Peabody Picture Vocabulary Test at 4 years old; EEG power: average baseline power at F3 and F4 channels measured at 5 months; 5m MI free play: maternal intrusiveness during free play task at 5 months; 5m MI peekaboo: maternal intrusiveness during peekaboo task at 5 months; 10m MI free play: maternal intrusiveness during free play task at 10 months; 10m MI peekaboo: maternal intrusiveness during peekaboo task at 10 months; 4y EF: executive function composite at 4 years old

Table 2.

Hierarchical Regression Analysis of Maternal Intrusiveness during Peekaboo and Infant EEG Predicting Age Four Executive Function Composite

		B	Std. Error	Beta	t	Sig.
Step 1	4y Verbal ability	0.02	0.00	.21	3.38	.001
	Maternal education	0.09	0.06	.10	1.58	.114
	Sex	0.30	0.12	.15	2.64	.009
	$R^2 = .10$ $F = 9.30$ (3, 244) $p < .001$					
Step 2	4y Verbal ability	0.01	0.00	.20	2.90	.004
	Maternal education	0.11	0.06	.13	1.87	.063
	Sex	0.19	0.13	.09	1.48	.141
	5m EEG power	0.28	0.14	.15	2.06	.041
	5m MI peekaboo	0.29	0.14	.13	2.13	.034
	10m MI peekaboo	-0.36	0.15	-.15	-2.45	.015
	$R^2 = .16$ $F = 7.50$ (6, 207) $p < .001$					
Step 3	4y Verbal ability	0.01	0.00	.20	2.88	.004
	Maternal education	0.12	0.06	.14	1.92	.056
	Sex	0.18	0.13	.09	1.42	.158
	5m EEG power	0.26	0.14	.13	1.86	.064
	5m MI peekaboo	0.28	0.14	.13	2.02	.045
	10m MI peekaboo	-0.30	0.15	-.12	-1.97	.051
	5m MI peekaboo $\times$ 5m EEG power	-0.45	0.36	-.10	-1.25	.212
	10m MI peekaboo $\times$ 5m EEG power	0.28	0.32	.06	0.87	.385
	$R^2 = .17$ $F = 5.11$ (8, 205) $p < .001$					

Notes. Maternal Education is scored on the following scale: 0 = did not complete high school, 1 = high school diploma, 2 = technical school, 3 = college degree, 4 = graduate degree. Sex was coded 1 for boys and 2 for girls. Verbal ability: standardized score on Peabody Picture Vocabulary Test at 4 years old; EEG power: average baseline power at F3 and F4 channels measured at 5 months; 5m MI peekaboo: maternal intrusiveness during peekaboo task at 5 months; 10m MI peekaboo: maternal intrusiveness during peekaboo task at 10 months; 4y EF: executive function composite at 4 years old.

Table 3.

Hierarchical Regression Analysis of Maternal Intrusiveness during Free Play and Infant EEG Predicting Age Four Executive Function Composite.

		B	Std. Error	Beta	t	Sig.
Step 1	4y Verbal ability	0.01	0.00	.21	3.38	.001
	Maternal education	0.09	0.06	.10	1.58	.114
	Sex	0.30	0.12	.15	2.64	.009
	$R^2 = .10$ $F = 9.30$ (3, 244) $p < .001$					
Step 2	4y Verbal ability	0.02	0.00	.22	3.31	.001
	Maternal education	0.10	0.06	.12	1.72	.087
	Sex	0.22	0.13	.11	1.74	.084
	5m EEG power	0.28	0.14	.14	2.08	.039
	5m MI free play	0.15	0.14	.07	1.03	.304
	10m MI free play	-0.02	0.12	-.01	-0.18	.857
	$R^2 = .13$ $F = 5.37$ (6, 213) $p < .001$					
Step 3	4y Verbal ability	0.02	0.00	.23	3.40	.001
	Maternal education	0.10	0.06	.12	1.74	.083
	Sex	0.18	0.13	.09	1.38	.170
	5m EEG power	0.23	0.15	.12	1.62	.196
	5m MI free play	0.19	0.15	.09	1.31	.191
	10m MI free play	-0.01	0.12	-.01	-0.09	.927
	5m MI free play $\times$ 5m EEG power	-0.63	0.29	-.14	-1.82	.070
	10m MI free play $\times$ 5m EEG power	0.21	0.35	.05	0.71	.476
$R^2 = .14$ $F = 4.47$ (8, 211) $p < .001$						

Notes. Maternal Education is scored on the following scale: 0 = did not complete high school, 1 = high school diploma, 2 = technical school, 3 = college degree, 4 = graduate degree. Sex was coded 1 for boys and 2 for girls. Verbal ability: standardized score on Peabody Picture Vocabulary Test at 4 years old; EEG power: average baseline power at F3 and F4 channels measured at 5 months; 5m MI free play: maternal intrusiveness during free play task at 5 months; 10m MI free play: maternal intrusiveness during free play task at 10 months; 4y EF: executive function composite at 4 years old.