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Longitudinal links between maternal factors and infant cognition: Moderation by infant sleep

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Abstract

The current study examined the moderating role of infant sleep in the link between maternal factors (i.e., maternal education, depressive symptoms, sleep disturbance) and infant cognition. Data come from 95 African American parent–child dyads. At 3 months of age, infant sleep was objectively measured using videosomnography and actigraphy, from which measures of sleep regulation and consolidation were calculated. Mothers also self-reported their level of education, depressive symptoms, and sleep quality. At 6 months of age, infants completed cognitive assessments, including a measure of general cognitive ability and observed attention behavior. Findings revealed that infant sleep quality interacted with maternal education and sleep disturbances to predict cognition. Specifically, the link between maternal education and infants' attention behavior was significant and positive for infants with better regulated sleep, but not for infants with poorly regulated sleep. Similarly, the link between maternal sleep disturbance and infant cognition depended on infant sleep quality. For infants with poorer sleep consolidation, increased maternal sleep disturbance predicted poorer infant general cognitive ability. For infants with better sleep consolidation, maternal sleep disturbance was positively related to both general cognitive ability and attention behavior. These findings suggest that infant sleep quality moderates the impact of environmental factors on cognitive functioning.

1 | INTRODUCTION

Individual differences in early cognitive functioning have been attributed to a host of intrinsic and extrinsic factors such as genetic factors, physiological functioning, parental characteristics, and socioeconomic status (e.g., Mills-Koonce et al., 2015; Staton, El-Sheikh, & Buckhalt, 2009; Tucker-Drob, Briley, & Harden, 2013). For example, a substantial body of research has shown that, whereas sensitive-responsive parent–child interactions and parental scaffolding behaviors are positively related to general cognitive functioning in early childhood, factors such as parental depressive symptoms and socioeconomic risk are related to lower cognitive functioning (Liu et al., 2017; Mills-Koonce et al., 2015; Roberts, Bornstein, Slater, & Barrett, 1999). One potentially modifiable intrinsic factor associated with cognitive functioning in children is sleep quality, and there is some evidence that poor sleep quality is related to lower cognitive functioning in infants as well (Dearing, Mccartney, Marshall, & Warner, 2001; Geva, Yaron, & Kuint, 2016; Scher, 2005). However, little is known about the interplay between infants' sleep quality and extrinsic factors in predicting cognitive functioning. Research on preschool and school-aged children suggests that child sleep quality can moderate the associations between characteristics of the caregiving environment and children's behavioral and cognitive outcomes (Bernier, Bélanger, Tarabulsy, Simard, & Carrier, 2014; Bordeleau, Bernier, & Carrier, 2012; El-Sheikh, Hinnant, Kelly, & Erath, 2010). In line with these findings, the current study aims to examine the interaction between infant sleep and characteristics in the caregiving environment during infancy.

1.1 | Maternal factors and infant cognition

There are rapid changes in information processing across the first year of life, as evidenced by studies of infant attention and visual recognition memory (for reviews, see Colombo, 2001; Rose, Feldman, & Jankowski, 2004). Infants become more efficient information processors across the first six months of life, as indicated by quicker habituation and better visual recognition memory (Reynolds & Romano, 2016). This phenomenon of decreased looking across the first half of the first year of life may be attributed to the development of the attentional orienting network and the ability to voluntarily shift and disengage visual fixation (Colombo, 1995; Posner & Petersen, 1990). At around six months of age, development of the executive attention network allows for better voluntary control over fixation, including the ability to inhibit attention to distracters and to sustain attention for longer periods, when it is appropriate (e.g., in response to more complex or face-like stimuli; Courage, Reynolds, & Richards, 2006). Given that these fundamental cognitive abilities have been shown to predict later child outcomes, include executive functioning and IQ (e.g., Bornstein et al., 2006; McCall & Carriger, 1993; Rose, Feldman, & Jankowski, 2012), much research has investigated the earliest predictors of individual differences in infant cognition. The current study focuses on maternal education, maternal depressive symptoms, and maternal sleep quality as three potential environmental predictors of infant cognition.

1.1.1 | Maternal education

Parental education, a nonmaterial stable indicator of socioeconomic status often used in developmental studies, has been associated with a broad range of child outcomes, including cognitive functions (Roberts et al., 1999). There are multiple mechanisms through which maternal education can impact children's cognition, including enrichment to the child's home learning environment, scaffolding mother–child interactions, and increased family resources (Magnusson & McGroder, 2001). Indeed, previous research has consistently demonstrated that higher maternal educational attainment is related better general cognitive functioning, visual recognition memory, and school readiness in infancy and early childhood (Koutra et al., 2012; NICHD Early Child Care Research Network, 1999; Roberts et al., 1999; Rose & Wallace, 1985).

1.1.2 | Maternal depressive symptoms

Maternal depressive symptoms may be adversely related to children's cognitive development in several ways. For example, mothers experiencing depression may be less able to meet their infants' emotional and physical needs, which can have implications for neurological maturation processes (Cornish et al., 2005). Moreover, depressive symptoms may hinder mothers' ability to provide age-appropriate stimulation to facilitate their children's cognitive development (Sohr-Preston & Scaramella, 2006). However, the literature on the link between maternal depressive symptoms and children's early cognitive development has been inconsistent, with some studies indicating that maternal depression had negligible or no effects on children's general cognitive functioning (Kurstjens & Wolke, 2001; Murray, 1992) and others showing negative associations (Conroy et al., 2012; Cornish et al., 2005). A recent meta-analysis indicated that the mean cognitive score for children whose mothers had high depressive symptoms was 0.25 S.D. lower than that for children whose mothers had few or no depressive symptoms (Liu et al., 2017). However, the authors warrant that these findings should be interpreted with caution because the majority of studies did not control for confounding variables such as family income and maternal education (Liu et al., 2017).

1.1.3 | Maternal sleep

The quality of maternal sleep has been found to have pervasive effects on multiple aspects of maternal functioning. For example, there is strong evidence that poor maternal sleep is significantly related to increased severity of depressive symptoms (e.g., Chang, Pien, Duntley, & Macones, 2010; Coo, Milgrom, & Trinder, 2014; Dorheim, Bondevik, Eberhard-Gran, & Bjorvatn, 2009). Poor maternal sleep quality has also been related with family dysfunction (Piteo et al., 2013) and more negative maternal perceptions of the mother–infant relationship (Tikotzky, 2016; Tikotzky, Chambers, Kent, Gaylor, & Manber, 2012). In general, poor sleep quality is associated with increased irritability as well as reductions in motivation, vigilance, attention, and memory (see Tikotzky, 2016 for a review), all of which may interfere with mothers' ability to engage with infants in ways that facilitate their emerging cognitive skills. In the current study, we examined the direct and indirect links between maternal sleep quality and infant cognition for the first time.

1.2 | Infant sleep and cognitive functioning

Like infant cognition, infant sleep develops rapidly across the first year of life. Changes in infant sleep patterns can be described as they relate to the underlying processes of sleep consolidation and regulation (for a recent review, see Camerota, Propper, & Teti, 2019). Briefly, sleep consolidation occurs as infants begin to sleep in longer continuous stretches that primarily occur during the nighttime, as opposed to shorter bouts of sleep that are interspersed throughout the day and night. Across the first year, there is a general decrease in infants' total sleep time, which is primarily due to a reduction in the amount of daytime sleep (e.g., Iglowstein, Jenni, Molinari, & Largo, 2003; Sadeh, Mindell, Luedtke, & Wiegand, 2009). This change in day–night patterning of sleep is additionally evidenced by an increase in the nighttime sleep ratio (NSR; ratio of nighttime sleep to 24-hr sleep), which shows the biggest changes between 0–2 and 3–5 months of age (Sadeh et al.., 2009). At the same time, the longest continuous sleep period (LSP) increases, with the most rapid changes again occurring within the first six months of life (Galland, Taylor, Elder, & Herbison, 2012; Henderson, France, & Blampied, 2011). Sleep regulation, on the other hand, describes the infant's ability to transition between sleep and wakefulness without outside intervention. In the first year of life, infants are increasingly able to sleep through the night, meaning that they are able to fall asleep independently at bedtime and put themselves back to sleep following nighttime wakings (Henderson, France, Owens, & Blampied, 2010). Similar to the trend seen in sleep consolidation, rates of sleeping through the night increase the most during the first six months of life (Henderson et al., 2011). Rates of self-soothed waking also increase across this time period, while overall nighttime wakefulness decreases (e.g., Burnham, Goodlin-Jones, Gaylor, & Anders, 2002; Goodlin-Jones, Burnham, Gaylor, & Anders, 2001; Scher, Epstein, & Tirosh, 2004).

There are reasons to believe that sleep and cognition are two intimately linked processes. Research with clinical and non-clinical populations of adults has identified deficits in higher-order cognitive processing, such as executive functions, in individuals experiencing inadequate or poor quality sleep (for reviews, see Beebe & Gozal, 2002; Curcio, Ferrara, & De Gennaro, 2006; Jones & Harrison, 2001). However, links between infant sleep and cognitive functioning are less well understood. Several studies (e.g., Mäkelä et al., 2018; Scher, 2005) have examined the relations between various aspects of sleep and performance on the Bayley Scales of Infant Development (Bayley, 1993, 2006), a standardized assessment that captures infant functioning across multiple cognitive domains (e.g., sensorimotor development, exploration and manipulation, memory). Other studies have relied on maternal report measures of infants' cognitive functioning (e.g., Mindell & Lee, 2015). However, these studies have yielded mixed findings. Whereas some studies did not observe correlations between different aspects of sleep and overall cognitive functioning (Mäkelä et al., 2018; Mindell & Lee, 2015; Spruyt et al., 2008), other studies have yielded divergent patterns of results. For example, one study on a small sample of low-risk infants found that more motor activity in sleep and more fragmented sleep were associated with lower mental developmental index (MDI) scores at 10 months (Scher, 2005). Similarly, a longitudinal study found that higher NSR at 7 and 19 months was positively associated with MDI scores at 24 months (Dearing et al., 2001). Other studies of low-risk infants have found opposite directions of effects, with higher neonatal longest sleep period (LSP) being linked to lower MDI scores at 6 months (Freudigman & Thoman, 1993).

Moving beyond general cognitive ability, one study specifically examined the relationship between neonatal sleep and attention orienting at 4 months (Geva et al., 2016). Infants who were classified as poor sleepers (i.e., below median sleep efficiency) exhibited longer first gazes during the familiarization phase of a visual recognition task, as compared to good sleepers (Geva et al., 2016). Although the sample was made up exclusively of premature infants who were monitored in the NICU, relations between sleep and attention were found independently of degree of prematurity. These findings are interpreted as evidence of impaired attention orienting in the poor sleepers group, as fixation duration (i.e., gaze length) is inversely related to the ability to disengage attention (Colombo, 2001), as well as processing speed (Colombo et al., 1991). However, additional research is needed in order to better understand the links between infant sleep and attention.

1.3 | The moderating role of infant sleep

Contemporary developmental science frameworks highlight the interactive links between children's characteristics and multiple aspects of their caregiving environment in shaping cognitive and social–emotional development (Calkins, Perry, & Dollar, 2016; Ellis, Boyce, Belsky, Bakermans-Kranenburg, & van Ijzendoorn, 2011; Sameroff, 2010). In the context of child sleep, El-Sheikh and Sadeh (2015) proposed a developmental ecological systems perspective, suggesting that child sleep is nested within multiple environmental systems that jointly contribute to children's developmental outcomes over time. Drawing from these theoretical perspectives, a growing body of evidence suggests that children's sleep may act as a moderator of the links between characteristics of the caregiving environment and children's developmental outcomes (Bernier et al., 2014; Bordeleau et al., 2012; El-Sheikh et al., 2010). These studies consider sleep as a bioregulatory factor that facilitates or hampers the capacity to exert volitional control over emotional and cognitive processes (Dahl, 1996), consequently modulating children's reactivity to environmental influences (El-Sheikh et al., 2010).

Indeed, findings from several studies suggest that high quality sleep may either buffer infants from the negative impacts of adverse environments, or help infants take advantage of an enriched environment. For example, two studies have shown that negative parenting techniques (e.g., psychological control, negative affect) predict worse socioemotional functioning, but only for children who have poorer nighttime sleep (El-Sheikh et al., 2010; Julian et al., 2019). These findings are consistent with a diathesis-stress model (Monroe & Simons, 1991), where children with certain risk characteristics (e.g., poor sleepers) are more susceptible to the negative effects of adverse experiences. The opposite of the diathesis-stress model is the vantage sensitivity model (Pluess & Belsky, 2013), which predicts that children with certain endogenous characteristics (e.g., good sleepers) are better able to reap the benefits of positive environmental experiences. In support of this theory, one study found that the link between maternal sensitive parenting and child executive functioning was only significant among infants who had higher NSRs (Bernier et al., 2014). These two groups of findings support the notion that infant sleep may moderate the influence of environmental experience on children's development, but that the pattern of findings may differ based on the nature of the environmental influence considered (e.g., whether it is a positive or negative influence).

1.4 | The current study

The current study examined whether infant sleep moderated associations between both positive (e.g., maternal education) and negative (e.g., maternal depressive symptoms, maternal sleep disturbance) environmental factors and infant cognition in the first year of life. Given the evidence that sleep consolidation and regulation are two distinct processes that underlie infant sleep development, we examined these as two separate indices of infant sleep quality. However, in the absence of previous literature, we did not have specific hypotheses regarding how these two components of sleep quality might differentially interact with maternal factors to predict infant outcomes. Based on previous studies with toddlers and school-aged children (Bernier et al., 2014; Bordeleau et al., 2012; El-Sheikh et al., 2010; Julian et al., 2019), we hypothesized that infant sleep quality would moderate the links between maternal factors (i.e., depressive symptoms, education, and maternal sleep) and infants' cognitive outcomes. Specifically, we predicted that maternal education would be related to better cognitive functioning and behavioral attention, but only for infants with high sleep quality. In addition, we hypothesized that maternal depressive symptoms and maternal sleep disturbance would be related to poorer cognitive functioning and behavioral attention, but only for infants with poor sleep quality.

2 | METHODS

2.1 | Participants

Data come from the Neonatal and Pediatric Sleep Study (NAPS), a longitudinal study of 95 African American parent–infant dyads. Families who lived within a 50-mile radius of a large public university in North Carolina were identified using public birth record data. Potential participants were excluded if mothers were younger than age 18, did not identify as African American, did not speak fluent English, or if infants had experienced serious medical complications at birth (e.g., NICU stay >7 days), or were part of a twin pair. Seven infants (7.4%) were born prematurely (e.g., gestational age <37 weeks). The home visits for premature infants were scheduled based on their corrected ages (i.e., their chronological age reduced by the number of days born before 37 weeks' gestation). The average adjustment for prematurity was 13 days (range = 1–30). The average age of mothers in our sample was 29 years (range = 19–48). The average number of years of education was 14.6 (*SD* = 2.2), with 99% of mothers having received a high school degree or higher, and 40% of mothers having received a four-year college degree of higher. A minority of infants (35%) were firstborn, and a majority of infants (63%) resided in the same household as their biological father.

2.2 | Procedures

Infants and caregivers were visited in their home for a data collection visit when infants were 3 and 6 months of age. During this home visit, dyads participated in parent–child interaction tasks and caregivers completed questionnaires. At 6 months of age, infants completed additional cognitive assessments. The Bayley Cognitive Scale was administered on the day after the initial 6-month home visit, to minimize infant fatigue. Starting on the evening after the 3- and 6-month home visits, families completed a one-week sleep assessment, consisting of one night of videosomnography, seven days and nights of actigraphy monitoring, and seven days of parental sleep diaries. The current investigation uses infant sleep data obtained from videosomnography and actigraphy at 3 months.

At the end of each home visit, infants were provided with a small toy and mothers received compensation of up to $130 in the form of a gift card. The present study was conducted according to guidelines laid down in the Declaration of Helsinki, with written informed consent obtained from a parent or guardian for each child before any assessment or data collection. All procedures involving human subjects in this study were approved by the institutional review board at the University of North Carolina at Chapel Hill.

2.3 | Measures

2.3.1 | Infant Sleep

Actigraphy

Actigraphy measures movement using a watch-sized monitor worn on the infant's ankle. It contains an accelerometer, which measures limb movement in 15-s epochs. At the end of the sleep assessment week, actigraphy data were downloaded to a PC computer and edited using Phillips Actiware software (version 6.0). Actogram algorithm settings were selected as follows: Immobile minutes for sleep onset were set to 5 min; minimum rest interval size was set to 20 min; multiple rest intervals per day were allowed; automatically set minor rest intervals were allowed. Consistent with previous validation studies (So, Buckley, Adamson, & Horne, 2005), the activity threshold for scoring the infant as awake was set to the Automatic setting (0.888 × average activity count) at 3 months. Even with the appropriate algorithm settings, the Actiware program can miss intervals of sleep or wake, necessitating the manual entry of additional intervals. While more detail is beyond the scope of the current manuscript, additional details can be found elsewhere (Camerota, Tully, Grimes, Gueron-Sela, & Propper, 2018).

Infant sleep variables obtained from actigraphy and used in the current investigation include the following: longest sleep period (LSP; longest period where the infant was coded as being continuously asleep), nighttime sleep ratio (NSR; ratio of nighttime [7 p.m.–7 a.m.] sleep to total [24-hr] sleep), and duration of daytime naps (NAPD; total sleep time occurring outside the nighttime period). Infant LSP and NAPD were calculated each day and averaged over the sleep assessment week, whereas NSR was calculated for the entire study week (e.g., weekly daytime sleep divided by weekly total sleep). On the whole, actigraphy has been shown to be a valid method for assessing infant sleep quality (e.g., So et al., 2005), and the variables used in the current investigation have been used repeatedly in research on infant sleep (e.g., Acebo et al., 2005; Bernier, Carlson, Bordeleau, & Carrier, 2010).

Videosomnography

Behavioral sleep data were coded from videosomnography by trained research assistants. Because of the intensive nature of observational coding, overnight videos were coded for a 4-hr interval beginning when the infant went to sleep (Ball, Ward-Platt, Heslop, Leech, & Brown, 2006). A variety of infant and parent variables were recorded using 30-s interval coding. That is, for every 30-s interval, research assistants coded whether certain behaviors were present or absent. Pertinent to this investigation are codes indicating infant state and parental interventions.

Infant state was coded as asleep whenever the infants' eyes were closed and there was no gross body movement. Infant state was coded as awake whenever the infants' eyes were wide open, the infant was vocalizing, or when the infant was engaged in gross body movement for 15 s or more. Parental interventions were coded whenever a parent responded to an awake infant, and could include actions such as physical contact, verbal reassurance, nursing or bottle feeding, providing a pacifier, or taking care of the infants' non-nutritive needs (e.g., changing diaper, covering with a blanket). Importantly, five minutes (10 intervals) needed to pass after the end of one intervention to begin coding a second intervention. If a parent interacted with an infant more than once, but these interactions were not separated by five minutes, these actions were all considered part of the same intervention. Inter-rater reliability was established between two coders for all codes ($\kappa > 0.80$).

Infant sleep variables obtained from videosomnography and used in the current investigation include the following: total wake proportion (TWP; number of intervals where the infant was coded as awake divided by the length of the observation period), parental interventions (PINT; number of times parent interacted with awake infant during the nighttime period), and proportion of self-soothed wakings (SSWP; number of night wakings that did not receive a parental intervention divided by the total number of night waking). Proportion scores were used for TWP and SSWP because the length of the observation period could vary (e.g., parent turns off cameras, parent takes infant off camera). Previous studies have demonstrated the validity of videosomnography as a sleep assessment method, particularly for detecting infant wakefulness (e.g., Anders & Sostek, 1976). Additionally, the variables described here have previously been used in studies of infant sleep (e.g., Burnham et al., 2002).

Creation of composite variables

To increase reliability of our infant sleep measures, we created two composite scores using the actigraphy and videosomnography variables described above. This analytic strategy is consistent with recent approaches in the literature (e.g., Hoyniak et al., 2018) as well as with sleep theory (Goodlin-Jones et al., 2001), which makes a distinction between the processes of sleep consolidation and regulation. Sleep consolidation refers to the process by which sleep becomes increasingly diurnal, with the majority of sleep time occurring during one continuous nighttime episode. In our data, indices of better sleep consolidation include longer continuous sleep periods (LSP), higher nighttime sleep ratios (NSR), and shorter durations of daytime naps (NAPD). Sleep regulation, on the other hand, refers to the process by which infants become increasingly able to exert control over their sleep/wake states (e.g., resume sleeping following a nighttime waking without parental assistance). In our data, better regulated sleep could be inferred by fewer parental interventions (PINT), higher proportions of self-soothed waking (SSWP), and lower proportions of nighttime wakefulness (TWP).

In support of our conceptualization of these dual facets of infant sleep quality, we found that LSP positively correlated with NSR ($r = 0.48$, $p < .001$), whereas NAPD was negatively correlated with both LSP ($r = -0.22$, $p = .04$) and NSR ($r = -0.92$, $p = .001$). Concerning indicators of regulation, PINT and TWP were positively correlated with one another ($r = 0.64$, $p < .001$), whereas SSWP was negatively correlated with both PINT ($r = -0.60$, $p < .001$) and TWP ($r = -0.44$, $p < .001$). A preliminary factor analysis additionally suggested that a two-factor model provided better fit to the data than a one-factor model, $\chi^2(1) = 22.02$, $p < .001$. The two-factor model had good global fit [$\chi^2(8) = 11.57$, $p = .17$, CFI = 0.97, SRMR = 0.08] and significant factor loadings of LSP, NAPD, and NSR on consolidation ($|\lambda| = 0.38$–0.74) and of TWP, PINT, and SSWP on regulation ($|\lambda| = 0.65$–0.94). Due to the practical difficulties of estimating latent interactions (e.g., Moosbrugger, Schermelleh-Engel, & Klein, 1997), we created two composite scores of infant sleep quality to use in substantive analyses. To create composite variables of sleep consolidation (LSP, NSR, NAPD) and regulation (SSWP, PINT, TWP), we first standardized all sleep quality variables. We then reversed indicators as needed to ensure that higher values indicated better sleep quality (in the case of NAPD, PINT, and TWP, for example), before taking the average across the indicators. The resulting composite variables for consolidation (CON; $\alpha = 0.78$) and regulation (REG; $\alpha = 0.79$) exhibited adequate internal consistency.

2.3.2 | Cognition

General cognitive ability

Infant general cognitive ability was measured at 6 months using the cognitive subscale of the Bayley Scales of Infant Development (BSID-III; Bayley, 2006). The BSID-III is a widely used measure of cognitive development for children in the first three years of life, and measures abilities such as sensorimotor development, object manipulation, memory, and simple problem-solving. Scaled scores were calculated based on infant performance and age at assessment.

Attention behavior

Infant attention behavior was measured at 6 months during a novel puppet presentation task. Infants sat on their mothers' laps 60 cm from the edge of the testing table [66 cm (L) × 45.7 cm (W) × 71.1 cm (H)]. Stimuli were green or purple glove puppets decorated with facial features on the palm of the glove and bells or buttons attached to each fingertip (Cuevas & Bell, 2014). The specific glove presented was counterbalanced across infants. Infants were presented with the glove puppet until they accrued four looks, with each look separated by at least three seconds (procedure and criteria adapted from Diamond, Prevor, Callender, & Druin, 1997). Looking time data were video-recorded to allow offline recording of infant look duration. Consistent with previous studies, the median look duration across the four looks was used as a measure of infant attention behavior (Cuevas & Bell, 2014). As infant looking time normatively increases in the second half of the first year of life (Swingler, Perry, & Calkins, 2015), longer looking was considered indicative of better infant attention. One infant was identified as an outlier in the attention data (>3 *SD* above mean) and was subsequently excluded from analyses.

2.4 | Maternal factors

2.4.1 | Maternal education

Demographic information was reported by mothers via questionnaires administered at the 3-month home visit. A continuous measure of maternal years of education was used in the current analyses (e.g., high school degree = 12 years; four-year college degree = 16 years).

2.4.2 | Maternal depressive symptoms

Maternal depressive symptoms (MDS) were measured at 3 months using the Center for Epidemiological Studies Depression Scale (CES-D; Radloff, 1977), a well-validated measure of depressive symptomology. The CES-D is a 20-item scale that asks the frequency with which mothers experienced various depressive symptoms (e.g., “I felt sad”), rated on a 4-point Likert scale ranging from 0 (rarely or none of the time) to 3 (most or all of the time). Maternal responses to the 20 items were summed to create an overall measure of MDS ($\alpha = 0.89$). The CES-D has been widely used in community samples, including samples of African American women (e.g., Brody, Murry, Kim, & Brown, 2002).

2.4.3 | Maternal sleep

Maternal sleep was measured using the Pittsburgh Sleep Quality Index (PSQI; Buysse, Reynolds, Monk, Berman, & Kupfer, 1989), a nineteen-item self-report questionnaire that assesses seven components of sleep (i.e., duration, disturbance, latency, daytime dysfunction, efficiency, quality, and medication dependency). The PSQI has been shown to demonstrate favorable psychometric properties, including reliability and validity (e.g., Backhaus, Junghanns, Broocks, Riemann, & Hohagen, 2002; Carpenter & Andrykowski, 1998; Pilcher, Ginter, & Sadowsky, 1997). The current analyses utilize the global sleep quality score, which is a sum of the seven subscales. Specifically, each subscale is scored on a 0 to 3 scale, with increasing numbers indicating increasingly poor sleep quality (range = 0 to 21; $\alpha = 0.83$). Because higher scores on this global scale indicate poorer sleep quality, we refer to this variable as a measure of maternal sleep disturbance.

2.5 | Analytic plan

Our primary goal was to test whether infant sleep quality moderated the relationship between maternal characteristics and infant cognition. For each of our three maternal characteristics tested (i.e., maternal education, depressive symptoms, and sleep disturbance), we estimated a series of three path models. Path models were chosen to allow us to include multiple dependent variables in the same model (e.g., infant general cognitive ability and attention behavior).

The first model included direct effects of covariates, the maternal characteristic of interest, and infant consolidation and regulation at 3 months on infant general cognitive ability and attention behavior at 6 months. The second model added two interaction terms (maternal characteristic × infant sleep consolidation; maternal characteristic × infant sleep regulation). The third model trimmed any non-significant interaction terms, to facilitate interpretation of main effects. In all models, our two outcomes (i.e., infant general cognitive ability and attention behavior) were allowed to covary. In addition, all continuous predictors were centered prior to testing interactive effects, to aid model interpretation.

For models where the interaction between the maternal factor and infant sleep was significant, we probed the interaction using simple slopes analyses. Specifically, we calculated the simple slopes for low (-1 *SD*) and high ($+1$ *SD*) levels of infant sleep quality. We also tested the regions of significance for each interaction. That is, for each model, we determined the level of infant sleep quality at which the relationship between the maternal factor and infant cognition was significant.

Substantive analyses were conducted using Mplus 8.1. Rates of missing data were low (7%–25%, depending on the variable) and were primarily due to participant non-response, experimenter error, or participant attrition. On the whole, participants missing specific sources of data did not systematically differ from those who had data, with one exception. Children missing attention data tended to have mothers with more depressive symptoms ($M = 15.5$, $SD = 10.9$), compared to children with attention data ($M = 9.5$, $SD = 7.9$), $t(84) = -2.76$, $p = .007$. Missing data were handled using full-information maximum likelihood (FIML).

3 | RESULTS

3.1 | Descriptive statistics

Descriptive statistics for all study variables are displayed in Table 1. Mothers in this sample had an average of 14.66 years of education ($SD = 2.21$), which is approximately equivalent to a two-year college degree. The mean level of maternal depressive symptoms was low ($M = 10.99$, $SD = 9.14$), with 13% of the sample meeting cutoff levels for clinically elevated symptom levels ($\text{CESD} \geq 23$). On the other hand, maternal sleep disturbance was moderate ($M = 6.86$, $SD = 3.67$), with 68% of the sample meeting the cutoff for poor sleep quality ($\text{PSQI} \geq 5$). These levels of depression (e.g., Karraker & Young, 2007) and sleep disturbance (Dørheim, Bondevik, Eberhard-Gran, & Bjorvatn, 2009) among mothers of infants are comparable to those reported elsewhere in the literature.

Among the covariates considered for inclusion in substantive models (i.e., child age, gender, prematurity status), only prematurity was marginally predictive of child cognitive outcomes ($|r| = 0.17$–0.19, $p < .15$) and was retained. Correlations among all analysis variables, including prematurity, are displayed in Table 2.

Although maternal education was unrelated to maternal depressive symptoms or maternal sleep disturbance ($r = -0.05$–0.02, $p > .63$), mothers reporting more depressive symptoms also tended to report more disturbed sleep ($r = 0.50$, $p < .001$). In turn, maternal depressive symptoms were marginally, positively related to infant general cognitive ability ($r = 0.19$, $p = .10$) and infant attention behavior ($r = 0.24$, $p = .06$). Maternal education ($r = 0.28$, $p = .02$) and sleep disturbance ($r = 0.30$, $p = .03$) were both positively related to infant attention behavior. There were no significant bivariate correlations among infant cognitive variables and either sleep consolidation or regulation. Infant sleep quality was also unrelated to maternal factors (i.e., education, depressive symptoms, and sleep disturbance).

TABLE 1 Descriptive statistics for all study variables

	N	*M*	*SD*	Range
Maternal characteristics				
Education (years)	88	14.66	2.21	10.00–18.00
Depressive symptoms	86	10.99	9.14	0.00–43.00
Sleep disturbance	71	6.86	3.67	1.00–16.00
Infant cognition				
Bayley scaled score	82	10.66	2.45	3.00–17.00
Median looking time, seconds	71	7.58	4.76	1.11–22.9
Infant sleep consolidation	80	0.00	0.83	−2.14 to 2.31
Longest sleep period (min)	80	293.18	82.68	119.2–527.3
Nighttime sleep ratio	80	0.73	0.08	0.51–0.91
Daytime naps (*n*)	80	2.95	0.68	1.20–4.83
Infant sleep regulation	81	0.02	0.85	−2.15 to 1.27
Parental interventions	81	2.07	1.87	0.00–8.00
Self-soothed waking (proportion)	76	0.32	0.39	0.00–1.00
Nighttime wakefulness (proportion)	81	0.06	0.06	0.00–0.26

3.2 | Substantive models

We tested a series of three substantive models for each maternal factor (direct effects only, interactive effects, trimmed interactive effects models). All model coefficients are displayed in Table 3. Because path models were fully saturated, we do not report model fit statistics.

TABLE 2 Correlations among study variables

	1	2	3	4	5	6	7	8
1. Maternal education (years)	—							
2. Maternal depressive symptoms	−0.05	—						
3. Maternal sleep disturbance	−0.02	0.50***	—					
4. Bayley scaled score	0.03	0.19	0.05	—				
5. Median looking time (s)	0.28*	0.24†	0.30*	0.17	—			
6. Infant prematurity	−0.07	−0.02	−0.10	−0.17	−0.19	—		
7. Infant sleep consolidation	−0.01	0.02	0.02	0.03	0.01	−0.17	—	
8. Infant sleep regulation	−0.09	0.04	0.01	−0.04	0.15	−0.18	0.25*	—

*$p < .05$, $^{**}p < .01$, $^{***}p < .001$, $^{\dagger}p < .10$.

3.2.1 | Maternal education

In our direct-effects only model (Model 1), we found that maternal education significantly predicted infant attention behavior (β = 0.28, *p* = .008). There were no direct effects of maternal education on general cognitive ability, nor were there direct effects of sleep consolidation or regulation on either cognitive outcome. In our full interactive model (Model 2), only the interaction between maternal education and infant sleep regulation was significant and was retained in our trimmed model (Model 3). In the final model (Model 3), there were no direct effects of maternal education or infant sleep, or any interactions between the two, predicting infant general cognitive ability. In contrast, maternal education significantly predicted infant attention behavior (β = 0.29, *p* = .004). There was also a significant interaction between maternal education and infant sleep regulation predicting infant attention behavior (β = 0.31, *p* = .003).

Probing this interaction indicated that maternal education became more predictive of infant attention for infants with better sleep regulation (Figure 1). That is, for infants with above average (+1 *SD*) levels of sleep regulation, there was a positive relationship between maternal education and infant attention behavior (*b* = 1.29, *p* < .001). For infants with below average (−1 *SD*) levels of sleep regulation, the relationship between maternal education and infant attention was not significant (*b* = −0.08, *p* = .81). Regions of significance analyses indicated that the relationship between maternal education and infant attention became significant when infant regulation was approximately 0.24 *SD* below the mean (*b* = 0.45, *p* = .05).

3.2.2 | Maternal depressive symptoms

In our direct-effects only model, we found marginally significant effects of maternal depressive symptoms on both general cognitive ability (β = 0.21, *p* = .07) and attention behavior (β = 0.24, *p* = .06). In the full interactive model (Model 2), there were no interaction terms that approached significance. Therefore, all interaction terms were trimmed, and the final model (Model 3) mirrored the direct-effects only model (Model 1), with no significant direct effects.

3.2.3 | Maternal sleep disturbance

Finally, in the direct-effects model (Model 1) for maternal sleep disturbance, prematurity marginally predicted infant general cognitive ability (β = −0.18, *p* = .10). In addition, maternal sleep disturbance positively predicted infant attention behavior (β = 0.30, *p* = .02). In the full interactive model (Model 2), there was a significant interaction between maternal sleep disturbance and infant sleep consolidation predicting both infant general cognitive ability (β = 0.49, *p* < .001) and attention behavior (β = 0.40, *p* = .007). There were no interactions involving infant sleep regulation, and thus, these terms were trimmed from the final model (Model 3). In Model 3, there were no direct effects of maternal sleep disturbance or infant sleep on infant general cognitive ability. However, the interaction between maternal sleep disturbance and infant sleep consolidation remained significant (β = 0.45, *p* = .001). In addition, there was a significant direct effect of maternal sleep disturbance on infant attention behavior (β = 0.33, *p* = .007), as well as a significant interaction between maternal sleep disturbance and infant sleep consolidation (β = 0.39, *p* = .01).

First, we probed the interaction predicting infant general cognitive ability. Simple slopes analyses revealed that there was a significant relationship between maternal sleep disturbance and infant

TABLE 3 Standardized model coefficients predicting infant cognition

	Model 1 Direct effects		**Model 2 Full model**		**Model 3 Trimmed model**	
Predictors	**Bayley**	**Attention**	**Bayley**	**Attention**	**Bayley**	**Attention**
Maternal education (Ed)						
Prematurity	−0.19†	−0.14	−0.18	−0.11	−0.17	−0.11
Maternal Ed	0.01	0.28*	0.00	0.29**	0.01	0.29**
Sleep Con	0.01	−0.07	0.01	−0.16	0.01	−0.14
Sleep Reg	0.18	0.18	−0.11	0.18	−0.08	0.17
Maternal Education × Sleep Con			0.15	−0.03		
Maternal Education × Sleep Reg			0.00	0.33**	0.07	0.31**
Model R^2	0.03	0.13	0.06	0.23	0.04	0.22
Maternal depressive symptoms (MDS)						
Prematurity	−0.18†	−0.16	−0.19†	−0.16.	−0.18†	−0.16
MDS	0.21†	0.24†	0.20†	0.26†	0.21†	0.24†
Sleep Con	−0.02	−0.05	0.01	−0.07	−0.02	−0.05
Sleep Reg	−0.06	0.09	−0.01	0.05	−0.06	0.09
MDS × Sleep Con			0.21	−0.18		
MDS × Sleep Reg			0.13	−0.06		
Model R^2	0.08	0.10	0.13	0.13	0.08	0.10
Maternal sleep disturbance (MSD)						
Prematurity	−0.18†	−0.15	−0.17†	−0.14	−0.17†	−0.14
MSD	0.05	0.30*	0.05	0.31*	0.05	0.33*
Sleep Con	0.00	−0.06	−0.01	−0.01	−0.04	−0.02
Sleep Reg	−0.07	0.10	0.02	0.15	0.01	0.12
MSD × Sleep Con			0.49***	0.40**	0.45**	0.39*
MSD × Sleep Reg			0.18	0.10		
Model R^2	0.04	0.13	0.28	0.24	0.22	0.24

Note: Con, Consolidation; Reg, Regulation.
$*p < .05$, $^{**}p < .01$, $^{***}p < .001$, $^{\dagger}p < .10$.

cognitive ability, but that the direction of this association depended on the infant's level of sleep consolidation (Figure 2a). When infant sleep consolidation was 1 *SD* below the mean, increasing levels of maternal sleep disturbance predicted lower Bayley scores ($b = -0.25$, $p = .04$). When infant sleep consolidation was 1 *SD* above the mean, this relationship was reversed, with increasing levels of maternal sleep disturbance predicting higher Bayley scores ($b = 0.31$, $p = .01$). Regions of significance analyses indicated that the negative relationship between maternal sleep disturbance and Bayley scores became significant when infant sleep consolidation was 0.90 *SD* below the mean, whereas the positive relationship between these factors emerged when infant sleep consolidation was 0.60 *SD* above the mean.

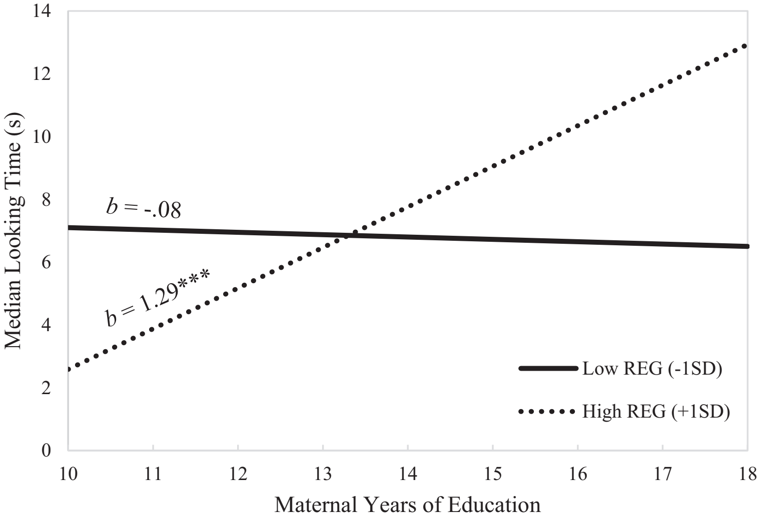


FIGURE 1 Interaction between maternal education and infant sleep at 3 months predicting infant attention behavior at 6 months. Maternal education positively predicted infant attention behavior, but only for infants who had above average sleep regulation (REG). $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$

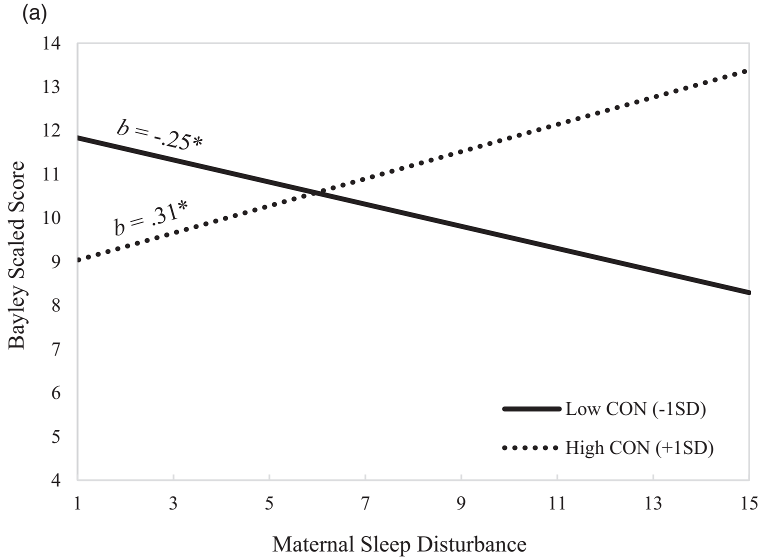
Next, we probed the interaction of maternal sleep disturbance and infant sleep consolidation predicting infant attention behavior (Figure 2b). Similar to the results for general cognitive ability, there was a positive association between maternal sleep disturbance and infant attention behavior when infant sleep consolidation was at the mean ($b = 0.42$, $p = .01$) or at 1 *SD* above the mean ($b = 0.90$, $p = .001$). This positive relationship became significant when infant sleep consolidation was 0.18 *SD* below the mean or higher.

3.3 | Sensitivity analysis

Given our modest sample size, we chose to test each of the three maternal factors in separate models. While this reduced model complexity, one question is whether the same results would be obtained if all maternal factors were included in the same model. We re-estimated a single model including direct and interactive effects for both maternal factors that were found to have significant associations with infant cognition (i.e., maternal education and maternal sleep disturbance). Results from this joint model were substantively similar to the results from separate models, reported above. Specifically, maternal education interacted with infant sleep regulation to predict infant attention ($\beta = 0.26$, $p = .03$), while maternal sleep disturbance interacted with infant sleep consolidation to predict both infant attention ($\beta = 0.35$, $p = .01$) and general cognitive ability ($\beta = 0.51$, $p < .001$).

4 | DISCUSSION

The current study investigated whether infant sleep quality moderated the relationship between maternal characteristics and infant cognition. We found support for this proposition in two out of three of the maternal characteristics we examined. In contrast, we failed to find direct associations between infant sleep and cognition in the first six months of life. These findings suggest that infant sleep



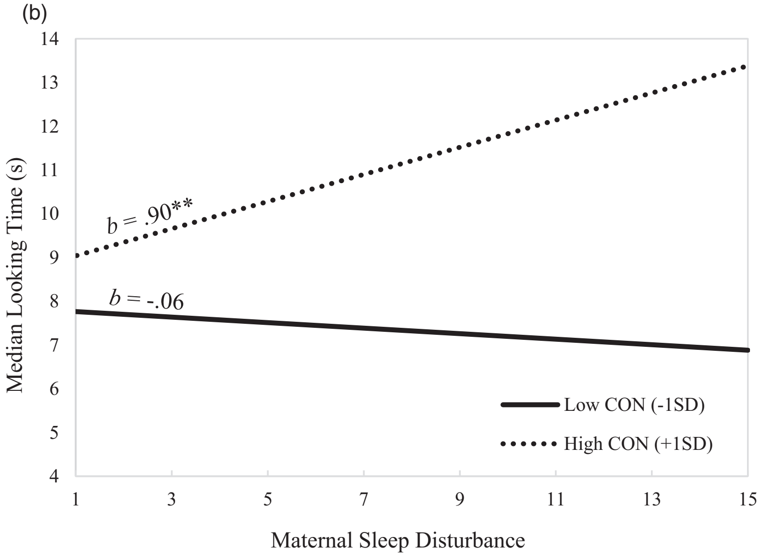


FIGURE 2 Interaction of maternal sleep disturbance and infant sleep consolidation (CON) predicting (a) infant general cognitive ability and (b) attention behavior. $^{*}p < .05$, $^{**}p < .01$, $^{***}p < .001$, $^{\dagger}p < .10$

quality should be considered not just as a direct correlate of infants' cognition, but also as a possible susceptibility or protective factor.

Concerning maternal education, we found that infant sleep regulation (an index of how independently an infant transitions between sleep and wake states) moderated the impact of maternal years of education on infant attention behavior. The positive relationship between maternal education and infant attention was only significant for infants who had average or above average levels of sleep regulation. These findings suggest that better sleep quality enables infants to take advantage of the developmental support provided by enriched environments. Although maternal education is merely a proxy for these types of enriched environmental experiences, robust evidence links maternal educational attainment with parental responsivity and learning stimulation, availability of learning materials, and time spent in play (e.g., Kalil, Ryan, & Corey, 2012; Zadeh, Farnia, & Ungerleider, 2010), which in turn are known to promote child cognitive development (e.g., Bradley & Caldwell, 1984; Mills-Koonce et al., 2015).

Our finding of an interaction between infant sleep and maternal education predicting infant attention behavior in line with findings from Bernier et al. (2014), which found that maternal sensitivity was only related to child executive functioning among children with better sleep consolidation. Whereas we found sleep regulation to be a significant moderator, rather than sleep consolidation, these differences may be due to different ages of children assessed (infants vs. toddlers) and different cognitive outcomes assessed (attention vs. executive function). Infant sleep regulation may be particularly implicated in the development of attention in the early years of life, which similarly involves an ability to exert control over one's internal states (e.g., to stay focused on a stimuli vs. shift attention away). On the whole, this set of findings are consistent with a dual-support or vantage sensitivity model, where better quality sleep, combined with more enriched environments, lead to the best outcomes for children (Pluess & Belsky, 2013).

What is it about good quality sleep that may enable children to take better advantage of environmental opportunity? One hypothesis concerns the role of sleep in consolidating short-term memories into long-term memory (Rasch & Born, 2013). Infants with better quality sleep may be better able to encode what is learned during the day (via stimulating interactions with caregivers) because of the role sleep plays in transferring and transforming memories into stable representations of daytime experiences. A second hypothesis is that poor nighttime sleep may lead to increased daytime sleepiness and/or irritability in infants, which in turn may make children less receptive to learning opportunities offered by caregivers during the course of their day. Sleep plays a role in maintaining functional connectivity between the prefrontal cortex and the limbic system (Yoo, Gujar, Hu, Jolesz, & Walker, 2007), enabling top-down control of emotionality under optimal sleep conditions. Under conditions of sleep deprivation, hyper-limbic behavior dominates (Heatherton & Wagner, 2011). Experimental work has confirmed this pattern of findings in children (Gruber, Cassoff, Frenette, Wiebe, & Carrier, 2012), although they remain to be examined in infants.

On the opposite end of the environmental spectrum, we expected that infant sleep would also interact with more negatively valanced maternal factors to predict infant cognition. Specifically, we predicted that poor quality sleep may exacerbate the negative influence of these maternal risk factors. However, in our models with maternal depression, we failed to find associations between maternal depressive symptoms and children's cognitive outcomes, regardless of child sleep quality. These findings are contrary to those reported elsewhere in the literature (e.g., Cornish et al., 2005; Liu et al., 2017), which suggest that maternal depression is a risk factor for poor cognitive development in children, although null results have also been reported (Kurstjens & Wolke, 2001; Murray, 1992). Concerning existing research on maternal depression and child cognition, there are few studies that assess cognition as early as 6 months of age. It is also relatively rare for studies to examine depressive symptoms on a continuum, rather than in a dichotomous fashion (i.e., exposed, unexposed). Therefore, additional work is needed in this area to elucidate the expected links between maternal depressive symptoms and infant functioning.

In models with maternal sleep as the focal predictor, we found that the impact of maternal sleep disturbance on infant cognition depended on infants' sleep quality. For infants with poorer sleep consolidation, increased maternal sleep disturbance predicted poorer infant general cognitive ability. These findings were in line with our hypotheses, and with diathesis-stress theory, as they suggest that when both infants and mothers are sleeping poorly, the poorest cognitive outcomes ensue. We would expect these dyads to have difficulty engaging in, or benefitting from, the types of stimulating interactions that are thought to promote cognitive development (Sadeh, Mindell, & Owens, 2011).

For infants with better sleep consolidation, maternal sleep disturbance was positively related to both general cognitive ability and attention behavior. Although these results were contrary to our hypotheses, the fact that the same pattern of findings held across both cognitive outcomes offers some credence to these findings, and suggests that it could be important to consider *why* mothers are experiencing poor sleep quality at this time. Some mothers who report higher levels of sleep disturbance (e.g., shorter sleep duration, more sleep disruptions, greater daytime dysfunction) may actually be sacrificing their own sleep in favor of promoting their infant's sleep, by spending time structuring the infant's bedtime routine or responding to a distressed infant during the night. Appropriate bedtime responsiveness and structuring, as well as nighttime interventions (e.g., intervening when infant is distressed) have been linked with infants' better sleep quality across the second half of the first year (Jian & Teti, 2016; Philbrook & Teti, 2016; Voltaire & Teti, 2018) and are also likely to be characteristic of more sensitive mothers who are attuned to their baby's needs during the day and night, although comparisons of daytime and nighttime parenting remain conspicuously absent in the literature. Therefore, when mothers report more disturbed sleep, but infants have good sleep quality, it is possible that mothers are sacrificing their own sleep to support their infant, and thus, infant cognition does not suffer; rather it flourishes.

It is important to note that maternal sleep was not correlated with infant sleep in this sample. This lack of a direct association further highlights the importance of understanding the reasons why maternal sleep is disturbed, in order to determine the relationship between maternal sleep disturbance and infant cognition. For example, maternal sleep quality might also be poor because mothers are intervening inappropriately with their infants (e.g., when infant is asleep or not distressed) or for reasons unrelated to their infants (e.g., non-traditional work hours). In these dyads, we would not expect increasing levels of maternal sleep disturbance to be an index of more sensitive parenting, nor would we expect it to predict better infant cognition. Although these results remain to be replicated, they suggest that it is important to unpack the potentially divergent reasons leading to maternal sleep disturbances, in order to understand their relationship to both infant sleep and cognition.

Strengths of this study include our use of objective measurement of infant outcomes, along with multimodal assessment of infant sleep. The use of objective measures is particularly important in the context of the current research questions, given that maternal characteristics (e.g., depression) are known to influence perceptions of infant behavior (e.g., De Los Reyes & Kazdin, 2005). In the current study, we also relied on composite scores of infant sleep consolidation and regulation, based on theoretically and empirically related variables, in order to increase the reliability of our sleep measures. Differentiating between these two sleep processes is important, as we demonstrate that they have differential associations with maternal characteristics and cognitive outcomes. For example, while infant sleep regulation moderated associations between maternal education and infant cognition, infant sleep consolidation moderated associations between maternal sleep disturbance and cognitive outcomes. Further understanding the antecedents and consequences of these two components of sleep quality are an important avenue for future research.

Despite these strengths and innovations, our study is limited by at least three factors. First, our sample was relatively small and comprised solely of African American dyads. While this is an important group to study given evidence of racial sleep disparities across the lifespan (e.g., Crosby, Lebourgeois, & Harsh, 2015), it is unclear whether our results would be generalizable to a more diverse sample. Second, we relied on maternal report of education, depression, and sleep disturbance, which were all crude indicators of maternal characteristics of interest (e.g., cognitive stimulation, sensitive responsiveness). Future research should expand upon these results using observations of daytime and nighttime caregiving behaviors, while also assessing contributions of other caregivers (e.g., fathers, grandparents, siblings) who spend considerable time with infants. Finally, although we hypothesized that the variables that comprised the consolidation (i.e., longest sleep period, nighttime sleep ratio, number of daytime naps) and regulation (i.e., parental interventions, self-soothed waking, nighttime wakefulness) composites were indicative of different components of sleep quality, it is also worth noting that the consolidation variables were derived solely from actigraphy, whereas the regulation variables were derived solely from videosomnography. Therefore, the relationships among these variables may be exaggerated due to shared-method variance.

In sum, the current study highlights the joint contributions of maternal characteristics and infant sleep to infant cognitive development in the first six months of life. Although infant sleep did not directly predict downstream outcomes, it interacted with various maternal characteristics to impact infant attention and general cognitive ability. Our observed patterns of moderation were consistent with either diathesis-stress or vantage sensitivity models, depending on the maternal factor examined. These findings suggest that infant sleep may play a more complex role in child cognitive and socio-emotional development, beyond exerting direct effects. Future research should continue to test the ways in which sleep operates as a modifier of both positive and negative environmental experiences to predict child functioning.

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CONFLICT OF INTEREST

The authors declare no conflicts of interest with regard to the funding sources for this study.

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