# EVALUATING A LATENT MEASUREMENT MODEL FOR INFANT SLEEP: FROM INTRINSIC AND EXTRINSIC PREDICTORS TO COGNITIVE OUTCOMES

Marie Camerota

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Approved by:

Martha J. Cox

Cathi B. Propper

Peter A. Ornstein

Kenneth A. Bollen

Michael T. Willoughby

ABSTRACT

Marie Camerota: Evaluating a Latent Measurement Model for Infant Sleep: From Intrinsic and Extrinsic Predictors to Cognitive Outcomes
(Under the direction of Martha J. Cox)

The development of infant sleep is thought to be jointly guided by the dual processes of sleep consolidation and regulation. However, until now, there have been few empirical studies testing whether there is evidence for these latent processes. The current study uses structural equation modeling to test whether sleep consolidation and regulation can be modeled by two distinct latent variables. Using observed indicators from multiple sleep assessment methods, we found that a two factor model representing the processes of consolidation and regulation fit better than a one factor, undifferentiated model. These two latent factors were predicted by different intrinsic (i.e., infant) and extrinsic (i.e., parenting) factors, as well as interactions between the two classes of predictors. Specifically, we replicated the interaction of infant temperament and maternal emotional availability in predicting both consolidation and regulation. We also found that infant sleep regulation longitudinally predicted infant attention regulation, although this relationship was only true for children whose mothers held a college degree or higher. These findings contribute to the literature by providing a novel measurement model that appropriately accounts for measurement error. Further, our findings suggest that considering the interaction between child characteristics and parental input in promoting high quality sleep is a key avenue for future research. Finally, by partially replicating sleep-cognition linkages previously observed in adolescents and adults, we find support for the notion of hierarchically organized self-regulatory abilities, which motivates areas for future investigation and possible intervention.

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| | |
|---|---|
| BIC | Bayesian information criteria |
| BSID-III | Bayley Scales of Infant Development (3rd Edition) |
| CES-D | Center for Epidemiological Studies Depression Scale |
| CFA | Confirmatory factor analysis |
| CFI | Comparative fit index |
| CON | Consolidation |
| EA | Emotional availability |
| EAS | Emotionality Availability Scales |
| ECG | Electrocardiogram |
| EEG | Electroencephalography |
| EFF | Efficiency |
| HPA | Hypothalamic-pituitary-adrenocortical |
| IBQ-R | Infant Behavior Questionnaire-Revised |
| ICC | Intraclass correlation coefficient |
| IUGR | Intrauterine growth restriction |
| LRT | Likelihood ratio test |
| LSP | Longest sleep period |
| MDI | Mental Development Index |
| MDS | Maternal depressive symptoms |
| ML | Maximum likelihood |
| NAPD | Nap duration |
| NAPN | Number of naps |

| | |
|---|---|
| NAPS | Neonatal and Pediatric Sleep |
| NICU | Neonatal intensive care unit |
| NEG | Negative emotionality |
| NSR | Nighttime sleep ratio |
| NW | Night wakings |
| ORC | Orienting/regulatory capacity |
| PAS | Positive emotionality/surgency |
| PFC | Prefrontal cortex |
| PINT | Parental interventions |
| RMSEA | Root mean square error of approximation |
| REG | Regulation |
| RSA | Respiratory sinus arrhythmia |
| SD | Standard deviation |
| SES | Socioeconomic status |
| SEM | Structural equation modeling |
| SPD | Sleep period duration |
| SRMR | Standardized root mean square residual |
| SSWP | Proportion of self-soothed wakings |
| TSP | Total sleep proportion |
| TST | Total sleep time |
| TWP | Total wake proportion |
| TWT | Total wake time |
| VTT | Vanishing tetrad test |

## Chapter One: Introduction: Evaluating a Latent Measurement Model for Infant Sleep: From Intrinsic and Extrinsic Predictors to Cognitive Outcomes

### Introduction

Children spend more time asleep than awake in the entire first decade of life (Iglowstein, Jenni, Molinari, & Largo, 2003). Despite this, sleep problems are among the most common clinical concerns across early childhood (Goodlin-Jones, Burnham, & Anders, 2001; Mindell, Owens, & Carskadon, 1999), and have been linked to myriad problems in cognitive, emotional, and behavioral functioning (Sadeh, 2007). Given the rapid rates of brain development in the first two years of life (e.g., Knickmeyer et al., 2008), sleep problems experienced during this period may have the most profound effects on later developmental outcomes. Further, sleep problems that emerge in infancy tend to persist, at least into the toddler and preschool years (Scher, Epstein, & Tirosh, 2004; Tikotzky & Shaashua, 2012; Zuckerman, Stevenson, & Bailey, 1987). Therefore, understanding the development of normative patterns of sleep in the first year of life is a critical first step towards identifying children who may be at risk for later sleep problems, as well as cognitive, emotional, and behavioral difficulties.

The gradual shift from immature to mature sleep patterns across the first years of life is thought to be jointly guided by two biopsychosocial processes: sleep consolidation and regulation (Goodlin-Jones, Burnham, Gaylor, & Anders, 2001). Sleep consolidation describes the shift from undifferentiated to diurnal patterning of sleep/wake states. Whereas newborns initially sleep in multiple bouts interspersed equally throughout the day and night, over time the majority of sleep will begin to take place during one extended nighttime episode. Sleep regulation, on the other hand, describes the ability of the infant to fall asleep independently at bedtime and following nighttime wakings. Caregivers initially provide extensive external support for infants' sleep/wake states, by promoting alertness during wake periods, and engaging in comforting activities that facilitate drowsiness during the transition to sleep (Sameroff, 2010). Over time, children gradually assume more of the responsibility for regulating their level of arousal, until no parental intervention is needed.

Maturation clearly plays a role in the development of sleep consolidation and regulation, as evidenced by factors such as the emergence of a circadian rhythm over the first few months of life (McGraw, Hoffmann, Harker, & Herman, 1999). However, great variability is often observed in the amount, patterning, and control of sleep across the first year of life, suggesting a role for individual differences in infant and parent characteristics in shaping the development of sleep patterns. An extensive body of literature has identified intrinsic and extrinsic factors that contribute to sleep development in infancy, with much of the work focusing on predictors of poorly consolidated and/or regulated sleep (e.g., DeLeon & Karraker, 2007). Of note, Sadeh's transactional model of infant sleep (Sadeh, Tikotzky, & Scher, 2010) highlights the direct and indirect effects of infant characteristics and parental behavior on infant sleep, through mechanisms such as parent-child interactions. However, there is no theoretical and little empirical work explicitly considering the interaction between parental input and infant characteristics in predicting infant sleep. This omission is especially surprising given the wealth of developmental research and theory suggesting that the fit between child needs and parental input is critical in predicting child outcomes (e.g. Thomas & Chess, 1977).

Understanding the factors that promote or hinder the development of consolidated, well-regulated sleep in the early years is important for several reasons. As stated previously, sleep problems that are established in infancy tend to persist into toddlerhood and the preschool period, possibly leading to accumulating amounts of suboptimal sleep time and quality across the first years of life (Scher et al., 2004; Tikotzky & Shaashua, 2012; Zuckerman et al., 1987). In addition, links between sleep and daytime functioning have consistently been found in both the adult (e.g., Pilcher & Huffcutt, 1996) and child literatures (e.g., Sadeh, 2007). Of note, the deficits associated with suboptimal sleep fall primarily within the domain of higher-order regulatory functioning, such as emotional and cognitive regulation. These findings seem to suggest that children's emerging control over their state of arousal (e.g., sleep/wake state) may be a fundamental regulatory process that also supports later-developing regulatory competencies (Calkins & Fox, 2002; Dahl, 1996). While some work has explored the link between sleep and cognitive functioning in children, studies have not yet tested these relationships in infants.

The goals of this dissertation are therefore threefold. First, we will test whether the hypothesized distinction between sleep consolidation and regulation is empirically supported in 3- and 6-month-old infants. Using a structural equation modeling (SEM) approach, we will make use of multiple manifest indicators of sleep behavior, obtained through multiple assessment methods, to explore whether sleep consolidation and regulation can be modeled by two distinct, though possibly correlated, latent variables. A corollary aim is to examine the direction and amount of change in the latent sleep constructs between 3 and 6 months. Using the measurement model that best fits the data, our second goal is to explore the direct contributions of intrinsic infant characteristics (e.g., birth weight, temperament, heart rate variability) and extrinsic caregiving factors (e.g., bedtime parenting practices, emotional availability, and maternal depressive symptoms) to infant sleep consolidation and regulation, as well as the interactive effects of select intrinsic and extrinsic factors. Finally, our third goal is to test whether infant sleep consolidation and/or regulation is associated with downstream cognitive outcomes, including general cognitive ability and attention regulation. The conceptual model underlying these three research goals is depicted in Figure 1.

Addressing these three research goals will substantially advance the literature on infant sleep. Using a latent approach for modeling sleep regulation and consolidation will bring consistency and clarity to the literature in terms of which sleep variables are manifestations of these two hypothesized processes, as well as enable us to better understand the nature of development in sleep consolidation and regulation over time (i.e., magnitude of change from 3 to 6 months). By examining both direct effects and interactions between intrinsic and extrinsic factors, we will move the discussion away from a one-size-fits-all strategy towards a consideration of the complex relationship between multiple factors that support or undermine infant sleep. Finally, we aim to extend downward the findings that show cognitive deficits among children and adults experiencing too little or poor quality sleep.

In addition to advancing the literature in these ways, a unique component of this research is the use of an exclusively African-American sample, a group that is currently underrepresented in the sleep literature. African-American adults and children are at higher risk for poor quality sleep as compared to Caucasian counterparts (Crosby, LeBourgeois, & Harsh, 2005; Stamatakis, Kaplan, & Roberts, 2007), though the origin of these disparities is unknown. Therefore, it is particularly important to understand the overall patterns of change in sleep consolidation and regulation, as well as predictors of individual differences in sleep development, among infants in this higher-risk group. This study is uniquely situated to examine these questions, using objective and observational data, as well as state-of-the-art equipment. Our high quality, minimally intrusive data collection techniques allow us to observe the unfolding of infant sleep development in the natural home environment.

### 1.1 Development of Infant Sleep

The study of infant sleep has a long history, stemming originally from the medical literature. These studies aimed to derive reference values for sleep variables of clinical interest, as well as define characteristics of problematic sleep (e.g., Acebo et al., 2005; Iglowstein et al., 2003; Mindell & Owens, 2015; Mindell et al., 1999). More recently, the psychological literature has begun to examine the development of infant sleep, focusing on characterizing individual differences in sleep, testing possible causes and consequences of these individual differences, and describing the extent to which there is stability or change in sleep across this period (e.g., Scher et al., 2004; Teti et al., 2015; Touchette et al., 2005). In addition to these differences in orientation, the existing work on infant sleep has been conducted using various methodologies. Although polysomnography is generally considered the gold standard of sleep measurement, it is rarely used in practice (notable exceptions include Hoppenbrouwers, Hodgman, Arakawa, Geidel, & Sterman, 1988; Louis, Cannard, Bastuji, & Challamel, 1997). Instead, actigraphy, videosomnography (i.e., observation), and parent-report measures are common. These different methodologies tend to converge on common findings, though we will highlight the unique information provided by each approach as it arises.

As discussed previously, the development of sleep in the early years of life is thought to be guided by the processes of sleep consolidation and regulation (Goodlin-Jones, Burnham, Gaylor, et al., 2001). Extant literature has identified and discussed variables that represent these two processes, though they do not discuss development of these two processes per se. Variables indicative of sleep consolidation reflect increasing concentration of total sleep time during the night, as well as longer continuous periods of sleep. On the other hand, variables indicative of sleep regulation reflect increasing infant control over sleep/wake states, such as more self-soothed wakings and fewer parental interventions during the night. Although observational methods are the best way to capture sleep regulation, as infant wakings can be further categorized as self-soothed or not, actigraphic and self-report measures indicative of wakefulness can also be used as more indirect measures of regulation. A full list of sleep variables that can be derived from actigraphy, videosomnography, and parent-report, as well as their hypothesized relationships to sleep consolidation and regulation, is presented in Table A1.

Sleep Consolidation

Changes in sleep consolidation are driven at least in part by the development of distinct circadian rhythms, which are immature at birth. As a result, neonatal sleep patterns are guided largely by hunger and satiety cues, rather than the presence of light and darkness. More specifically, when infants are hungry, they wake up and feed; when they are satiated, they fall back to sleep. In this way, newborns sleep an average of 16 hours a day in 5-6 intervals interspersed equally through the day and night. By 12 months, total sleep time decreases to an average of 12-13 hours a day, consolidated into one extended nighttime episode and one or more daytime naps (de Roquefeuil, Djakovic, & Montagner, 1993; El-Sheikh & Sadeh, 2015; Mindell & Owens, 2015). Although these mean trends clearly depict increased consolidation across the first year of life, there is considerable variability around these average values.

The increase in consolidation seen across infancy is primarily due to a reduction in the number and duration of daytime naps (Iglowstein et al., 2003). At the same time, periods of sustained sleep during the nighttime increase. Indeed, findings from one study found a significant increase in the nighttime sleep ratio (i.e., ratio of nighttime sleep to total [24-hour] sleep; NSR) between 0 and 12 months as reported by parents (Sadeh, Mindell, Luedtke, & Wiegand, 2009). In addition, a videosomnography study showed that infants' longest continuous sleep period (LSP) increases from about 4 hours in newborns to about 7 hours by 5 months of age, after which point it levels off (Anders & Keener, 1985). A similar study confirmed that the LSP increases across this time period, but only from about 3 hours at 1 month to 5 hours at 12 months (Burnham, Goodlin-Jones, Gaylor, & Anders, 2002). Although both of these studies used videosomnography in the home environment, it is possible that differences in coding of infant sleep/wake states may have contributed to the discrepancy in mean LSPs reported. Even with these differences, findings across studies consistently find increasing consolidation over the first year.

Sleep Regulation

Concerning changes in infant sleep regulation, research has found that wake time during nighttime sleep periods tends to decrease across the first year of life (e.g., Sadeh, Mindell, Luedtke, & Wiegand, 2009). However, findings are less consistent in regard to changes in the number of infant night wakings. While some studies have found declines in the number of night wakings from birth to 3 (Burnham et al., 2002; Hoppenbrouwers et al., 1988) or 6 months (Scher et al., 2004), others have not found systematic changes across the first year of life (Goodlin-Jones, Burnham, Gaylor, et al., 2001). Though all of the aforementioned studies used objective measurement of infant sleep (e.g., polysomnography, actigraphy, or videosomnography), their disparate findings may be explained by the use of different thresholds of continuous wakefulness in order to characterize a night waking (e.g., 2 minutes versus 5 minutes). Another possible explanation is that the degree of individual variability in waking is high and persistent across infancy, precluding the identification of a single pattern of change. In support of this heterogeneity, one study examining sleep efficiency (defined as the ratio of time spent asleep to time spent in bed) did not find large mean-level improvements between 3 and 12 months (Scher et al., 2004).

Substantial variability in the extent of self-soothed wakings further highlights the degree of individual differences in sleep regulation across infancy. Several studies have tested whether the ability to 'sleep through the night' increases across the first year, as this criterion is often described as the most important sleep milestone in infancy (Anders, Halpern, & Hua, 1992), as well as the marker of self-regulated sleep (Henderson, France, Owens, & Blampied, 2010). Sleeping through the night does not mean that an infant does not wake at all during the nighttime sleep period. Rather, an infant who can 'sleep through the night' is able to soothe himself back to sleep following a night waking. Because the infant does not signal for intervention, caregivers of self-soothing infants may not be aware of these wakings, and thus perceive that the infant has slept continuously through the typical nighttime sleep period (e.g., from 10:00PM – 6:00 AM; see Henderson et al., 2010 for a discussion of three different criteria). Although rates of self-soothing have been found to increase linearly across the first year of life (Burnham et al., 2002), only about half of infants consistently self-soothe by 8 (Anders et al., 1992) or 12 months (Goodlin-Jones, Burnham, Gaylor, et al., 2001). Another study found that between 15-30% of infants are not sleeping through the night by 12 months, depending on the criterion used (Henderson et al., 2010). Therefore, it is clear that there is a subgroup of children who do not achieve self-regulated sleep by the end of the first year.

Taken together, these studies document dramatic increases in sleep consolidation and regulation during infancy, as well as a high degree of variability in these processes. However, all of these previous studies have focused on predicting indicators of consolidation and regulation, rather than the hypothesized underlying constructs. Only one study of which we are aware used a factor analytic technique to explain how individual sleep parameters may map onto a smaller number of latent constructs. From 46 nights of objective and subjective sleep data in adults, Johns (1975) classified four sleep factors, two of which loosely map onto the processes described here. The first factor is described as sleep fragmentation, which may represent the converse of consolidation. Another factor, described as delay before falling asleep, could possibly indicate poor sleep regulation. Thus, there is some precedent in an adult literature for examining sleep consolidation and regulation as possible latent factors underlying a larger number of sleep variables assessed objectively and subjectively. Drawing upon multiple sleep variables and multiple assessment methods has the potential to increase our precision of measurement and our understanding of the development of sleep over time.

**1.2 Intrinsic and Extrinsic Influences on Infant Sleep**

Clearly, there are individual differences in sleep consolidation and regulation that emerge during infancy. Understanding possible contributors to these individual differences is important, as multiple studies have documented stability in sleep problems and parameters from infancy into toddlerhood and the preschool period (Scher et al., 2004; Tikotzky & Shaashua, 2012; Zuckerman et al., 1987). A large body of literature has identified child and parent characteristics that afford higher risk for sleep problems (DeLeon & Karraker, 2007; Mindell et al., 1999; Sadeh et al., 2010; Zuckerman et al., 1987), with one consistent finding being that both intrinsic and extrinsic factors contribute substantially to individual differences in infant sleep. Intrinsic factors refer to characteristics of infants which are thought to have a biological basis, though are not necessarily assumed to be innate. These characteristics include, but are not limited to, birth weight, temperament, and heart rate variability (i.e., respiratory sinus arrhythmia). On the other hand, extrinsic factors refer to contextual influences that shape infant sleep development. Due to infants' complete reliance on caregivers, these contextual influences are typically experienced via caregiver interactions, and include maternal bedtime behaviors, emotional availability at bedtime, and depressive symptoms. We explain the research on each of these intrinsic and extrinsic factors in turn.

Intrinsic Factors

Consistent with Barker's hypothesis (1995), the quality of the prenatal environment can have lifelong implications for health and development. Research has consistently shown that infant birth weight is both a useful indicator of fetal conditions (Bollen, Noble, & Adair, 2013; Camerota & Bollen, 2016), as well as a predictor of individual differences in sleep. For example, one study found that adults born with a very low birth weight are 2.2 times more likely to experience sleep-disordered breathing, compared to adults born at a normal birth weight (Paavonen et al., 2007). In children, intrauterine growth restriction (IUGR), one cause of low birth weight, has been shown to predict shorter durations of nighttime sleep in 4- to 7-year-olds (Yiallourou, Wallace, Miller, & Horne, 2016). In slightly older children, lower birth weights were associated with lower sleep efficiency (Pesonen et al., 2009). Specifically, every standard deviation decrease in birth weight was associated with a 1.7 fold increase in risk for low sleep efficiency ($\leq 10^{th}$ percentile). Thus, there seems to be some association between birth weight and measures of sleep consolidation and regulation, though this relationship has not yet been examined in an infant sample.

A larger number of studies have investigated infant temperament as a predictor of individual differences in sleep, focusing primarily on difficult temperament as a risk factor for sleep problems. Most of these studies have utilized parent-report measures of temperament, which may be problematic because parents' interactions with their infants at bedtime and throughout the night may bias their ratings of temperamental difficulty (Schwichtenberg & Goodlin-Jones, 2010). In support of this limitation, one study found that the relationship between temperament and sleep differed based on whether the mother's or father's temperament ratings were used (Keener, Zeanah, & Anders, 1988). Only one study of which we are aware has utilized objective measurement of both temperament and infant sleep (Halpern, Anders, Coll, & Hua, 1994). In this study, researchers found that infants who spent more time awake at night and who had lower LSPs at 3 months of age were observed to be less sociable and more difficult to soothe. However, these relationships were observed concurrently, precluding any inferences about the direction of effects. It is certainly possible that infants who are experiencing poor quality sleep may concurrently express more irritability. Thus, while preliminary objective evidence suggests that certain temperamental characteristics are related to infant sleep, it is unknown whether these same relationships would be observed longitudinally.

Finally, individual differences in infants' physiological reactivity may contribute to sleep development. One physiological process that may be particularly important to examine, due to existing associations with emotional and behavioral regulation (e.g., Fox, 1989), is the parasympathetic branch of the autonomic nervous system. Parasympathetic control of the heart, measured as the amplitude of respiratory sinus arrhythmia (RSA) or the variability in heart rate associated with respiration, is an index of individual reactivity and may underlie the capacity for self-regulation (Fox, 1989). At rest, an individual's baseline RSA is thought to reflect the capacity to adaptively change states in response to environmental demands, with higher baseline RSA indicating more appropriate modulation of reactivity and arousal (Porges, 1996). Many studies have shown that higher baseline RSA is related to better developmental outcomes, including greater sustained attention (Richards & Cronise, 2000) and more appropriate expression of negative affect (Fox, 1989; Huffman et al., 1998). However, few studies have examined the relationship between RSA and sleep. In one study with preschoolers, higher baseline RSA concurrently predicted lower actigraphic sleep activity and higher sleep efficiency (Elmore-Staton, El-Sheikh, Vaughn, & Arsiwalla, 2012). However, a second study did not find a main effect of baseline RSA in infancy on parent-reported sleep problems at 18 months (Gueron-Sela et al., 2017). While differences in the ages of assessment in these two studies may explain their disparate findings, neither study explicitly addresses the relationship between baseline RSA and sleep in infancy. Therefore, the relationship between individual differences in physiological reactivity and infant sleep remains to be tested.

<u>Extrinsic Factors</u>

In addition to intrinsic characteristics that may predispose an infant to better or worse sleep, the role of extrinsic, or environmental, influences cannot be overstated. A large body of work on the role of environmental influences in shaping infant sleep has concluded that parents are the single largest contributor to the development of sleep patterns in the first five years of life (Sadeh et al., 2010). For parents of infants, a fundamental caregiving role is to serve as an external source of regulation, whether in response to hunger/satiety, emotional, or sleep/wake cues. Concerning sleep, parents initially provide external regulation to promote appropriate modulation of sleep/wake state, by supporting alertness and attention during wake periods, and engaging in soothing, quiet activities to facilitate drowsiness during the transition to sleep (Sameroff, 2010). Successful experiences of state regulation provided by caregivers early in development later become internalized in terms of the infants' own regulatory competency in this domain. Specific aspects of parenting that have been examined in relation to infant sleep include parents' bedtime practices, emotional availability, and depressive symptoms. While parenting practices describe *what* parents do at bedtime, emotional availability and depressive symptoms describe *how* and *why* parents do what they do (Teti et al., 2015). As these three components of parenting provide unique, complementary information about the social ecology of infant sleep, we will consider them each in turn.

Much of the research on parenting and sleep has focused on the relationship between specific parenting practices at bedtime and infants' sleep consolidation and regulation. Cross-sectional work yielded initial evidence that merely having parents present in the room at infant bedtime was related to greater number of infant night wakings (Adair, Bauchner, Philipp, Levenson, & Zuckerman, 1991). Concerning more specific parenting behaviors, infants who were put into their cribs already asleep, or who received more active parental interventions (e.g., feeding, rocking) also tended to spend more time awake during the night, and had shorter continuous sleep periods (DeLeon & Karraker, 2007; Goodlin-Jones, Burnham, Gaylor, et al., 2001; Mindell, Sadeh, Kohyama, & How, 2010; Sadeh et al., 2009; Touchette et al., 2005). These preliminary findings suggest that too much parental involvement at bedtime can interfere with sleep consolidation and regulation, although the majority of these studies are based on parental report of nighttime behaviors, which are subject to bias or inaccurate recall. In addition, the direction of effects cannot be established within cross-sectional studies such as these. It is possible that infants who have sleep difficulties elicit more active parental involvement at bedtime (Adair et al., 1991; Sadeh, Gruber, & Raviv, 2003).

Longitudinal work has fortunately begun to shed light on the direction of effects between parental bedtime behaviors and infant sleep, although much work has, again, relied on parents' reports of their nighttime activities and infant sleep. For example, Morrell and Steele (2003) found that active physical comforting at bedtime (e.g., cuddling, feeding) predicted continuity in infant sleep problems from age 1 to age 2. Studies using observational measurement of infant sleep have tended to support this pattern of findings. One study using parent-report of bedtime and nighttime practices and videosomnography determination of infant state and self-soothing found that higher parental latency to intervention at 3 months predicted more self-soothed wakings at 12 months (Burnham et al., 2002). This study also found that infants who were removed from their crib fewer times over the first year of life were more likely to self-soothe following night wakings at 12 months. Similarly, children whose parent-reported sleep problems persisted or arose between age 1 and age 2 had parents who continued or increased their use of active physical comforting over this time period (Morrell & Cortina-Borja, 2002). These findings suggest a possible causal relationship between bedtime practices and infant sleep consolidation and regulation, where continued use of active settling strategies predicts poorer quality sleep. However, these studies also demonstrate the importance of considering timing of effects: whereas active parental strategies may be necessary to help infants settle to sleep earlier in the first year of life, over time, caregivers may need to shift to more passive strategies that give the child a chance to harness his/her own regulatory abilities. As very few studies have examined parenting in the first 6 months of life, the timing of this shift is currently unknown, though it certainly may depend on intrinsic characteristics of infants.

The study of parents' emotional availability (EA) at bedtime further explores the role of contingency and appropriateness in parents' responses to infant sleep cues (Philbrook & Teti, 2016; Teti, Kim, Mayer, & Countermine, 2010). This body of work is built off previous theory that suggests it is not *what* parents do, but *how* they do it, that influences infant outcomes (Darling & Steinberg, 1993). Further, sleep theory posits that the emotional quality of parent-child interactions at bedtime is particularly important in supporting the infant's feeling of safety in his or her sleep environment, allowing the infant to relinquish vigilance and surrender to sleep (Dahl, 1996; Teti et al., 2015). Empirical work testing these hypotheses have coded parents' EA from videotaped parent-child interactions at bedtime (Philbrook & Teti, 2016; Teti et al., 2010). Parents rated as high on EA accurately interpret and respond to infant cues, while engaging in structured and soothing activities that successfully guide the child towards sleep. Parents rated as low on EA may ignore infant cues, engage in arousing activities, or otherwise prolong wakefulness at bedtime. Therefore, this coding scheme takes into account what parents do, in relation to what infants signal for and benefit from.

Only two studies have examined the relationship between parental EA at bedtime and infant sleep. One cross-sectional study found that parenting practices, including holding, nursing, and quiet activities (e.g., singing, rocking), were unrelated to infant sleep when EA was accounted for (Teti et al., 2010). However, EA was negatively related to infant night wakings, and these links were stronger for younger infants (one standard deviation below mean infant age; range = 1 to 24 months). A follow-up study using objective, longitudinal measurement of EA and infant sleep confirmed the aforementioned results. Within-person effects indicated that at time points when mothers were more emotionally available, infants exhibited less nighttime distress and longer sleep durations (Philbrook & Teti, 2016). Further, the effects of parents' bedtime practices interacted with EA to predict infant sleep, suggesting that it is important to consider the appropriateness and emotional context of specific parenting practices.

Finally, research on the relationship between maternal psychopathology and infant sleep suggest that mothers experiencing elevated depressive symptoms are less able to support consolidated and regulated sleep (e.g., Karraker & Young, 2007). Given potential reporting biases among mothers experiencing psychiatric symptomology (e.g., De Los Reyes & Kazdin, 2005), the strongest evidence for this link has come from longitudinal studies with objective measurement of children's sleep. For example, from qualitative coding of naturalistic nighttime videos, Teti and colleagues (2012) observed that mothers reporting higher depressive symptoms had infants who experienced more night waking. They further hypothesized that the relationship between maternal depressive symptoms and child sleep difficulties operates via parents' altered sleep-related behaviors. In support of this hypothesis, researchers observed that depressed mothers tended to be hyper-responsive to their infants throughout the night, intervening when no intervention was necessary (i.e., when child was non-distressed or asleep). Mothers with higher levels of depressive symptoms also tended to use bedtime behaviors that prolonged wakefulness in their infants (Teti & Crosby, 2012). Thus, in these dyads, bedtime and nighttime interactions may be parent-driven, rather than infant-driven, serving to fulfil mothers' own emotional needs rather than promoting infant regulation of their sleep/wake states.

The studies described above explain the importance of considering not just *what* parents do with their infants at bedtime, but also *how* and *why* they do it. The same parenting behaviors (e.g., rocking an infant to sleep) may be experienced differently by infants based on a number of factors, including the sensitivity of the parent to the infants' regulatory needs. Therefore, a balanced consideration of parental input and infant need is warranted.

### Interaction of Intrinsic and Extrinsic Factors

Considerable developmental theory suggests that it is the interaction between infant characteristics and parental input that best predicts development. Thomas and Chess (1977) first proposed the concept of 'goodness of fit' which suggests that for optimal development to occur, there must be a match between children's characteristics and parental input. Although their theory focused solely on child temperament as an individual characteristic, other child variables indicative of reactivity or regulation could also be considered. Specifically related to sleep, we might consider whether children who are predisposed to sleep difficulties, due to either adverse prenatal conditions, highly reactive temperaments, or maladaptive physiological reactivity, are more dependent on appropriate parental input to guide their development of sleep consolidation and regulation.

Only two studies thus far have tested the interaction of intrinsic and extrinsic characteristics in predicting infant sleep. Possibly motivated by the mixed findings regarding the relationship between infant temperament and sleep, one study examined whether infant temperamental characteristics interacted with nighttime parenting to predict sleep development across the first six months of life (Jian & Teti, 2016). Using maternal report of infant temperament combined with objective measurement of infant sleep, this study found that mothers' observed EA at bedtime was related to increases in nighttime sleep duration from 1 to 6 months, but only for infants who were rated as highly surgent (e.g., emotionally positive, physically active, easily excited). For infants who were rated as low on surgency, maternal EA did not predict changes in nighttime sleep duration across this period. These findings suggest that infants who are intrinsically more active and excitable may require more parental responsiveness, structuring, and warmth at bedtime in order to settle and stay asleep throughout the night.

A second study examined the interaction between infants' intrinsic physiological reactivity (as indexed by RSA) and maternal depressive symptoms (MDS) in predicting later sleep problems (Gueron-Sela et al., 2017). Baseline RSA and maternal report of depressive symptoms were both measured at 3 and 6 months, while sleep problems were reported by mothers at 18 months.  This study found that the relationship between MDS and infant sleep problems were exacerbated for infants with high baseline RSA (Gueron-Sela et al., 2017). For infants with low baseline RSA, elevated MDS did not predict higher rates of sleep problems. These two studies suggest that infant characteristics indicative of high propensity for reactivity (i.e., surgent temperament, high baseline RSA) interact with both positive (EA) and negative (MDS) dimensions of parenting to predict infant sleep. Although more studies are needed to unpack the specific interactions among intrinsic and extrinsic characteristics that promote optimal sleep development, these preliminary studies suggest that examining infants' regulatory needs in combination with parental input is a fruitful area of inquiry.

### 1.3 Sleep and Cognition

Thus far, we have described normative developmental changes in sleep consolidation and regulation, including consideration of the intrinsic and extrinsic factors that independently and interactively predict individual differences in these two processes. One final question, which has importance for researchers, clinicians, and parents, regards the developmental sequelae associated with individual differences in infant sleep. Self-regulation theory suggests that infants' ability to modulate arousal through control over sleep/wake states constitutes a fundamental form of physiological regulation that has downstream implications for more sophisticated forms of regulation, including emotional and cognitive regulation (Calkins & Fox, 2002). However, very little empirical research has tested the plausibility of this theory using samples of infants.

Research with clinical and non-clinical populations of adults have 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). Two experimental studies with school-age children confirm that sleep restriction selectively impairs performance on higher-order cognitive tasks, such as the Wisconsin Card Sort Task (Randazzo, Muehlbach, Schweitzer, & Walsh, 1998) and the Continuous Performance Task (Sadeh et al., 2003). Similarly, findings from neuroimaging studies suggest that sleep plays a particularly important role in resting and resetting functional connections between the prefrontal cortex (PFC) and various subcortical regions, allowing for optimal next-day integrity of prefrontal-subcortical systems (Kaufmann et al., 2016; Yoo, Gujar, Hu, Jolesz, & Walker, 2007). If this recalibration does not occur, either due to restricted or disrupted sleep, subcortical regions of the brain may come to dominate daytime behavior, which would be manifested in failures of cognitive regulation (Heatherton & Wagner, 2011).

The role of infant sleep in promoting cognitive development is less well-understood. Several studies have examined the long-term cognitive sequelae associated with poorly consolidated and regulated sleep in infancy. One set of findings suggest that higher nighttime sleep ratios (i.e., ratio of nighttime sleep to total [24-hour] sleep) at 12 and 18 months predict better executive function at age 2 (Bernier, Carlson, Bordeleau, & Carrier, 2010) and age 4 (Bernier, Beauchamp, Bouvette-Turcot, Carlson, & Carrier, 2013). Another longitudinal study found that higher sleep percent (an actigraphic measure similar to sleep efficiency) and fewer night wakings at age 1 predicted better executive attention when children were 3-4 years of age (Sadeh et al., 2015). Interestingly, concomitant measures of sleep did not predict executive attention, suggesting that infant sleep may be particularly important in shaping the development of higher-order cognition.

Examining the relationship among sleep and cognitive outcomes in infancy is a harder task, due to the few cognitive measures available for use in this age group. Several studies have examined the relationship between sleep and performance on the Bayley Scales of Infant Development, a standardized assessment that captures infant functioning across multiple cognitive domains (e.g., sensorimotor development, exploration and manipulation, memory). Unfortunately, these studies have yielded mixed findings. One study on a small sample of low-risk infants found that higher sleep efficiency and fewer night wakings at 10 months predicted better cognitive development, as measured concurrently by Bayley Mental Development Index (MDI) scores (Scher, 2005). Other studies of low-risk infants have found opposite directions of effects, with higher neonatal LSPs being linked to lower MDI scores at 6 months (Freudigman & Thoman, 1993). However, differences in the timing and methodology of sleep assessment may contribute to these disparate findings (Ednick et al., 2009). Specifically, more mature, consolidated sleep in the early neonatal period may actually indicate a greater stress response to the birth process (Freudigman & Thoman, 1993), rather than advanced sleep development per se. Therefore, measuring sleep later in the first year of life may provide a more accurate window into infant sleep development, and may subsequently yield the expected positive relationship between sleep and cognition.

Moving beyond general cognitive ability, one study specifically examined the relationship between neonatal sleep and attention regulation at 4 months (Geva, Yaron, & Kuint, 2016). Although the sample was made up exclusively of premature infants who were monitored in the NICU, relationships between sleep and attention were found independently of degree of prematurity. Specifically, 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). These findings are interpreted as evidence of impaired attention regulation in the poor sleeper 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).

Thus, there is some reason to believe that both general cognitive ability and higher-order cognitive processes (i.e., attention regulation) are related to individual differences in infant sleep consolidation and regulation. These findings are further supported by research in older children and adults that suggest that sleep is particularly important for higher-order cognitive abilities, such as executive function (e.g., Turnbull, Reid, & Morton, 2013), and that these effects may have neural underpinnings (e.g., Yoo et al., 2007). However, given that there are very few studies on this topic in normally-developing infants, and almost none that approach this question from a developmental perspective, it is necessary to further test whether individual differences in infant sleep development predict infant cognitive functioning.

### 1.4 Current Study

The overarching goal of the current dissertation is to better understand the development of infant sleep across the first six months of life, including identifying the precursors and correlates of individual differences in sleep consolidation and regulation. Specifically, our questions and hypotheses are as follows:

*Q1a: Does a two factor model of infant sleep regulation and consolidation provide a better fit for objective and self-report infant sleep data (i.e., actigraphy, videosomnography, sleep diaries) at 3 and 6 months than an undifferentiated, one factor model?*

H1a: We hypothesize that two empirically distinct latent factors representing the dual processes of sleep consolidation and regulation will fit the data better than a one factor model.

*Q1b: What is the direction and magnitude of change in our latent sleep construct(s) from 3 to 6 months?*

H1b: We expect to find significant, positive increases in our latent construct(s) from 3 to 6 months of age.

*Q2a: Are there direct effects of intrinsic (birth weight, temperament, RSA) and extrinsic (parenting practices, emotional availability, depressive symptoms) predictors at 3 months on sleep consolidation and regulation at 6 months?*

H2a: We expect that lower infant birth weight, higher temperamental reactivity, and lower baseline RSA will predict poorer sleep consolidation and regulation. Additionally, we predict that extrinsic influences such as more active maternal involvement at bedtime, less emotional availability, and higher maternal depressive symptoms will be negatively related to sleep consolidation and regulation.

*Q2b: Do these intrinsic and extrinsic factors interact to predict sleep consolidation and regulation? Specifically, can we replicate extant findings on the interaction between temperament and EA in prediction of sleep and extend this finding by looking at the same interaction with a physiological marker of reactivity (i.e., RSA)?*

H2b: We expect to replicate previous interactions between temperament and EA such that the positive relationship between EA and infant sleep will be stronger for infants who are rated higher on temperamental reactivity. We expect to find similar results for the interaction between

RSA and EA such that the positive relationship between EA and infant sleep will be stronger for infants who have higher baseline RSA.

*Q3: Do sleep consolidation and regulation at 3 months predict infant general cognition (as measured by the Bayley Cognitive Scale) and infant attention regulation at 6 months?*

H3: We predict that infants with more consolidated and regulated sleep at 3 months will demonstrate more attention regulation (e.g., shorter gaze length) and score higher on the Bayley Cognitive Scale at 6 months. Following previous research, we expect the magnitude of these relationships to be greater for attention regulation.

# Chapter Two: Methods

## 2.1 Sample

Data come from the Neonatal and Pediatric Sleep Study (NAPS), a longitudinal study of 95 African-American parent-infant dyads. Using publically available birth record data, we identified families who lived within a 50-mile radius of a large public university in North Carolina and who had recently given birth to an infant. 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) and thus their visit dates were delayed until they reached the appropriate adjusted age. 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.

## 2.2 Procedure

Infants and caregivers were visited in their home for one data collection visit when infants were 3 and 6 months of age. During this home visit, dyads participated in parent-child interaction tasks, caregivers completed questionnaires, and infants wore a wireless heart rate monitor. 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. When infants were 9 months of age, caregivers completed additional questionnaires, either electronically or via printed mailing, but were not visited in person.

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. At the beginning of the home visit, a lightweight actogram (Actiwatch-2) was placed on the infant's left ankle. Parents were instructed to keep the device on the infant for the entire sleep assessment week, except during baths lasting longer than 20 minutes. Following the completion of home visit activities, research assistants set up four infrared, high-definition, color Hikvision (DS-2CD2432F-IW) cameras with internal microphones. Research assistants probed caregivers about the infant's sleep location, as well as any other areas of the home where the infant and caregiver might spend time together before bedtime or during the night. These locations guided the choice of camera placement. In addition, at least one camera was set up directly above the infant's intended sleep location. Cameras were connected to an Exacq (IPS04-1000-LC) video surveillance recorder via Power over Ethernet (PoE) ports of a NETGEAR ProSafe Plus (GS108PE) switch. Ethernet cables were secured to the floor and furniture for safety. Caregivers were instructed to turn on the video equipment at 6:30pm. Research assistants returned to the home the following morning to terminate the video recording and collect the video equipment. Data were downloaded off the video recorder using ExacqVision Client software (version 8.4) and stored on external hard drives for later video coding.

Every day during the sleep assessment week, research assistants called mothers to obtain information about the previous day's naps and nighttime sleep, including number, location, and duration of naps, infant bed time, number of night wakings, types of interventions used during night wakings, and infant rise time (e.g., Hall, Liva, Moynihan, & Saunders, 2015). Mothers were also asked to report any unusual occurrences that may have influenced the previous night's sleep, such as child illness. At the end of the sleep assessment week, research assistants returned to the home to collect the actogram. Infants were provided with a small toy at the end of each home visit, and mothers received compensation of up to $130 in the form of a gift card. All procedures were approved by an institutional review board, and participants gave written consent prior to data collection.

**2.3 Measures of Infant Sleep**

Infant sleep was measured using three different methods: actigraphy, videosomnography, and sleep diaries. Specific details on data editing and coding associated with each of these methods is described below. We also discuss the various sleep outcome variables derived from each method. A summary of these sleep variables, including their hypothesized relationship to regulation and consolidation, is presented in Appendix A (Table A1).

<u>Actigraphy</u>

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 minutes; minimum rest interval size was set to 20 minutes; 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 (.888 x average activity count) at 3 months and to the Low setting (20 activity counts) at 6 months.

Even with the appropriate algorithm settings, the Actiware program can miss intervals of sleep or wake, necessitating the manual entry of additional intervals. In order to determine our guidelines for manually inserting intervals, we compared actigraphy data at 3 and 6 months to behavioral coding of infant state from overnight observation. Three cases were compared at each time point, and the following rules for inserting missed wake and sleep intervals were determined. Sleep intervals were manually added when periods greater than 20 minutes showed low or no activity for the infant. Wake intervals were added when periods greater than 5 minutes in length showed typical waking activity levels for the infant. Excluded intervals were added when no activity was recorded for extended (> 6 hr) periods of time, indicating that the infant was not wearing the actogram. Rules for manually adding intervals were jointly determined by two research assistants in consultation with the principal investigator. Subsequently, one research assistant edited all 3 month actigraphy data, and the other edited all 6 month actigraphy data.

For each night (7PM-7AM) of data collected, the following variables were determined: total sleep time (TST), total wake time (TWT), sleep efficiency (EFF), number of long (> 5 minute) wakings (NW), and longest continuous sleep period (LSP). For each day (7AM-7PM) of data collected, the following variables were determined: number of sleep periods (NAPN; number of daytime naps) and total duration of sleep periods (NAPD; duration of daytime naps). These variables were averaged together across the entire study week. The nighttime sleep ratio (NSR; ratio of nighttime sleep to total [24-hour] sleep) was also calculated across the entire study week. Families with complete data had 7 nights and 6 days of data. However, cases were included as long as 3 nights of useable data were collected. A majority of families at 3 (66%) and 6 months (73%) had complete data.

Videosomnography

Behavioral sleep data were coded from videosomnography by trained research assistants. Because of the intensive nature of our observational coding, overnight videos were coded for a 4-hour 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 second interval coding. That is, for every 30 second 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 second 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 > .80).

From these observational codes, several variables were constructed. Total sleep proportion (TSP) was calculated as the number of intervals where the infant was coded as asleep divided by the length of the observation period. Total wake proportion (TWP) was calculated as the number of intervals where the infant was coded as awake divided by the length of the observation period.[1] The longest continuous sleep period (LSP) was defined as the longest period where the infant was coded as being continuously asleep. The number of night wakings (NW) captured the frequency of wake episodes. In order to be considered a true wake episode (as opposed to a transient period of movement), the infant needed to exhibit two consecutive intervals (i.e., 1 minute) of non-distressed wakefulness, or one interval (i.e., 30 seconds) of distressed wakefulness. Proportion of self-soothed wakings (SSWP) was determined by the number of night wakings that did not receive a parental intervention divided by the total number of night wakings. Finally, we summed the number of parental interventions (PINT).

Sleep Diaries

Parents' retrospectively reported on their infants' sleep using daily sleep diaries. These diaries asked parents to recall the number (NAPN) and duration (NAPD) of daytime naps, as well as the number of perceived night wakings (NW). Parents also reported on their infants' sleep onset time and morning wake time. From these variables, we calculate the duration of the nighttime sleep period (SPD). All variables were averaged across the 7 nights of data collection.

**2.4 Measures of Intrinsic Factors**

Three intrinsic (e.g., child-level) factors were investigated in terms of their relation to infant sleep.

Birth Weight

Mothers reported infant birth weight in pounds and ounces on the 9 month questionnaire. Birth weight was converted to grams for all analyses.

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[1] Proportion scores were used here because the length of the observation period could vary (e.g., parent turns off cameras, parent takes infant off camera).

Temperament

Infant temperament was measured at 3 months using the very short form of the Revised Infant Behavior Questionnaire (IBQ-R; Gartstein & Rothbart, 2003), a well-established parent report measure of temperament that is appropriate for 3 to 12 month old infants. The very short form (Putnam, Helbig, Gartstein, Rothbart, & Leerkes, 2014) consists of 37 items assessing three broad scales: Positive Emotionality/Surgency (PAS; 13 items), Negative Emotionality (NEG; 12 items), and Orienting/Regulatory Capacity (ORC; 12 items). The PAS scale ($\alpha = .74$)[2] included items from the Approach, Smiling and Laughter, High Intensity Pleasure, Vocal Reactivity, Activity Level, and Perceptual Sensitivity subscales. The NEG scale ($\alpha = .72$) included items from the Sadness, Distress to Limitations, and Fear subscales. The ORC scale ($\alpha = .76$) included items from the Low Intensity Pleasure, Cuddliness, Duration of Orienting, and Soothability subscales. Consistent with previous sleep studies (e.g., Jian & Teti, 2016), we averaged items from each of the three scales to use as predictors.

Respiratory Sinus Arrhythmia

Infant baseline respiratory sinus arrhythmia (RSA) was assessed at 3 months. At the beginning of the 3 month home visit, experimenters placed two disposable pediatric electrodes on the infant's chest. The electrodes were connected to an Actiwave Cardio device (CamNtech; Boerne, TX), a wireless, single channel ECG recorder that captures heart interbeat intervals (IBI). Infant IBI was recorded for a 4 minute interval during a time when the infant was not being held and was not receiving stimulation from caregivers or experimenters. If the infant

[2] We report Cronbach's alpha as an index of internal consistency for all questionnaire measures because it is standard convention in the field. However, we acknowledge that this index has several serious limitations, including its inability to detect the internal structure of a subscale or questionnaire (Sijtsma, 2009).

became distressed at any point during the baseline recording, the assessment would be repeated once the infant had settled. This method ensured that RSA data accurately reflected infant physiological functioning during a neutral and calm state. Following the home visit, data were downloaded to a PC computer. Cardiac data were edited for artifact using the Porges (1985) method and CardioEdit (2007) software. Artifacts are common in infant cardiac data due to infant movement. RSA was calculated in 30 second epochs across the baseline period and subsequently averaged together to yield a single baseline RSA measure.

**2.5 Measures of Extrinsic Factors**

Three extrinsic (i.e., parent-level) factors were investigated in relation to infant sleep.

Bedtime Parenting Practices

Bedtime parenting practices were coded from the overnight filming during the hour leading up to the infant falling asleep for the night. We utilized an interval sampling (30s) coding system to indicate the presence or absence of certain bedtime parenting practices. Of interest in the current study are maternal presence, close contact, quiet activities, and infant state at final put down. Maternal presence was determined by the total number of intervals in which the mother and infant were in the same room. Close contact captured intervals in which the mother was holding the infant close to her body (e.g., cuddling, feeding). Quiet activities captured instances in which the mother and infant were engaged in quiet, soothing activities (e.g., book reading, rocking, or talking). Infant state (i.e., asleep or awake) was coded at the time the infant was put down in his or her final sleep location. Being put down awake meant that the infant was awake prior to being laid down in the final sleep location. Being put down asleep meant that the infant was asleep when put down in the final sleep location, or fell asleep in the parents' arms. Because the infant was sometimes taken to a location off camera, the number of codeable intervals varied by dyad. Therefore, maternal presence, close contact, and quiet activities were converted into proportion scores. Infant state at final put down was dichotomized as whether or not the infant was put down while already asleep (henceforth referred to as put down asleep). Three research assistants, including a master coder, were responsible for coding bedtime practices at 3 months. Research assistants trained until they were reliable with the master coder on all codes (kappa > .80). Approximately 10% of tapes (n = 8) were double coded as continuing reliability checks.

<u>Emotional Availability</u>

Maternal emotional availability (EA) was separately coded from the overnight filming during the infant's hour-long bedtime interval. The original Emotional Availability Scale (EAS; Biringen, Robinson, & Emde, 1998) has previously been adapted for the nighttime context (Teti et al., 2010). Four scales were used: sensitivity, structuring, non-intrusiveness, and non-hostility. Mothers were rated as high on sensitivity when they were affectively in tune with their infants, were clearly aware of infant cues, and responded to infant cues contingently and appropriately. Mothers rated as high on structuring used quiet and soothing bedtime routines that effectively guided the child towards sleep. Non-intrusiveness was reflected by mothers who refrained from initiating new interactions with a sleepy infant and who did not engage in loud, intrusive talk with the infant or other family members. An additional factor related to non-intrusiveness was refraining from rough, physical manipulation of the infant's body. Finally, mothers rated high on non-hostility showed no instances of overt or covert irritability with the infant during bedtime, and did not create an environment of hostility (e.g., yelling at other family members in the infant's presence). One research assistant trained to achieve reliability with a master coder (ICC > 80% on all scales) and subsequently coded all videos from the current study. Following previous studies (e.g., Philbrook et al., 2014; Teti et al., 2010), a composite EA score was created by converting the four subscales to z-scores and averaging them together.

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 ($\alpha = .89$). The CES-D has been widely used in community samples, including samples of African-American women (e.g., Brody, Murry, Kim, & Brown, 2002). The rate of clinically elevated depression (CES-D > 23) was relatively low in our sample (12.5%).

**2.6 Cognitive Measures**

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 two 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 Regulation

Infant attention regulation was measured at 6 months during a puppet task. Infants sat on their mothers' laps 60cm from the edge of the testing table [66cm (L) x 45.7cm (W) x 71.1cm

(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. One video camera was placed directly behind and above the experimenter's head, focused on a close-up view of the puppet and the infant's face. A research assistant coded each infant's look duration using ExacqVision software (Fishers, IN). Individual trials were excluded in the case of experimenter error (e.g., ending the trial before infant looked away for 3 seconds, failing to end the trial when the infant looked away for 3 seconds). Consistent with previous studies, the median look duration across the four looks was used as a measure of infant attention regulation (Cuevas & Bell, 2014).

### 2.7 Demographic Covariates

Demographic information was reported by mothers via questionnaires administered at the 3 month home visit. Infant gender, prematurity (gestational age < 37 weeks), and age at visit (adjusted for prematurity as necessary), as well as maternal years of education were retained as demographic covariates.

### 2.8 Missing Data

Of the 95 families who participated in the NAPS study, 94 had infant sleep data at either 3 or 6 months and were therefore included in the current analyses. Of these, 80 (85%) had actigraphy data, 82 (87%) had videosomnography data, and 90 (96%) had sleep diary data at 3 months. One additional case was excluded from 3 month videosomnography data because the infant was off-camera for the majority of the observation period. It was not possible to calculate sleep period duration from the sleep diaries of three infants because mothers failed to report either the infant's bedtime or rise time. At 6 months, 74 infants (79%) had actigraphy data, 65 infants (69%) had videosomnography data, and 84 infants (89%) had sleep diary data. Ten infants did not wake at all during the observation period, and thus the proportion of self-soothed wakings could not be determined. It was not possible to calculate sleep period duration from the sleep diaries of four infants because mothers failed to report either the infant's bedtime or rise time. There were no differences in maternal education, prematurity, or gender for infants who contributed data at one versus two time points (all $p > .05$).

Considering intrinsic factors, 61 mothers (65%) reported infant birth weight and 76 (81%) reported infant temperament on the IBQ. There were 67 infants (71%) for whom RSA data were available. Two infants' birth weight data were excluded as outliers (>3 SD above the mean). Concerning extrinsic factors, 76 dyads (81%) had bedtime practices data. One infant was not observed being put down in his/her final sleep location, and therefore it could not be determined whether s/he was put down asleep. There were 64 dyads (68%) for which EA data could be coded. Finally, 86 mothers (91%) reported their depressive symptoms on the CES-D.

Finally, 82 (87%) infants had Bayley data at 6 months, while 72 (77%) had useable attention task data. We identified one outlier (>3 SD above the mean) in the attention data, which was subsequently excluded.

**2.9 Analysis Plan**

Descriptive statistics were estimated using SAS version 9.4. We first examined bivariate correlations among our various indicators of infant sleep, to determine which set of correlated variables would be entered into subsequent measurement models. Next, we examined the distributions of all infant sleep variables to assess whether there were any deviations from normality (i.e., skewness and/or kurtosis beyond ±3; Kline, 2005). Non-normally distributed variables were examined for outliers and/or transformed.

We tested our substantive research questions using factor analytic and structural equation modeling techniques in Mplus 8.1 (Muthén & Muthén, 2017). The maximum likelihood (ML) estimator was used for all models, as previous research has demonstrated that it performs the best in small samples (Tanaka, 1987). Missing data were handled using full-information maximum likelihood.

To evaluate the global fit of each model, we assessed the chi-square test statistic ($\chi^2$) comparative fit index (CFI), root mean square error of approximation (RMSEA), standardized root mean square residual (SRMR), and Bayesian Information Criteria ($BIC = T_m - df\ln(N)$). Following the guidelines of Hu and Bentler (1999) and Raftery (1995), we used the following criteria as evidence of good model fit: non-significant $\chi^2$, CFI $\geq$ .95, RMSEA $\leq$ .05, SRMR $\leq$ .08, and BIC < 0. In addition to evaluating global model fit, we also examined the component fit of all models. Specifically, we looked for improper solutions (also called ‘Heywood cases’). Improper solutions refer to sample estimates that take on impossible values, such as negative variance estimates or correlations that are greater than one.

Research Question 1

The first research question was to determine whether a two latent factor model representing sleep regulation and consolidation fit the data better than a one factor, undifferentiated model. Because these were the only two structures being compared, we fit two confirmatory factor analysis (CFA) models to the underlying sleep indicators at 3 and 6 months. Global and component fit for the two models were examined using the guidelines described above. As the two models are nested, likelihood ratio tests (LRT) were used to determine whether the two factor model provided a better fit to the data than the one factor model. In addition, we used a BIC difference test as corroborating evidence by comparing the difference in the BICs of the one and two factor models to suggested guidelines (Raftery, 1995). A difference score between 0 and 2 suggests weak evidence, a score between 2 and 6 suggests positive evidence, a score between 6 and 10 suggests strong evidence, and a score above 10 suggests very strong evidence for the difference between the two models. In all cases, the model with the smallest (i.e., most negative) BIC is preferred. Based on the optimal factor structure we determined using the above criteria, we next examined the amount of variance and the correlation between our latent sleep variable(s) at both time points.

Next, we aimed to describe change in infant sleep from 3 to 6 months of age. Qualitatively, we examined whether the same number of factors were found to provide the best fit to the data at both time points. Quantitatively, we aimed to compared the means and variances of our latent sleep variable(s) at 3 and 6 months. In order to do so, we first tested for evidence of longitudinal measurement invariance, using steps outlined elsewhere (Putnick & Bornstein, 2016; Widaman, Ferrer, & Conger, 2010). This step is necessary in order to confirm that our indicators of sleep were operating in an equivalent manner at both time points. To compare increasingly restrictive models in a longitudinal measurement invariance framework, we used LRTs, where a significant p-value indicated a significant decrement in model fit. We also compared CFI values between nested models. Models with a CFI difference ($\Delta$ CFI) $\leq .01$ are considered to provide equally good fit to the data (Cheung & Rensvold, 2002). On the other hand, when $\Delta$CFI $> .01$, the model with the larger CFI is thought to provide better fit to the data.

<u>Research Question 2</u>

The second research question concerns the extent to which intrinsic and extrinsic factors have direct and interactive effects on infant sleep. Using the best fitting measurement model determined in part one, we estimated a series of structural equation models predicting our 6 month sleep factor(s) from three blocks of variables. Our first block consisted of demographic covariates (e.g., maternal education, child gender, prematurity, age at assessment). Our second block consisted of intrinsic characteristics (e.g., birth weight, temperament, baseline RSA), measured at 3 months. Our third block consisted of extrinsic factors (e.g., bedtime parenting practices, emotional availability, maternal depressive symptoms), also measured at 3 months. Due to our small sample size, non-significant predictors in one block were removed prior to estimating the subsequent block of variables.

To test the interaction of intrinsic and extrinsic factors in predicting infant sleep, we next estimated an additional three models. These models each included the direct effects of one intrinsic and one extrinsic factor, as well as the interaction between them. For the purpose of this study, we focused on just three interactions. To replicate previous findings (Jian & Teti, 2016), we examined the interaction between infant temperamental reactivity (both positive and negative dimensions) and maternal emotional availability. We aimed to extend these previous findings by examining the interaction between a physiological indicator of infant reactivity (i.e., baseline RSA) and emotional availability.

Research Question 3

Our third research question concerned the relationship between infant sleep at 3 months and infant cognitive outcomes at 6 months. To answer this question, we estimated one structural equation model predicting infant general cognitive ability and attention regulation at 6 months from our 3 month sleep factor(s) and relevant demographic covariates (e.g., maternal education, child gender, prematurity, age at assessment).

Power Analysis

Given the relatively small size of the sample, preliminary Monte Carlo simulations with 10,000 iterations were conducted to ensure adequate power for our proposed CFAs. These simulations demonstrate that with our sample size, we will have adequate power to detect moderately sized factor loadings ($\lambda \geq .5$). We used GPower 3.1 (Faul, Erdfelder, Lang, & Buchner, 2007) to conduct power analyses for research questions two and three. For all regression analyses, we will be underpowered to detect small effects ($f^2 = .02$), but have > 90% power to detect medium effects ($f^2 = .15$).

# Chapter Three: Results

## 3.1 Preliminary Analyses

Preliminary analyses focused on identifying a subset of correlated infant sleep measures for inclusion in subsequent CFA models. Correlations among all infant sleep measures indicative of consolidation and regulation at 3 and 6 months are presented in the appendix (Tables A2-A5). Within each time point and construct, correlation tables were visually inspected in order to identify subsets of variables that were significantly intercorrelated with one another. Based on this strategy, we identified six variables to be included in subsequent measurement models. Variables indicative of consolidation (CON) included LSP (actigraphy), NSR (actigraphy), and NAPN (actigraphy). Variables indicative of regulation (REG) included TWP (videosomnography), SSWP (videosomnography), and PINT (videosomnography).

## 3.2 Descriptive Statistics

Descriptive statistics for all study variables appear in Table 1. Correlations among 3 and 6 month sleep indicators are presented in Tables 2 and 3, respectively. Indicators of sleep consolidation (LSP, NSR, NAPN) were moderately intercorrelated at 3 ($r$ = -.35 - .48, all $p$ < .05) and 6 months ($r$ = -.47 - .31, all $p$ < .01) in the expected directions (i.e., NAPN was negatively correlated with LSP and NSR, while LSP and NSR were positively correlated). Indicators of sleep regulation (TWP, SSWP, PINT) were also moderately to strongly correlated at 3 ($r$ = -.60 - .64, all $p$ < .001) and 6 months ($r$ = -.63 - .46, all $p$ < .01) in the expected directions (i.e., SSWP was negatively correlated with TWP and PINT, while TWP and PINT were positively correlated).

Skewness and kurtosis values for each of the sleep indicators indicated significant deviations from normality in PINT and TWP at 6 months. An examination of extreme cases indicated that there were two infants who were outliers on both of these variables (> 3SD above the mean). After excluding these two infants, the skewness and kurtosis values of these variables returned to within acceptable limits (skewness < 3, kurtosis < 10; Kline, 2005).

### 3.3 Measurement Models of Infant Sleep

With our six indicators of infant sleep, we estimated two latent measurement models. The first model included a single latent variable with six reflective indicators. The second model included two latent variables, each with 3 reflective indicators. The consolidation factor included indicators of LSP, NSR, and NAPN, while the regulation factor included indicators of TWP, SSWP, and PINT. Model fit for these two measurements models at 3 and 6 months are summarized in Table 4.

<u>3 Months</u>

From the model fit statistics displayed in Table 4, it is clear that the one latent variable model fit the data poorly (Model 1), while the two latent variable model fit the data well (Model 2). A likelihood ratio test (Nested Test 1) indicated that the two latent variable model provided significantly better fit than the one latent variable model, $\chi^2$ (1) = 22.02, $p < .001$. Similarly, the BIC difference between the two models was 17.53, indicating strong support for the two latent variable model (BIC = -24.34) over the one latent variable model (BIC = -6.81).

Parameter estimates, including factor loadings, residual variances, and latent correlations are depicted in Figure 2a. All factor loadings were significant for both the CON ($|\lambda|$ = .38 - .74, all $p < .01$) and REG factors ($|\lambda|$ = .65 - .94, all $p < .01$). The variance of the REG factor was significant ($\varphi_{REG}$ = .42, $p < .01$), whereas it was trending towards significance for the CON factor

($\varphi_{CON}$ = .54, $p$ = .07). The CON and REG factors were positively correlated ($\varphi_{CON, REG}$ = .36, $p$ = .03), indicating that children with more consolidated sleep also tended to have more regulated sleep.

<u>6 Months</u>

At 6 months, the one latent variable model fit the data poorly (Table 4, Model 3), while the two latent variable model fit the data well (Table 4, Model 4). A likelihood ratio test (Table 4, Nested Test 2) indicated that the two latent variable model provided significantly better fit than the one latent variable model, $\chi^2$ (1) = 42.33, $p$ < .001. The BIC difference between the two models was 37.94, also providing strong support for the two latent variable model (BIC = -24.01) over the one latent variable model (BIC = 13.93).

Parameter estimates for the two factor model at 6 months are displayed in Figure 2b. All factor loadings were significant for both the CON ($|\lambda|$ = .46 - .72, all $p$ < .01) and REG factors ($|\lambda|$ = .56 - .82, all $p$ < .01). The variances of the CON ($\varphi_{CON}$ = .43, $p$ = .04) and REG factors ($\varphi_{REG}$ = .59, $p$ < .01) were both significant, indicating significant individual differences in these two processes at 6 months. Unlike at 3 months, CON and REG were not significantly correlated at 6 months ($\varphi_{CON, REG}$ = -.14, $p$ = .40).

<u>Change from 3 to 6 Months</u>

In order to describe quantitative differences in the levels and variances of these latent variables at 3 and 6 months, we had to test for longitudinal measurement invariance. First, we estimated a baseline model that included four latent variables (i.e., CON and REG at both 3 and 6 months). Following a recommended identification strategy (Widaman et al., 2010), we restricted the factor loadings on one indicator per construct (e.g., the referent item) to be equal at both time points, while also setting the intercept on these items to be equal. The means and variances of our two latent constructs at 3 months were set to 0 and 1, respectively. All other factor loadings, item intercepts, residual variances, factor means, factor variances, and factor covariances were freely estimated.

As originally estimated, the baseline model did not fit well, $\chi^2$ (48) = 95.04, $p < .001$, CFI = .80, RMSEA = .10, SRMR = .11, BIC = -122.52 (Table 4, Model 5). An examination of the modification indices suggested adding a residual correlation between LSP at 3 and 6 months. Adding this additional path improved model fit, but still did not result in a baseline model with adequate fit, $\chi^2$ (47) = 64.72, $p = .04$, CFI = .92, RMSEA = .06, SRMR = .11, BIC = -148.31 (Table 5, Model 5a). A second examination of modification indices suggested adding cross-time residual correlations between the other two consolidation indicators (NSR and NAPN). Doing so improved model fit and resulted in a well-fitting baseline model, $\chi^2$ (45) = 51.66, $p = .23$, CFI = .97, RMSEA = .04, SRMR = .10, BIC = -152.31 (Table 5, Model 5b).

To test for metric invariance, we next constrained the factor loadings for each construct to be equal across time (e.g., $\lambda_{\text{LSP(3 mo)}} = \lambda_{\text{LSP(6 mo)}}$). This constraint resulted in a significant decrement to model fit, $\chi^2$ (4) = 11.74, $p = .02$, $\Delta$ CFI = .03. Reasonable attempts to improve model fit, by freeing factor loadings one at a time, were unsuccessful. That is, all likelihood ratio tests comparing partial metric invariant models to the baseline model were significant. Therefore, we concluded that the measurement model only exhibited configural invariance. Without evidence of at least partial metric invariance, further interpretation of changes in latent consolidation and regulation from 3 to 6 months was not possible. However, examining the observed indicators of consolidation and regulation across time suggested that behaviors indicative of consolidation and regulation changed across time in the expected directions (i.e., LSP, NSR, and SSWP increased while NAPN, PINT, and TWP decreased; see Table 1).

### 3.4 Main Effects of Intrinsic and Extrinsic Factors on Infant Sleep

Next, we estimated a series of structural equation models predicting 6 month CON and REG factors from three blocks of variables: demographic covariates, intrinsic factors (i.e., birth weight, temperament, heart rate variability), and extrinsic factors (i.e., bedtime parenting practices, emotional availability, and maternal depressive symptoms). Correlations among these variables are displayed in Table 5. Due to sample size constraints, variables that did not approach significance ($p \leq .15$) in a block were trimmed from the model before adding the next block of variables. Model coefficients are presented in Table 6.

In block one, child age in months ($\beta = .37$, $p < .05$) was positively associated with sleep regulation at 6 months. Prematurity was marginally related to infant regulation ($\beta = .34$, $p = .06$). Child gender ($|\beta| = .10 - .12$, $p > .40$) and maternal education ($|\beta| = .03 - .20$, $p > .17$) were not related to either sleep consolidation or regulation, and were therefore removed from subsequent models.

Adding in intrinsic factors, maternal report of infants' orienting/regulatory capacity (ORC) was positively related to sleep consolidation ($\beta = .45$, $p = .01$), whereas infant birth weight was marginally related to sleep consolidation ($\beta = .23$, $p = .14$). There were no independent effects of any intrinsic factors on infant sleep regulation. Infant RSA, positive emotionality/surgency (PAS), and negative emotionality (NEG) were not related to either sleep consolidation or regulation, and were trimmed from subsequent models.

Considering extrinsic predictors of infant sleep, quiet activities ($\beta = .28$, $p = .10$), being put down asleep ($\beta = .24$, $p = .15$), and maternal depressive symptoms ($\beta = .25$, $p = .09$) were all positively, albeit marginally, related to infant sleep consolidation. Regarding infant sleep regulation, only close contact ($\beta = -.43$, $p = .02$) was a significant predictor. Maternal presence and emotional availability were unrelated to infant sleep consolidation and regulation and were trimmed from the model.

The final model contained only those variables that were related ($p \leq .15$) to either sleep consolidation or regulation in the third model. Specifically, this model included demographic factors of prematurity and child age, intrinsic factors of birth weight and ORC, and extrinsic factors of close contact, quiet activities, put down asleep, and maternal depressive symptoms. The final model fit the data well, $\chi^2$ (44) = 49.67, *p* = .26, CFI = .94, RMSEA = .04, SRMR = .07, BIC = -150.23.

In the final model, infant birth weight (β = .31, *p* = .05) and ORC (β = .35, *p* = .02) were both positively related to sleep consolidation. Quiet activities (β = .29, *p* = .08) and maternal depressive symptoms (β = .27, *p* = .06) were positively, albeit marginally, related to infant sleep consolidation, whereas close contact (β = -.31, *p* = .11) was marginally, negatively related. Concerning sleep regulation, child age was positively related (β = .42, *p* = .002), whereas close contact was negatively related (β = -.43, *p* = .007). Prematurity was positively, although marginally, related to sleep regulation (β = .30, *p* = .11). The final model explained 34% of the variance in sleep consolidation and 40% of the variance in sleep regulation.

### 3.5 Interaction of Intrinsic and Extrinsic Factors Predicting Infant Sleep

Although we failed to find main effects of emotional availability, baseline RSA, or infant temperamental reactivity (e.g., PAS, NEG), these findings did not preclude the possibility that these factors may interact with one another in the prediction of infant sleep regulation and/or consolidation. Therefore, we proceeded to test whether there were interactive effects among these variables in a series of three models. Each model included main effects of demographic covariates (e.g., prematurity, child age in months), one index of infant reactivity (e.g., PAS, NEG, RSA), maternal EA, and the corresponding interaction term (e.g., PAS x EA, NEG x EA, RSA x EA). Model results are summarized in Table 7.

Tests of interactive effects indicated a significant interaction between child PAS and maternal EA in predicting both sleep consolidation (β = -.38, $p$ = .02) and regulation (β = .41, $p$ = .009). To better characterize the nature of these interactions, we conducted simple slopes (Figure 3) and regions of significance analyses. Simple slopes were calculated for low (one standard deviation below the mean), moderate (mean), and high (one standard deviation above the mean) levels of the moderator. These analyses indicated that for infants who were rated low on PAS, higher maternal EA predicted better sleep consolidation ($b$ = .43, $p$ =.03). For infants who were rated moderate or high on PAS, there was not a significant relationship between maternal EA and infant sleep consolidation ($b$ = .07 and -.29, respectively, $p > .21$). Regions of significance analyses indicated that the positive relationship between maternal EA and sleep consolidation became significant ($b$ = .35, $p$ = .05) for values of child PAS below -.70 (-.77 SD).

Concerning the interaction between PAS and maternal EA in predicting sleep regulation, simple slopes analyses revealed that there was a significant, positive relationship between maternal EA and sleep regulation, but only for infants who were rated as high on PAS ($b$ = .59, $p$ = .02). For infants who were rated moderate or low, there was not a significant relationship between maternal EA and infant sleep regulation ($b$ = .13 and -.33, respectively, $p > .11$). Regions of significance analyses indicated that the positive relationship between maternal EA and sleep regulation became significant ($b$ = .36, $p$ = .05) for values of child PAS above .45 (+.50 SD).

Additionally, there was a marginal interaction between child RSA and maternal EA in predicting sleep consolidation (β = -.41, $p$ = .11). Because the interaction only approached significance, we did not further probe the simple slopes or regions of significance.

**3.6 Infant Sleep Predicting Cognition**

To answer research question 3, we modeled infant general cognitive ability and attention regulation as a function of covariates and 3 month latent sleep factors. Model results are summarized in Table 8. The addition of the first block of variables indicated that only prematurity and maternal education significantly or marginally predicted infant cognitive outcomes, and thus only these covariates were retained. After adding the second block of variables (3 month latent sleep factors), the model provided adequate fit to the data, $\chi^2$ (28) = 36.40, $p$ = .13, CFI = .93, RMSEA = .06, SRMR = .08, BIC = -90.81. Child prematurity marginally, negatively predicted infant general cognitive ability (β = -.20, $p$ = .08), while maternal education positively predicted infant median looking time (β = .26, $p$ = .02). Controlling for these covariates, there were no significant relationships between 3 month sleep factors and 6 month infant cognitive outcomes.

In an exploratory post-hoc analysis, we tested whether the relationship between infant sleep and cognition might differ based on contextual factors, specifically maternal education. To do so, we added two latent interaction terms to the above model (i.e., latent sleep consolidation x maternal years of education; latent sleep regulation x maternal years of education; Table 8, Step 3). Although traditional model fit statistics are not available when testing latent interactions, model $R^2$ values indicated that this model explained 11% of the variance in sleep consolidation and 35% of the variance in sleep regulation, an improvement of 7% and 19%, respectively, over the variance explained by the direct effects model (Table 8, Step 2).

In this model, infant sleep regulation significantly predicted infant looking time (β = .29, $p = .05$). Further, there was a significant interaction between maternal years of education and infant sleep regulation (β = .41, $p = .002$). We probed this interaction at levels of maternal education that corresponded to a high school degree (12 years education) and a four-year college degree (16 years education). These analyses, visually presented in Figure 4, show that the relationship between infant sleep regulation and looking time was significant and positive for infants whose mothers had a college education (b = 4.05, $p < .001$). For infants whose mothers had only a high school education, there was no significant interaction between sleep regulation and looking time (b = -1.59, $p = .22$). Regions of significance analyses indicated that the relationship between sleep regulation and looking time became significant ($b = 1.74$, $p = .05$) when mothers had obtained 14.4 years of education (-0.14 SD), which is approximately equivalent to two years of college.

### 3.7 Sensitivity Analyses

We conducted several sensitivity analyses in order to bolster our confidence in the present findings. First, we tested whether the relationship between our sleep indicators and latent constructs were best construed as formative or reflective. The utility and interpretability of formative versus reflective indicators is one that is currently up for debate (Bollen, 2007; Howell, Breivik, & Wilcox, 2007). Typical CFA models, such as the type used in these analyses, suppose that observed variables are reflective, or effect, indicators of underlying latent processes. That is, it is assumed that unobservable latent variables give rise to measurable indicators (e.g., an infant's level of sleep consolidation gives rise to his observed longest sleep period). These relationships are pictured in path diagrams by arrows that point from a latent variable towards its observed indicators (as in Figure 2). However, an alternative hypothesis is that observed variables are formative, or causal, indicators of latent processes. In this case, the direction of arrows in a path diagram would point from observed indicators towards the latent variable.

Although further discussion of the merits of formative versus reflective measurement models is beyond the scope of this dissertation, we chose to employ existing statistical techniques to test whether our sleep variables were best construed as formative or reflective indicators. Specifically, we used vanishing tetrad tests (VTT) to determine whether our final measurement model, which supposed all reflective indicators, was consistent with our data (Bollen, Lennox, & Dahly, 2009). Using steps outlined elsewhere (Hipp, Bauer, & Bollen, 2005), we conducted 100 randomized sets of VTTs for each time point (i.e., 3 and 6 months). The average probability value associated with these tests was > .05, indicating that a measurement model with all reflective indicators was consistent with the data. Therefore, the results of our VTT analysis support our use of a traditional CFA model with all reflective indicators.

A second possible concern centers on our decision to trim non-significant covariates from our stepwise regression models estimating direct (Table 6) and indirect (Table 7) effects of intrinsic and extrinsic characteristics on infant sleep, as well as the effects of infant sleep on cognition (Table 8). This decision was made because we were concerned about overfitting our model, especially given our small sample size. However, an alternative argument is that variables thought to be theoretically important should always be retained, because of the possibility that they are explaining some amount of variance, even if that amount does not reach the threshold of statistical significance. Therefore, we re-estimated our final models including all covariates initially theorized to be relevant to infant sleep outcomes (i.e., child gender, age, prematurity, and maternal years of education). The addition of these additional covariates did not change our substantive conclusions, with one exception.

In the interactive model predicting infant sleep consolidation and regulation from both child baseline RSA and maternal EA, the interaction between RSA and EA became significant ($\beta = -.50$, $p = .04$), rather than marginally significant, when all covariates were retained as predictors. Probing this interaction and its regions of significance (Figure 5), we found that there was a positive relationship between maternal EA and infant sleep consolidation, but only for children who had low (-1SD) baseline RSA ($b = .56$, $p = .04$). For children with moderate to high baseline RSA, there was no significant relationship between EA and consolidation ($|b| = .13$ - $.24$, $p > .16$). Regions of significance analysis indicated that the relationship between EA and consolidation was significant when child RSA was -0.6 (-.71 SD) or lower ($b = .46$, $p = .05$).

## Chapter Four: Discussion

The primary goals of this dissertation were to establish a well-fitting latent measurement model for infant sleep from a set of observed indicators, investigate the main and interactive effects of intrinsic and extrinsic predictors on these latent sleep processes, and test whether these latent sleep processes longitudinally predict infant cognitive outcomes. We found that a two latent variable model representing the dual processes of sleep consolidation and regulation fit the data better than a one factor, undifferentiated model of infant sleep quality. While the same two factor model provided the best fit to the data at both 3 and 6 months, a lack of measurement invariance impeded our ability to describe changes in the latent means and variances of consolidation and regulation between these time points. We found direct effects of several intrinsic and extrinsic factors, measured at 3 months, on infant sleep consolidation and regulation at 6 months. We also found significant interactions among hypothesized intrinsic (i.e., infant temperament, baseline RSA) and extrinsic factors (i.e., emotional availability) in predicting infant sleep. Finally, we documented a relationship among infant sleep regulation at 3 months and infant attention at 6 months, but this relationship only held for infants with more highly educated mothers. Taken together, this set of findings advances our methodological and substantive understanding of infant sleep, while suggesting many areas for future inquiry. We turn next to a thorough consideration of each of our key research findings, including how they fit within the existing infant sleep literature.

## 4.1 Latent Measurement Model for Infant Sleep

As hypothesized, we found support for a two factor model of infant sleep, which represented the corresponding processes of sleep consolidation and regulation. These two biopsychosocial processes have thus far only been discussed in a theoretical manner, in terms of how they might guide changes in infant sleep behavior during the first years of life (Goodlin-Jones, Burnham, Gaylor, et al., 2001). This study is the first to empirically test whether these latent processes do in fact give rise to observable variations in infant sleep quality. Using confirmatory factor analysis and a multitude of sleep measures obtained from various assessment methods (e.g., actigraphy, videosomnography, sleep diaries), we found that a two factor solution best described the data. A one factor, undifferentiated model, did not fit the data well at either 3 or 6 months.

In our two factor model, the latent variable indicative of sleep consolidation was comprised of three actigraphy measures: infants' longest continuous sleep period, nighttime sleep ratio, and number of naps. Infants with better-consolidated sleep were primarily sleeping during the nighttime, taking fewer daytime naps, and sleeping in longer continuous stretches. This characterization is consistent with the theoretical definition of sleep consolidation, which describes the emergence of a diurnal patterning of sleep/wake states as well as longer periods of sustained sleep (Goodlin-Jones, Burnham, & Anders, 2001). Empirically distinct from consolidation, the latent variable indicative of sleep regulation was comprised of three videosomnography measures: proportion of time spent awake during the night, proportion of self-soothed wakings, and number of parental interventions. In this case, infants with better-regulated sleep spent less time awake during the night, self-soothed more often upon waking, and received fewer parental interventions. Again, this characterization of sleep regulation is consistent with its theoretical definition, which describes the process by which infants gain increasing control over their sleep/wake states (Goodlin-Jones, Burnham, Gaylor, et al., 2001). Put another way, infants with better sleep regulation are able to fall asleep independently at bedtime and following nighttime wakings. As a result, they also spend less time awake during the nighttime sleep period.

Although the underlying factor structure of sleep quality has not yet been assessed in an infant population, our finding of multiple dimensions of sleep quality is consistent with some work in the adult and older adult literature (Cole et al., 2006; Johns, 1975; Keklund & Akerstedt, 1997; Parrott & Hindmarch, 1978). For example, Cole and colleagues (2006) found that the Pittsburg Sleep Quality Index, a widely used measure for assessing adult sleep disturbances, was best described by three underlying factors representing distinct facets of sleep (i.e., sleep efficiency, quality, and disturbance). More recently, a study published with toddlers used principal components analysis to reduce the number of actigraphy variables entered into subsequent analyses (Hoyniak et al., 2018). They found that four components emerged, representing the processes of sleep duration, timing, activity, and variability. While it is unclear how the factors derived from previous studies correspond with the latent factors found in the current investigation, this group of findings as a whole demonstrate the utility of a factor analytic approach for exacting a more nuanced understanding of the multiple underlying processes that contribute to sleep development and disturbance. Further attention to when these latent processes emerge and how they change across the lifespan may prove fruitful.

It is interesting to point out that the two factors of sleep consolidation and regulation found in the current study were comprised of indicators from two different sleep assessment methods. Only actigraphy, which objectively measures the amount of sleep occurring during the day and night, contributed observable indicators of sleep consolidation. Subjective sleep diary data, which in theory should also provide information about sleep patterns across the day and night, was unrelated to actigraphy data and therefore not considered in the measurement model. This lack of correspondence between actigraphy and sleep diaries could be due to many factors. For one, mothers may have been unaware of their infants' sleep and wake behavior during times when they were not present (e.g., if child was in daycare or slept in separate room). General recall failure due to study fatigue or other factors may also have contributed to inaccuracies. Indeed, other studies have documented lack of correspondence between actigraphy and sleep diaries (e.g., Sadeh, 1994, 1996).

In contrast to sleep consolidation, only variables derived from videosomnography were indicators of sleep regulation. It is perhaps not surprising that videosomnography provided the best measures of infant sleep regulation, as this is the only method that allowed for direct observation of infant and parent behavior following nighttime waking (i.e., self-soothing, intervention). Previous studies examining self-soothing behavior in infants have also made use of videosomnography (e.g., Anders et al., 1992; Burnham et al., 2002; Goodlin-Jones, Burnham, Gaylor, et al., 2001). However, beyond self-soothed waking and parental interventions, which can only be measured using videosomnography, we expected some correspondence between actigraphy and videosomnography for variables such as amount of time spent awake during the nighttime period. This lack of relationship could be due to various factors, including different methods used to score wakefulness. For example, actigraphy scored infant sleep and wake states exclusively from the degree of movement detected in each epoch. Videosomnography, on the other hand, used additional cues for wakefulness, such as infant eye opening or vocalization. These differences in coding infant state likely led to a lack of inter-method agreement.

Although we found that the same underlying factor structure fit the data well at both 3 and 6 months, we failed to find evidence of longitudinal measurement invariance. This lack of invariance means that our observed indicators of infant sleep operated differently at the two time points. For example, some indicators may have been more or less related to their latent sleep construct across time. As a result, we are unable to make conclusions about changes in the means and variances of the latent constructs of sleep consolidation and regulation from 3 to 6 months. Future studies should attempt to examine this question in a larger sample of infants across a wider range of ages, to see if measurement invariance can be inferred across different periods of time in the first year of life (e.g., 4 to 6 months, 6 to 9 months).

There are several reasons why our measurement model may not have been invariant across our specific age range. First, there is reason to believe that parental expectations and structuring of infant sleep may be different at 3 months than at 6 months. At 3 months, the circadian rhythm is still relatively immature, and thus sleep is only beginning to be consolidated into longer nighttime stretches (McGraw et al., 1999). As a result, parents may be more attuned to their baby's own internal rhythms, putting him/her to bed when the baby signals sleepiness rather than at a set bedtime. At 6 months, when the circadian rhythm is relatively well-established, parents may be setting and sticking to a stricter bedtime, and perhaps even attempting to prevent the child from napping during the day, in order to facilitate longer periods of nighttime sleep. Similarly, for sleep regulation, infant self-soothing is relatively infrequent at 3 months compared to 6 months (Burnham et al., 2002). Therefore, parents may be more likely to intervene with their 3-month-old whenever s/he wakes during the night. At 6 months, parents may be intervening less because they believe the infant has a greater capacity for self-soothing. In addition, sleep training techniques (including methods such as extinction/"cry-it-out") may be adopted by families when their infant reaches 4 to 6 months of age (Ferber, 2006; Weissbluth, 2015). Adoption of a sleep training technique between the 3 and 6 month time points would greatly change the ways in which parents structure the bedtime process, as well as how they respond to their infant following night wakings.

Besides changes in parents' sleep-related attitudes and behaviors, infants are developing rapidly across multiple domains between 3 and 6 months. These changes within other systems could all contribute to fluctuations in the relationship between observable indicators of sleep behavior and the underlying latent processes of consolidation and regulation. For example, in the realm of motor development, infants are better able to roll over and reach for objects by 6 months of age (Adolph, in press). These increases in gross motor movement may mean that infants are waking themselves up more during the night, but these wakings may be shorter and require less parental assistance than wakings that are caused by an infant's need for feeding or changing. At the same time, the ability to reach for objects may assist infants in reinserting a dislodged pacifier or grasping a comforting item (e.g., blanket, toy) during the night, increasing their ability to effectively self-soothe. Cognitively, 6-month-olds show a greater awareness of the world around them and are more object-oriented than are 3-month-olds (Rochat, 1989). These cognitive changes may mean that certain infants have more trouble disengaging with the external environment when it is time for sleep or following nighttime wakings, and may actually need more parental structuring in order to begin or resume sleep. Finally, within the emotional domain, the infant-caregiver attachment bond is rapidly developing across the first year of life. As such, infants are synthesizing information about their caregivers' patterns of responsiveness during the day and night into an organized strategy that guides their own signaling and comfort-seeking strategies (Ainsworth, 1985). Individual differences in these emerging attachment strategies may subsequently influence nighttime parent-child interactions in ways that are relevant for sleep development (Morrell & Steele, 2003). Therefore, both normative developmental milestones, and individual differences within the domains of motor, cognitive, and emotional development, may contribute to changes in the relationship of observable sleep behaviors to underlying latent sleep processes between 3 and 6 months.

### 4.2 Direct Effects Predicting Infant Sleep

Our second research question was to examine the direct effects of intrinsic (i.e., birthweight, temperament, baseline RSA) and extrinsic (i.e., parenting practices, emotional availability, depressive symptoms) factors on infant sleep consolidation and regulation. In the final model predicting sleep consolidation, significant predictors included infant birthweight and temperament. Specifically, higher birthweight and higher temperamental orienting/regulatory capacity predicted better sleep consolidation. Several extrinsic factors were related to sleep consolidation, including amount of close contact and quiet activities at bedtime, but these relationships were only marginally significant. We therefore refrain from interpreting these relationships further.

The significant relationship between infant birth weight and sleep consolidation supports Barker's hypothesis (1995), which proposes that prenatal conditions have lasting implications for health and development. Birth weight is thought to be one useful proxy of prenatal conditions. While other studies have similarly reported a relationship between birth weight (or conditions leading to low birth weight) and children's sleep (Pesonen et al., 2009; Yiallourou et al., 2016), ours is the first to show that these relationships are evident in infancy. Further, our results are the first to show that birth weight remains a significant predictor above and beyond other intrinsic and extrinsic factors that may be important to consider. In this way, we add to the literature on the prenatal origins of infant sleep development, and to the fetal origins literature more generally, which implies that it is important to begin tracing developmental trajectories from conception, rather than from birth.

Infant orienting/regulatory capacity (ORC), as reported by mothers on the IBQ, was the second significant predictor of infant sleep consolidation. While other studies have investigated the relationship between infant temperament and sleep, these results mainly suggest that children with high negative reactivity are more likely to suffer from sleep problems (Halpern et al., 1994; Morrell & Steele, 2003). However, one study indicated that infants with shorter longest sleep periods, an indicator of poor sleep consolidation, were more difficult to soothe (Halpern et al., 1994). This finding is consistent with the current results documenting a positive relationship between sleep consolidation and ORC, given that the ORC scale of the IBQ includes items related to soothability. One explanation for these findings is that sleep consolidation and regulatory capacity may reflect similar aspects of infant biological organization or maturity (Halpern et al., 1994), such as central nervous system integrity. A second explanation is that children who are more easily soothed at 3 months are better able to adapt to day/night patterning of sleep/wake states, as imposed by parents' own sleep schedules and preferences, and therefore achieve better-consolidated sleep by 6 months of age. Finally, it is possible that there are maternal behaviors or characteristics that contribute both to her infant's behavior (which is then reflected in her report on the IBQ) and to her infant's subsequent sleep development (Crockenberg & Acredolo, 1983). For example, provision of sensitive daytime and nighttime maternal care might lead to an infant displaying both higher regulatory capacity and better consolidated sleep. Regardless of mechanism, these findings and others suggest that it is important to consider both reactivity and regulatory ability as two separate temperamental dimensions that may potentially be related to infant sleep. Although the current study only found support for the regulatory dimension of temperament, our findings may have been different if we made use of multiple informants (i.e., fathers or other caregivers) or objective assessment of infant temperament. Therefore, linkages between reported temperament, observed temperament, and infant sleep development clearly remain to be untangled.

In contrast to sleep consolidation, intrinsic characteristics such as birth weight and temperament did not significantly predict infant sleep regulation. With the exception of infant age, which positively predicted regulation, the only significant predictor was an extrinsic factor. Specifically, higher proportions of maternal close contact at bedtime predicted worse infant sleep regulation at 6 months. This finding is consistent with a long literature suggesting that active physical comforting at bedtime may impede children's ability to independently regulate their own sleep/wake states (e.g., Morrell & Cortina-Borja, 2002; Morrell & Steele, 2003). However, the majority of this literature has included samples of children older than 6 months of age. That we find a relationship between 3 month parental behaviors and 6 month sleep is noteworthy, as it suggests that the transition from externally-regulated to self-regulated sleep begins early, and thus parents must be aware from an early age how they can best support infant's autonomous sleep regulation.

However, we must take care to interpret the directionality of these relationships cautiously, as it may be that parents are using more active physical comforting at bedtime with children who are exhibiting poor sleep regulation. It is also important to point out that our findings conflict with those from another set of studies (Philbrook & Teti, 2016; Teti et al., 2010), which found that it is not *what* parents do at bedtime, but *how* they do it (e.g., the emotional availability with which they provide care) that predicts infant sleep development.

Interestingly, these previous studies were based on a primarily Caucasian sample, while the current study was based on an exclusively African American sample. Our disparate findings suggest that it may be important to consider how race and/or socioeconomic status modify the relationships between parenting practices, parenting quality, and infant sleep. This is an especially important research question given evidence that individuals of different ethnicities ascribe different meanings to the same parental behaviors (Mason, Walker-Barnes, Tu, Simons, & Martinez-Arrue, 2004).

Contrary to study hypotheses and extant findings in the literature, we did not find significant direct effects of child RSA, maternal emotional availability or depressive symptoms in predicting infant sleep consolidation or regulation. As stated above, these null findings may have been due to differences in the racial composition of our sample as compared to others. Previous studies have also tended to test individual child and parent factors, without considering or controlling for others. Finally, it is possible that these factors were related to sleep, but that their effect sizes were too small to detect given the sample size of the current study. Preliminary power analyses indicated that we had sufficient power to detect moderate, but not small effects. Larger studies may shed light on whether these factors make an independent contribution to infant sleep development, above and beyond the other factors considered here.

Taken together, these findings indicate that different classes of predictors are differentially related to the latent processes of consolidation and regulation. These different patterns of predictors suggest that consolidation and regulation are two distinct processes with separable antecedents. Consolidation was primarily predicted by intrinsic factors, including birth weight and child temperament. Regulation, on the other hand, was predicted by an extrinsic factor, specifically the proportion of close contact at bedtime. These findings suggest that consolidation may be a process that is primarily influenced by the child's own characteristics, although whether those characteristics are biologically or environmentally determined is up for debate. Current research acknowledges that both biological and environmental influences contribute to individual differences in temperamental characteristics (Shiner et al., 2012). Similarly, maternal and child genetics, as well as alterations in the quality of the fetal environment, work together to determine infant birth weight (for a review, see Valero De Bernabé et al., 2004). In contrast, sleep regulation seems primarily determined by external factors, including parenting behaviors at nighttime. Given the crucial role of parents in supporting other forms of regulation, including in the emotional and cognitive domains (e.g., Sameroff, 2010), this distinction is not altogether surprising. We would expect that the other-regulation provided by caregivers early in development, combined with increasing opportunities for the infant to practice self-regulation of sleep/wake states, would make an important contribution to infant's sleep regulation in this time period.

### 4.3 Interactive Effects Predicting Infant Sleep

Next, we moved beyond direct effects models to understand the interaction of child characteristics and parental input in predicting sleep consolidation and regulation at 6 months. Specifically, we tested whether children who differed in reactivity would be more or less dependent on nighttime parenting for the development of consolidated, well-regulated sleep. Overall, our findings supported our hypothesis that child temperament and emotional availability (EA) and to a lesser extent, child RSA and EA, would interact to predict infant sleep quality. Regarding child temperament and EA, we found that these two factors interacted to predict both infant sleep consolidation and regulation, but in different ways. For sleep regulation, children who were rated high on the positive affect/surgency (PAS) scale were more influenced by maternal EA, showing the best outcomes when mothers were highly emotional available, and the worst outcomes when mothers were not. Regions of significance analyses revealed that the relationship between EA and sleep regulation became significant when children were half a standard deviation above the mean on PAS ($n = 25$). This finding revealed that for approximately 1/3 of our sample who were exhibiting the highest amounts of PAS, maternal EA was particularly important in predicting optimal sleep regulation.

The direction of this interaction is consistent with previous findings on which we based our hypotheses. Specifically, one previous study found that children who were rated as high on PAS and had mothers who were high on EA showed the greatest increase in nighttime sleep minutes from 1 to 6 months (Jian & Teti, 2016). For children who were low on PAS, there was no relationship between EA and change in nighttime sleep minutes across this time period. These findings suggest that children who are intrinsically more active and excitable, characterized by more smiling and laughing, vocal reactivity, and high-intensity pleasure, may rely more strongly on sensitive and structured nighttime care in order to learn to detach from caregivers during the transition to sleep. In turn, infants who are better able to regulate sleep/wake state at bedtime may be more effective at self-soothing following nighttime wakings. However, it is important to note that the sleep outcome used in the previous study (i.e., changes in nighttime sleep minutes) is not clearly related to either sleep consolidation or regulation, as defined in the current study. Increases in sleep minutes could reflect a higher proportion of 24-hour sleep occurring during the nighttime, or a higher proportion of the nighttime sleep period spent asleep (and conversely a lower proportion spent awake). The relationship between sleep quantity, as measured in previous studies, and sleep quality, as indexed here by sleep consolidation and regulation, remains to be determined.

The interaction between temperament and EA in predicting sleep consolidation demonstrated a very different pattern of findings than the ones described above. In this case, children who were rated low on PAS benefitted the most from high EA. For children who were rated high on PAS, EA was not a significant predictor of consolidation. The positive relationship between EA and sleep consolidation became significant when children were three-quarters of a standard deviation below the mean ($n$ = 17). Although there was a smaller proportion of our sample who met this criterion, there was still a non-trivial number of individuals characterized by low levels of PAS who relied on high maternal EA for developing well-consolidated sleep.

As opposed to our findings predicting sleep regulation, the direction of this interaction was the opposite of what we expected. However, given that consolidation and regulation seem to be theoretically and empirically separable processes, perhaps it is not surprising that intrinsic and extrinsic factors interact in different ways to promote or hinder their development. In order to interpret this counterintuitive interaction, it is helpful to understand, more precisely, what the PAS scale is measuring. In our sample, scores on the PAS scale were unrelated to scores on the NEG scale ($r = .12$, $p > .05$), suggesting that the absence of positive affect in this sample should not be interpreted as evidence for high negative affect. Rather, consistent with previous studies with infants (Gartstein & Rothbart, 2003; Jian & Teti, 2016), scores on the PAS scale were significantly, positively correlated with scores on the ORC scale ($r = .57$, $p < .05$; see Table 5). Therefore, infants rated low on PAS may be less emotionally expressive, active, and sensitive to perceptual information (PAS items), as well as possibly less soothable, less cuddly, and less likely to sustain orientation for long periods of time (ORC items). This type of infant may rely more on parental input in order to develop consolidated sleep because they may be less clear in their signals of sleepiness or alertness. For example, when an infant is typically highly emotionally expressive, sensitive to perceptual stimuli, and soothable, it may be more clear when the infant is tired because of the dampening of these qualities. For an infant who displays lower levels of these behaviors regardless of state, it may be less clear when the infant is becoming tired. A more emotionally available parent, however, may be more sensitive to infant cues, even subtle ones, and therefore engage with these infants in ways that promote consolidated sleep (e.g., providing a consistent nighttime routine at an age-appropriate bedtime).

Our findings suggesting an interaction between positive emotionality and parenting are particularly noteworthy given the relative lack of attention to this temperamental construct in the literature. Most studies examining the interaction between child temperament and parenting quality have tended to use negative emotionality as a susceptibility or risk factor (e.g., Belsky, Bakermans-Kranenburg, & Van Ijzendoorn, 2007). However, there is some evidence that low positive emotionality may also make children more susceptible to parental input. For example, one study found that among children of divorced parents, parental rejection was more strongly predictive of adjustment problems for children low in positive emotionality, while children high in positive emotionality seemed buffered from these negative effects (Lengua, Wolchik, Sandler, & West, 2000). Clearly, more work needs to be done to understand the behavioral profile of children who are low in positive emotionality, including how these behaviors are perceived and responded to by parents, and how they may exacerbate or protect against environmental factors. In doing so, we may be able to better understand the interaction between positive emotionality and parenting in predicting sleep, a finding which has now been replicated in two different samples of infants.

Finally, there was a marginally significant interaction between infant RSA and maternal EA in predicting infant sleep consolidation, which became significant in subsequent sensitivity analyses. While we should use caution in interpreting these findings until they are replicated, the direction of this interaction was interesting in that it was contrary to our hypotheses. That is, infants with low (rather than high) RSA were the most influenced by maternal EA. In our sensitivity analyses, we showed that for infants who had below average RSA (-.71 SD), there was a positive relationship between maternal EA and sleep consolidation whereas for infants who had high baseline RSA, there was no relationship between EA and sleep. These findings conflict with the results of two extant studies that found that high baseline RSA operates as a susceptibility factor in the prediction of child outcomes (Conradt, Measelle, & Ablow, 2013; Gueron-Sela et al., 2017). Specific to sleep, one recent study found that infant RSA interacts with maternal depression in predicting toddler sleep problems (Gueron-Sela et al., 2017), such that children high in baseline RSA showed the highest levels of sleep problems when maternal depression was high.

These conflicting findings may be due to study differences, including the age at which sleep was assessed (i.e., infancy versus toddlerhood) and the sleep assessment method (i.e., reported sleep problems versus objective measurement). Additionally, maternal depression may be representative of a broader set of demographic and psychological risk factors (e.g., Cummings & Davies, 1994), as opposed to our measure of emotional availability, which specifically describes parents' behavior in a sleep context. Finally, whether RSA is operationalized as a susceptibility versus a risk factor for child outcomes is important to note. Our findings are consistent with the broader developmental science literature, where high RSA is most-often interpreted as an index of age-appropriate engagement and regulation that predicts other positive developmental outcomes (for a review, see Beauchaine, 2001). In light of this larger literature, low RSA would be interpreted as a risk factor for maladaptive child outcomes. Indeed, there is evidence that low RSA in preschool children is associated with lower sleep efficiency (Elmore-Staton et al., 2012), supporting the notion that children with low RSA may be predisposed to more sleep difficulties, and therefore require more sensitive nighttime care in order to develop optimal sleep patterns. Therefore, while our findings confirm that both child physiology and parental input are important contributors to infant sleep development in our sample, a next step in the field is to more closely examine developmental periods, contexts, and measures to better understand the specific ways in which these factors interact to predict better or worse sleep.

### 4.4 Relationship between Infant Sleep and Cognition

A final aim of the current investigation was to test whether the latent processes of sleep consolidation and regulation at 3 months predicted infant cognition at 6 months. Contrary to our hypotheses, we did not find direct effects of either consolidation or regulation on infant general cognitive ability or attention regulation. The only other studies that have tested the longitudinal relationship between infant sleep and general cognitive ability/attention assessed infant sleep in neonates (Freudigman & Thoman, 1993; Geva et al., 2016), a time period in which sleep behavior is thought to represent an infant’s response to the stress of the birth process, rather than their development of sleep consolidation and regulation, per se. Other studies have made use of concurrent associations between infant sleep and cognitive ability (Scher, 2005), meaning that the direction of effects cannot be disentangled. Therefore, there is little precedence for studying the relationship between infant sleep at 3 months and cognitive outcomes at 6 months.

Despite a failure to find main effects, we did find preliminary evidence of a relationship between sleep and cognition for a subgroup of infants in our sample. Specifically, we found that maternal education interacted with sleep regulation in predicting attention regulation, such that for infants whose mothers had achieved a college degree or higher, there was a positive relationship between their sleep regulation at 3 months and their attention behavior (i.e., looking time) at 6 months. For infants whose mothers had a high school degree, there was no relationship between sleep and cognition across these time points. These findings are of interest for several reasons.

First, better infant sleep regulation positively, rather than negatively, predicted infant looking time in the more highly educated group. We originally hypothesized that shorter looking times would be an index of better attention regulation, given evidence that there are normative decreases in looking behavior across the first 6 months of life. This decrease in looking time is commonly attributed to development in the information processing and attention orienting systems, and specifically in the ability to disengage attention (Colombo, 2001). Supporting this notion, one study found that better quality neonatal sleep predicted shorter first gaze durations in a visual-recognition-memory task at 4 months of age (Geva et al., 2016). However, sometime around the 6 month time point, infant attention normatively begins to increase as the ability to sustain attention develops (Swingler, Perry, & Calkins, 2015). In turn, sustained attention measured during the second half of the first year of life has been shown to predict later emotion regulation (Perry, Swingler, Calkins, & Bell, 2016). Therefore, longer looking times during this time period may represent more mature development of sustained attention, rather than less mature development of attention orienting. In support of this, infant looking time on the attention task was positively correlated with Bayley scores in the current study. Thus, our findings support the notion of Swingler and colleagues (2015), which suggest that longer looking times in 6-month-olds are an index of better attention development. As such, while sleep may support infants' ability to disengage attention in the first six months of life (Geva et al., 2016), higher quality sleep may subsequently support better sustained attention after about 6 months of age.

Second, the finding that sleep interacted with maternal education in predicting infant cognition sheds light on possible mechanisms underlying sleep-cognition linkages. One hypothesized mechanism is that sleep promotes optimal neural functioning and development, which in turn is reflected in better cognitive outcomes for children (Bernier et al., 2010; Dahl, 1996; Yoo et al., 2007). However, a second hypothesis is that high quality sleep enables children to better reap the benefits of an enriched environment. Supporting this hypothesis, one study found that the positive relationship between maternal sensitivity and several domains of child functioning (e.g., executive function, attachment security) was only evident for children achieving adequate amounts of nighttime sleep (Bernier, Bélanger, Tarabulsy, Simard, & Carrier, 2014). This finding is consistent with the current study, in which children with better sleep regulation and more educated mothers had the highest levels of sustained attention. However, we cannot make strong assumptions about causality based on either of these correlational studies. An equally plausible alternative hypothesis is that children who are better regulated overall, due to a variety of factors (e.g., prenatal programing, high quality maternal care), exhibit better sleep and attention regulation. Further research is needed to in order to test these multiple mechanistic explanations.

Finally, our finding that sleep predicts attention regulation in some infants partially support the notion that self-regulatory abilities are hierarchically organized, with early differences in physiological regulation giving rise to later differences in cognitive and emotional regulation (Calkins & Fox, 2002). Thus far, physiological regulation has primarily been studied in terms of heart rate variability, hypothalamic-pituitary-adrenocortical (HPA) axis functioning, and brain activity (e.g., EEG). Developmental psychology has not widely considered infant regulation of sleep/wake states as another pertinent domain of physiological regulation, even though this may be one of the very first regulatory competencies to emerge. Our finding that sleep predicts cognitive regulation, at least among certain groups of children, suggests that studying sleep regulation in infancy may provide another window into the assessment of individual differences in early regulatory ability, and may prove to be a possible intervention point for infants considered ‘at-risk’ for later regulatory problems.

### 4.5 Strengths and Limitations

Strengths of the current study include our reliance on multiple, objective indicators of infant sleep, as well as objective measurement of many intrinsic (e.g., infant RSA) and extrinsic factors (e.g., maternal EA). Further, our use of a sample of exclusively African-American families presented a unique opportunity to study the factors related to sleep development in a group that is known to be at risk for poor sleep across the lifespan (Crosby et al., 2005; Stamatakis et al., 2007). Understanding how to best promote high-quality sleep starting in infancy is a question of great practical importance, as reducing disparities in sleep quality has been identified as a key stepping stone to reducing overall race-related health disparities (Laposky, Van Cauter, & Diez-Roux, 2016). Despite this, the development of sleep patterns in African-American infants is an area that has received practically no attention in the literature until now. Another strength of our sample was the relative diversity in terms of socioeconomic status (SES). As opposed to previous studies in which race and SES tend to confounded, we sampled African-American families along a wide SES gradient (i.e., 12% of mothers had a high school degree or less while 37% had a college degree or higher). As a result, our findings may better represent the heterogeneous experiences of African-American families in our region of the Southeastern United States.

However, care should also be taken in interpreting these findings due to several study limitations. Most obviously, our small sample size limited our power to detect significant relationships among our variables of interest. This lack of power may have limited our ability to identify sleep variables that were significantly correlated with one another and therefore entered in our factor analysis. It may also have contributed to an inability to detect significant predictors of our latent sleep constructs, or to identify significant relationships among infant sleep and cognitive measures. Additionally, our use of an exclusively African-American sample may limit our ability to generalize these findings to infants of all racial groups. Although we do not have reason to believe that the latent structure of infant sleep would vary by race, there may be differential relationships among infant and parent characteristics and infant sleep in African-American versus Caucasian families. For example, an increased propensity to bedshare among African-American families may contribute to different types, frequencies, or meanings of nighttime parenting behaviors (e.g., Colson et al., 2013). Therefore, given our sample size and characteristics, it would be important to replicate and extend the findings from the current investigation using a larger, racially diverse sample.

Further, our data included some subjective measures of infant and parent characteristics, specifically infant temperament and maternal depression. It is widely acknowledged that parental perceptions of their children may be influenced by social desirability bias, as well as parents' own characteristics, including their stress levels (De Los Reyes & Kazdin, 2005). Maternal reporting of her depressive symptoms may similarly suffer from these biases. However, previous studies have shown acceptable correlations between the IBQ and laboratory assessments of temperament (Parade & Leerkes, 2008). Similarly, the CES-D has been shown to discriminate between clinical and non-clinical populations (Radloff, 1977). A possible larger issue concerning these questionnaire measures is that each scale was treated as a manifest variable, rather than modeled as one or more latent variables. In doing so, we assumed that each construct (e.g., negative emotionality, depression) was unidimensional and measured without error. Although establishing the underlying latent structure of the IBQ and CES-D was outside the scope of the current dissertation, further attention to the measurement properties of our predictor variables, in addition to our sleep variables, might provide a clearer picture of the relationships among these factors.

Another possible limitation, which could be addressed in future studies, was inconsistencies in the way sleep data were collected, coded, and edited across our three different assessment methods. For example, due to feasibility constraints, only the first four hours of videosomnography data were coded. However, the full night of actigraphy data was included in analyses. This discrepancy may have resulted in a lack of cross-method agreement. While other studies have used this four hour coding duration (Ball et al., 2006), it is unclear whether infants' first four hours of sleep are representative of their entire night of sleep. Further, variables such as the longest continuous sleep period would clearly vary based on the observation period used. There were also some decisions made in terms of coding infant night wakings that may have contributed to between-method disagreements. Because actigraphy has been shown to over-estimate infant wakefulness (Insana, Gozal, & Montgomery-Downs, 2010; Meltzer, Montgomery-Downs, Insana, & Walsh, 2012) infants had to exhibit 5 continuous minutes of wakefulness in order for a night waking to be coded in our actigraphy data. In videosomnography, because infant eye opening and vocalization could be used as additional indicators of wakefulness, only 1 minute of continuous wakeful behavior (or 30 seconds of clear distress) were necessary in order to classify a night waking. For sleep diaries, mothers could report night wakings of any duration throughout the nighttime period. Thus, differences in both the observation period and coding criteria could have contributed to the weak inter-method correlations observed in the current study, which limited our ability to identify indicators of sleep consolidation and regulation across methods.

Finally, this study only assessed infants at two time points during the first six months of life. Although we would expect that the processes of sleep consolidation and regulation described in the current study would also be evident in the second half of the first year of life, this is an empirical question that remains to be tested. It is also possible that these two processes may become more or less related over time, new processes may emerge entirely (e.g., sleep duration may become differentiated from sleep quality), or new indicators of existing processes may become relevant (e.g., sleep disruption due to infant separation anxiety or nighttime fears may contribute to sleep regulation). The use of additional time points would also have enabled us to model trajectories of infant sleep development, using methods such as latent growth curve modeling. Finally, our use of this specific age group of infants limited the cognitive assessments that were possible. Continued assessment into the second year of life might provide a better lens for understanding the link between sleep and higher-order cognitive processes.

### 4.6 Implications and Future Directions

Despite the limitations of the current study, our finding that sleep consolidation and regulation are separable, latent processes is important for the future of infant sleep research for several reasons. First, the notion that there are two distinct components of infant sleep quality increases the specificity with which we can understand both the normative development of sleep across the first years of life, as well as factors that promote or hinder the development of these processes. Previous studies on infant sleep have tended to select only a subset of possible sleep variables as either predictors or outcomes, without a clear rationale for why those specific variables were considered. In addition, review papers have not yet synthesized the wide array of extant findings into a more specific, theoretical model of infant sleep development. While Sadeh and colleagues' (2010) transactional model remains the primary framework for understanding the direct and indirect effects of infant characteristics and parental input on infant sleep, this model does not differentiate between different types of sleep outcomes (e.g., sleep duration, quality, schedule). Differentiating between sleep processes is important because, as evidenced by our findings, there may be different antecedents and correlates of these two processes. For example, intrinsic characteristics were more strongly related to infant sleep consolidation, whereas extrinsic factors were more related to infant sleep regulation, and only infant sleep regulation seemed related to infant cognition. In addition, the same intrinsic and extrinsic factors (i.e., positive affect/surgency and emotional availability) interacted in different ways to predict these two processes. Clearly, there is more work to be done in unpacking these direct and interactive relationships as they relate to specific sleep processes. We expect that these efforts will likely contribute to expanded theoretical models of infant sleep development.

Our latent modeling approach not only increases the specificity of our understanding of infant sleep development, but it also provides a more precise metric with which to study it. Previous studies have tended to use individual indicators of infant sleep duration or quality as either predictor or outcome variables. In doing so, these studies implicitly assume that their observed variables are perfectly reliable indicators of underlying constructs. By ignoring measurement error, the findings from these studies may either be biased or imprecise (Bollen, 1989). Our approach is an improvement upon the status quo, in that our latent constructs appropriately parse out measurement error, resulting in measures of infant sleep consolidation and regulation that are more precise than their component indicators. We strongly urge future researchers to attempt to replicate this measurement model in their own samples, to better understand whether it is generalizable beyond African-American infants.

Another key finding from our latent variable model was that different methods seemed more or less useful as indices of different sleep processes. Whereas actigraphy was useful in providing indicators of sleep consolidation, it did not contribute to our latent variable indicative of sleep regulation. Videosomnography, on the other hand, was more useful in defining sleep regulation, as opposed to consolidation. These differences add to a growing debate regarding best practices for measuring infant sleep (for a review, see Sadeh, 2015). One conclusion from this debate is that researchers must take care to select the measures that best fit their research questions. For instance, researchers interested in studying the development of self-soothing must necessarily use videosomnography, as this is the only approach that allows researchers to observe infant and parent behavior during a night waking. On the other hand, researchers interested in the role of infant sleep in predicting parent outcomes (e.g., parental stress, psychopathology) might consider using sleep diaries, as these may do a better job at capturing parental perceptions of infant sleep. Our findings clearly suggest that using both actigraphy and videosomnography together may result in the most detailed picture of infant sleep, at least in the first six months of life. Future research might consider how parent's reports of their infant's sleep behavior fits into this picture.

Beyond advancing the measurement of infant sleep, the findings from this dissertation have implications for how we understand the transactions between children and parents that influence sleep development. The majority of research on infant sleep development has examined direct effects of child and parent characteristics on sleep, rather than the interaction between these factors. However, more recent research (including the current findings) suggest that examining the interaction between child- and parent-level factors may contribute to a deeper understanding of the individual differences between children that may make them more or less susceptible to parental input in order to develop consolidated, well-regulated sleep (Gueron-Sela et al., 2017; Jian & Teti, 2016). Although these ideas have existed in the domain of developmental science for some time, as indicated by concepts such as goodness-of-fit (Thomas & Chess, 1977) and theoretical models such as diathesis-stress (Monroe & Simons, 1991) and differential susceptibility (Belsky & Pluess, 2009), they have not yet been widely embraced in the sleep literature. However, given the clear challenge that infant sleep poses for parents, as indexed by high levels of clinically-reported concerns (Goodlin-Jones, Burnham, & Anders, 2001; Mindell et al., 1999) and a proliferation of sleep training techniques and evaluations (e.g., Gradisar et al., 2016), this type of research is likely to be both empirically and practically useful. Future research should continue to explore the interactions of child and parent factors in predicting infant sleep at different time points in development, moving beyond the specific factors and ages that were tested here.

Finally, the relationship between infant sleep and attention that we observed for at least some of our sample suggests that the sleep-cognition linkages that have been reported previously in the literature may have downward extensions to infancy. The mechanisms that concurrently link these two processes are beginning to be understood in adolescents and adults, and include the role of sleep in resting and resetting neural connections that subsequently promote daytime cognitive functioning (e.g., Yoo et al., 2007). It is unclear whether these same mechanisms are at work earlier in development. However, as others have argued (e.g., Dahl, 1996), sleep may play a particularly important role in supporting neural development at a time when the brain is rapidly establishing and calibrating its connectivity networks. Extant studies are just beginning to test this hypothesis. Beyond neural mechanisms, other pathways linking sleep and cognition should also be explored. These may include the role of high-quality sleep in supporting infants' ability to explore and reap the benefits of their environment (Bernier et al., 2014).

In sum, this dissertation suggests that sleep consolidation and regulation are two separable latent processes with different antecedents and downstream correlates. These findings advance our understanding of the underlying processes that shape infant sleep patterns across the first years of life, as well as the factors that may contribute to the substantial individual differences observed in these trajectories. Our findings also provide evidence of the utility of latent variable modeling using observed indicators of sleep behavior derived from different methods, which we hope will advance the current debate surrounding optimal measurement of infant sleep. Finally, our finding that sleep regulation contributes to infant's later attention regulation supports the notion that children's self-regulatory abilities are hierarchically organized, with early differences in physiological regulation giving way to later differences in more complex regulatory capacities (Calkins & Fox, 2002). As a whole, these findings help carve out a role for infant sleep within the wider realm of child development research. Like development in other domains, infant sleep is jointly determined by various parent and child characteristics, with the parent-child interactive context serving as the key medium in which these factors play out. We are hopeful that future years will bring increased attention to the role of infant sleep in supporting development across a wide range of domains, as well as an exploration of the mechanisms by which these relationships operate. At the same time, understanding the combination of parent and child factors that come together to optimally support infant sleep development will remain a top research priority. I am optimistic that the research presented in this dissertation will add meaningfully to these conversations.

Table 1. Descriptive statistics for all study variables

| Variable | N | Mean | SD | Minimum | Maximum |
|---|---|---|---|---|---|
| *Demographics* | | | | | |
| Gender = male | 94 | 0.54 | | | |
| Premature | 94 | 0.07 | | | |
| Age, months (3mo) | 91 | 3.56 | .46 | 2.63 | 5.10 |
| Age, months (6mo) | 86 | 6.47 | .49 | 5.52 | 8.35 |
| Maternal education, years | 88 | 14.66 | 2.21 | 10.00 | 18.00 |
| *Infant Sleep (3 Mo)* | | | | | |
| Longest sleep period, min (A) | 80 | 293.18 | 82.68 | 119.21 | 527.29 |
| Nighttime sleep ratio (A) | 80 | 0.73 | 0.08 | 0.51 | 0.91 |
| Number of naps (A) | 80 | 2.95 | 0.68 | 1.20 | 4.83 |
| Total wake proportion (V) | 81 | 0.06 | 0.06 | 0.00 | 0.26 |
| Self-soothed wake proportion (V) | 76 | 0.32 | 0.39 | 0.00 | 1.00 |
| Parental interventions (V) | 81 | 2.07 | 1.87 | 0.00 | 8.00 |
| *Infant Sleep (6 Mo)* | | | | | |
| Longest sleep period, min (A) | 74 | 309.40 | 80.74 | 146.71 | 563.64 |
| Nighttime sleep ratio (A) | 74 | 0.77 | 0.07 | 0.56 | 0.98 |
| Number of naps (A) | 74 | 2.54 | 0.62 | 1.40 | 4.33 |
| Total wake proportion (V) | 65 | 0.03 | 0.04 | 0.00 | 0.16 |
| Self-soothed wake proportion (V) | 57 | 0.41 | 0.42 | 0.00 | 1.00 |
| Parental interventions (V) | 65 | 1.40 | 1.56 | 0.00 | 7.00 |
| *Intrinsic Factors* | | | | | |
| Birth weight, grams | 59 | 3233 | 549 | 1644 | 4289 |
| RSA at baseline | 67 | 3.38 | .85 | 1.80 | 5.31 |
| IBQ – Positive Emotionality | 76 | 4.49 | .91 | 2.92 | 6.73 |
| IBQ – Negative Emotionality | 76 | 3.98 | .89 | 2.27 | 6.00 |
| IBQ – Orienting/Regulation | 76 | 5.65 | .69 | 4.08 | 7.00 |
| *Extrinsic Factors* | | | | | |
| Maternal presence, proportion | 76 | 0.71 | 0.34 | 0.00 | 1.00 |
| Close contact, proportion | 76 | 0.30 | 0.27 | 0.00 | 0.93 |
| Quiet activities, proportion | 76 | 0.16 | 0.16 | 0.00 | 0.63 |
| Infant put down asleep | 75 | 0.45 | | | |
| Emotional availability | 64 | 0.00 | 0.81 | -1.93 | 1.37 |
| Maternal depressive symptoms | 86 | 10.99 | 9.14 | 0.00 | 43.00 |
| *Cognitive Outcomes* | | | | | |
| Bayley scaled score | 82 | 10.66 | 2.45 | 3.00 | 17.00 |
| Median looking time, sec | 71 | 7.58 | 4.76 | 1.11 | 22.92 |

*Note*. mo = months; min = minutes, A = actigraphy; V = videosomnography; RSA = respiratory sinus arrhythmia; IBQ = Infant Behavior Questionnaire; sec = seconds.

Table 2. Bivariate correlations among 3 month sleep indicators.

| | LSP (A) | NSR (A) | NAPN (A) | TWP (V) | SSWP ( V) | PINT (V) |
|---|---|---|---|---|---|---|
| 1. LSP (A) | - | | | | | |
| 2. NSR (A) | .48*** | - | | | | |
| 3. NAPN (A) | -.22* | -.35** | - | | | |
| 4. TWP (V) | -.21 | -.15 | -.02 | - | | |
| 5. SSWP (V) | .31* | .11 | .10 | -.43*** | - | |
| 6. PINT (V) | -.35** | -.22 | -.08 | .64*** | -.60*** | - |

*Note*. $N$ = 67 – 80. $*p \leq .05$, $**p \leq .01$, $***p \leq .001$. LSP = longest sleep period; NSR = nighttime sleep ratio; NAPN = number of daytime naps; TWP = total wake proportion; SSWP = self-soothed wake proportion; PINT = parental interventions; A = actigraphy; V = videosomnography.

Table 3. Bivariate correlations among 6 month sleep indicators.

| | LSP (A) | NSR (A) | NAPN (A) | TWP (V) | SSWP ( V) | PINT (V) |
|---|---|---|---|---|---|---|
| 1. LSP (A) | - | | | | | |
| 2. NSR (A) | .31** | - | | | | |
| 3. NAPN (A) | -.33** | -.47*** | - | | | |
| 4. TWP (V) | -.02 | .03 | -.09 | - | | |
| 5. SSWP (V) | .19 | -.08 | .19 | -.42** | - | |
| 6. PINT (V) | .03 | .13 | -.16 | .46*** | -.63*** | - |

*Note*. $N$ = 51 – 74. *$p \leq .05$, **$p \leq .01$, ***$p \leq .001$. LSP = longest sleep period; NSR = nighttime sleep ratio; NAPN = number of daytime naps; TWP = total wake proportion; SSWP = self-soothed wake proportion; PINT = parental interventions; A = actigraphy; V = videosomnography.

Table 4. Model fit statistics for nested models.

| Model | Model Description | $\chi^2$ | *df* | *p* | RMSEA | CFI | SRMR | BIC |
|---|---|---|---|---|---|---|---|---|
| *Factor Structure* | | | | | | | | |
| 1 | 1 latent variable (3 mo) | 33.59 | 9 | < .001 | .18 | .77 | .12 | -6.81 |
| 2 | 2 latent variables (3 mo) | 11.57 | 8 | .17 | .07 | .97 | .08 | -24.34 |
| 3 | 1 latent variable (6 mo) | 53.48 | 9 | < .001 | .25 | .39 | .18 | 13.93 |
| 4 | 2 latent variables (6 mo) | 11.15 | 8 | .19 | .07 | .96 | .07 | -24.01 |
| *Longitudinal Measurement Invariance* | | $\chi^2$ | *df* | *p* | RMSEA | CFI | SRMR | BIC |
| 5 | Configural Invariance | 95.04 | 48 | <.001 | .10 | .80 | .11 | -122.52 |
| 5a | Configural Invariance w/ residual correlations (LSP) | 64.72 | 47 | .04 | .06 | .92 | .11 | -148.31 |
| 5b | Configural Invariance w/ residual correlations (LSP, NSR, NAPN) | 51.66 | 45 | .23 | .04 | .97 | .11 | -152.31 |
| 6 | Metric Invariance | 63.40 | 49 | .08 | .06 | .94 | .12 | -158.70 |
| *Nested Tests* | | $\Delta\chi^2$ | $\Delta$ *df* | *p* | | $\Delta$CFI | | |
| 1 | Model 2 vs. 1 | 22.02 | 1 | < .001 | | .20 | | |
| 2 | Model 4 vs. 3 | 42.33 | 1 | < .001 | | .57 | | |
| 3 | Model 6 vs. 5b | 11.74 | 4 | .02 | | .03 | | |

*Note*. RMSEA = root mean square error of approximation; SRMR = standardized root mean square residual; BIC = Bayesian information criteria; mo = month; LSP = longest sleep period; NSR = nighttime sleep ratio; NAPN = number of daytime naps.

Table 5. Bivariate correlations among all study variables.

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 | 20 | 21 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Gender (1= Male) | - | | | | | | | | | | | | | | | | | | | | |
| 2. Premature | .10 | - | | | | | | | | | | | | | | | | | | | |
| 3. Child age, mo (3mo) | -.16 | .06 | - | | | | | | | | | | | | | | | | | | |
| 4. Child age, mo (6mo) | .15 | -.14 | -.12 | - | | | | | | | | | | | | | | | | | |
| 5. Maternal edu, yrs | .00 | -.07 | -.20 | .12 | - | | | | | | | | | | | | | | | | |
| 6. Sleep Consolidation (3mo) | -.09 | -.18 | .18 | .03 | -.06 | - | | | | | | | | | | | | | | | |
| 7. Sleep Regulation (3mo) | .10 | -.23* | -.08 | .14 | -.01 | .36* | - | | | | | | | | | | | | | | |
| 8. Sleep Consolidation (6mo) | -.11 | -.06 | .06 | .15 | .23 | .47* | -.16 | - | | | | | | | | | | | | | |
| 9. Sleep Regulation (6mo) | .00 | .31 | .15 | .31* | .04 | .08 | .26 | -.14 | - | | | | | | | | | | | | |
| 10. Birth weight, kg | .07 | -.59* | -.02 | .24 | .19 | .31 | .07 | .17 | -.04 | - | | | | | | | | | | | |
| 11. RSA at baseline | .21 | .07 | -.07 | -.07 | -.08 | .01 | -.04 | -.02 | -.15 | .07 | - | | | | | | | | | | |
| 12. IBQ - PAS | -.06 | .01 | -.01 | .06 | -.02 | .14 | .14 | .02 | .18 | -.02 | -.08 | - | | | | | | | | | |
| 13. IBQ - NEG | -.29* | .07 | .08 | .01 | -.03 | -.28* | -.29* | -.10 | .09 | .05 | .00 | .12 | - | | | | | | | | |
| 14. IBQ - ORC | .02 | .00 | -.14 | .07 | .10 | .06 | .01 | .28 | .22 | -.07 | -.28* | .57* | -.10 | - | | | | | | | |
| 15. Maternal presence | -.04 | -.13 | -.17 | .01 | -.12 | .06 | .09 | -.10 | -.20 | .03 | .10 | .10 | .00 | .02 | - | | | | | | |
| 16. Close contact | .01 | .00 | -.18 | .06 | -.01 | .03 | .02 | -.07 | -.35* | .08 | .03 | .01 | .15 | -.04 | .59* | - | | | | | |
| 17. Quiet activities | -.09 | -.12 | -.05 | .04 | .06 | .11 | .10 | .21 | -.07 | .08 | -.16 | .07 | .01 | .09 | .42* | .50* | - | | | | |
| 18. Infant put down asleep | -.05 | .03 | -.14 | -.07 | .05 | .27 | .05 | .21 | -.20 | -.11 | .00 | .00 | -.08 | .12 | .28* | .39* | .25* | - | | | |
| 19. Emotional availability | .02 | -.09 | .03 | -.02 | .26* | .00 | -.21 | .15 | -.02 | -.13 | -.24 | .05 | -.11 | .17 | -.22 | -.04 | .18 | .15 | - | | |
| 20. Depressive Symptoms | .00 | -.02 | -.15 | .20 | -.06 | .08 | .01 | .13 | -.15 | .08 | -.06 | .08 | .09 | -.10 | .03 | .02 | .00 | -.08 | -.14 | - | |
| 21. Bayley scaled score | -.02 | -.17 | .03 | .15 | .03 | .00 | -.05 | .04 | .07 | .20 | -.06 | -.01 | -.01 | -.14 | .02 | -.12 | .01 | -.03 | .17 | .19 | - |
| 22. Looking time, sec | .07 | -.19 | .00 | .14 | .28* | .08 | .18 | .25 | -.12 | .20 | -.22 | .12 | .10 | -.03 | .13 | .13 | .19 | -.16 | .30* | .24 | .17 |

*Note*. *$p \leq .05$. mo = months; edu = education; yrs = years; kg = kilograms; RSA = respiratory sinus arrhythmia; IBQ = Infant Behavior Questionnaire; PAS = positive emotionality/surgency; NEG = negative emotionality; ORC = orienting/regulating capacity; sec = seconds. Associations involving sleep consolidation and regulation at 3 and 6 months represent correlations with the latent constructs.

Table 6. Standardized regression coefficients for direct effects models

| | Consolidation | | | Regulation | | |
|---|---|---|---|---|---|---|
| | β | 95% CI | Model $R^2$ | β | 95% CI | Model $R^2$ |
| *Step 1* | | | | | | |
| Male | -.12 | -.39 to .16 | | -.10 | -.35 to .16 | |
| Premature | .00 | -.37 to .37 | | .34± | -.02 to .69 | |
| Child age, mo | .13 | -.16 to .43 | | .37* | .09 to .65 | |
| Maternal education, yrs | .20 | -.09 to .49 | .07 | .03 | -.22 to .28 | .21 |
| *Step 2* | | | | | | |
| Premature | .10 | -.27 to .47 | | .34± | -.05 to .72 | |
| Child age, mo | .10 | -.20 to .39 | | .35* | .07 to .63 | |
| Birth weight, kg | .23± | -.08 to .54 | | .13 | -.31 to .57 | |
| RSA at baseline | .07 | -.27 to .41 | | .00 | -.37 to .37 | |
| IBQ - PAS | -.18 | -.54 to .17 | | -.01 | -.39 to .37 | |
| IBQ - NEG | -.02 | -.35 to .31 | | .10 | -.24 to .43 | |
| IBQ - ORC | .45** | .10 to .81 | .17 | .18 | -.20 to .55 | .24 |
| *Step 3* | | | | | | |
| Premature | .08 | -.29 to .46 | | .30± | -.10 to .70 | |
| Child age, mo | .09 | -.20 to .37 | | .41** | .14 to .68 | |
| Birth weight, kg | .24 | -.19 to .67 | | .18 | -.37 to .72 | |
| IBQ - ORC | .34* | .04 to .64 | | .15 | -.17 to .46 | |
| Maternal presence | -.22 | -.62 to .18 | | .06 | -.32 to .44 | |
| Close contact | -.16 | -.59 to .27 | | -.43* | -.77 to -.08 | |
| Quiet activities | .28± | -.06 to .63 | | .13 | -.17 to .43 | |
| Infant put down asleep | .24± | -.09 to .57 | | -.08 | -.37 to .21 | |
| Emotional availability | .02 | -.42 to .46 | | .00 | -.42 to .42 | |
| Depressive Symptoms | .25± | -.04 to .54 | .33 | -.16 | -.42 to .10 | .39 |
| *Final Model* | | | | | | |
| Premature | .15 | -.19 to .49 | | .30± | -.07 to .67 | |
| Child age, mo | .09 | -.18 to .37 | | .42** | .16 to .68 | |
| Birth weight, kg | .31* | .00 to .62 | | .26 | -.18 to .70 | |
| IBQ - ORC | .35* | .05 to .64 | | .14 | -.17 to .44 | |
| Close contact | -.31± | -.69 to .07 | | -.42** | -.73 to -.12 | |
| Quiet activities | .29± | -.04 to .62 | | .16 | -.13 to .45 | |
| Infant put down asleep | .20 | -.12 to .51 | | -.06 | -.35 to .23 | |
| Depressive Symptoms | .27± | -.02 to .56 | .34 | -.15 | -.41 to 10 | .40 |

*Note*. $^{\pm}p \leq .15$, $^{*}p \leq .05$, $^{**}p \leq .01$, $^{***}p \leq .001$. Child age refers to child age in months at the 6 month home visit. CI = confidence interval; mo = months; yrs = years; kg = kilograms; RSA = respiratory sinus arrhythmia; IBQ = Infant Behavior Questionnaire; PAS = positive emotionality/surgency; NEG = negative emotionality; ORC = orienting/regulating capacity.

Table 7. Standardized regression coefficients for interactive effects models

| | Consolidation | | | Regulation | | |
|---|---|---|---|---|---|---|
| | β | 95% CI | Model $R^2$ | β | 95% CI | Model $R^2$ |
| *Model 1* | | | | | | |
| Premature | .06 | -.33 to .45 | | .36* | .01 to .70 | |
| Child age, mo | .15 | -.15 to .45 | | .37** | .10 to .65 | |
| IBQ - NEG | -.08 | -.45 to .28 | | -.01 | -.35 to .33 | |
| EA | .14 | -.22 to .49 | | .05 | -.26 to .36 | |
| IBQ - NEG x EA | .00 | -.42 to .41 | .05 | .22 | -.15 to .60 | .27 |
| *Model 2* | | | | | | |
| Premature | .00 | -.36 to .37 | | .28± | -.10 to .65 | |
| Child age, mo | .07 | -.23 to .37 | | .50* | .23 to .77 | |
| IBQ – PAS | .11 | -.20 to .41 | | -.01 | -.31 to .30 | |
| EA | .09 | -.26 to .44 | | .13 | -.16 to .43 | |
| IBQ - PAS x EA | -.38* | -.71 to -.06 | .17 | .41** | .10 to .72 | .37 |
| *Model 3* | | | | | | |
| Premature | .03 | -.34 to .40 | | .33± | -.04 to .70 | |
| Child age, mo | .19 | -.12 to .49 | | .37** | .09 to .65 | |
| RSA at baseline | .03 | -.35 to .40 | | .01 | -.40 to .41 | |
| EA | .31± | -.09 to .71 | | .04 | -.34 to .42 | |
| RSA x EA | -.41± | -.92 to .09 | .19 | .05 | -.50 to .59 | .21 |

*Note*. ±$p \leq .15$, *$p \leq .05$, **$p \leq .01$, ***$p \leq .001$. Child age refers to child age in months at the 6 month home visit. CI = confidence interval; mo = months; IBQ = Infant Behavior Questionnaire; NEG = negative emotionality; PAS = positive emotionality/surgency; EA= Emotional availability; RSA = Respiratory sinus arrhythmia.

Table 8. Standardized coefficients for models predicting 6 month cognitive outcomes

| | Bayley Scaled Score | | | Median Looking Time (s) | | |
|---|---|---|---|---|---|---|
| | β | 95% CI | Model $R^2$ | β | 95% CI | Model $R^2$ |
| *Step 1* | | | | | | |
| Male | -.03 | -.24 to .19 | | .06 | -.16 to .28 | |
| Premature | -.15 | -.37 to .06 | | -.17$^{\pm}$ | -.37 to .04 | |
| Child age, mo | .15 | -.10 to .39 | | .07 | -.18 to .31 | |
| Maternal education, yrs | .00 | -.24 to .24 | .05 | .24* | .03 to .46 | .11 |
| *Step 2* | | | | | | |
| Premature | -.20$^{\pm}$ | -.42 to .02 | | -.16 | -.37 to .06 | |
| Maternal education, yrs | .02 | -.22 to .26 | | .26* | .05 to .46 | |
| Sleep Consolidation, 3 mo | .00 | -.35 to .34 | | -.21 | -.58 to .17 | |
| Sleep Regulation, 3 mo | -.10 | -.36 to .16 | .04 | .20 | -.09 to .49 | .16 |
| *Step 3* | | | | | | |
| Premature | -.24* | -.47 to -.02 | | -.11 | -.32 to .11 | |
| Maternal education, yrs | .02 | -.20 to .23 | | .25* | .03 to .47 | |
| Sleep Consolidation, 3 mo | -.02 | -.37 to .33 | | -.35$^{\pm}$ | -.72 to .03 | |
| Sleep Regulation, 3mo | -.20$^{\pm}$ | -.47 to .07 | | .29* | .00 to .58 | |
| Consolidation x Education | .17 | -.26 to .61 | | -.19 | -.52 to .15 | |
| Regulation x Education | -.03 | -.36 to .30 | .11 | .41** | .15 to .67 | .35 |

*Note*. $^{\pm}p \leq .15$, $*p \leq .05$, $**p \leq .01$, $***p \leq .001$. Child age refers to child age in months at the 6 month home visit. CI = confidence interval; mo = months; yr = years.

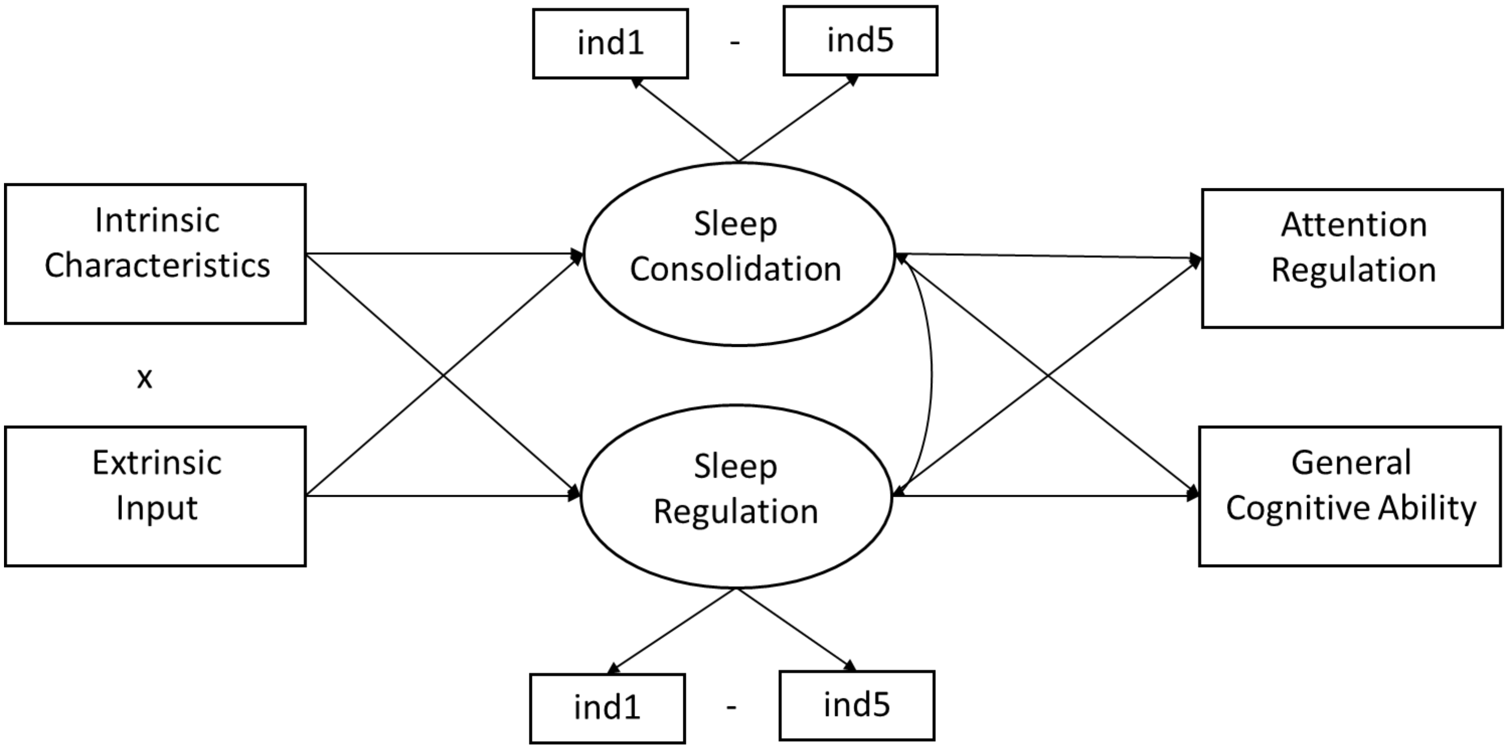


*Figure 1.* Conceptual model. Circles indicate latent variables while rectangles indicate observed (manifest) variables. The full measurement model for latent variables, with up to five indicators per construct, is not pictured. Intrinsic characteristics refer to characteristics of the infant, including temperament, birth weight, and heart rate variability. Extrinsic input refers to caregiver qualities or behaviors, including bedtime parenting practices, emotional availability, and maternal depressive symptoms. ind = indicator.

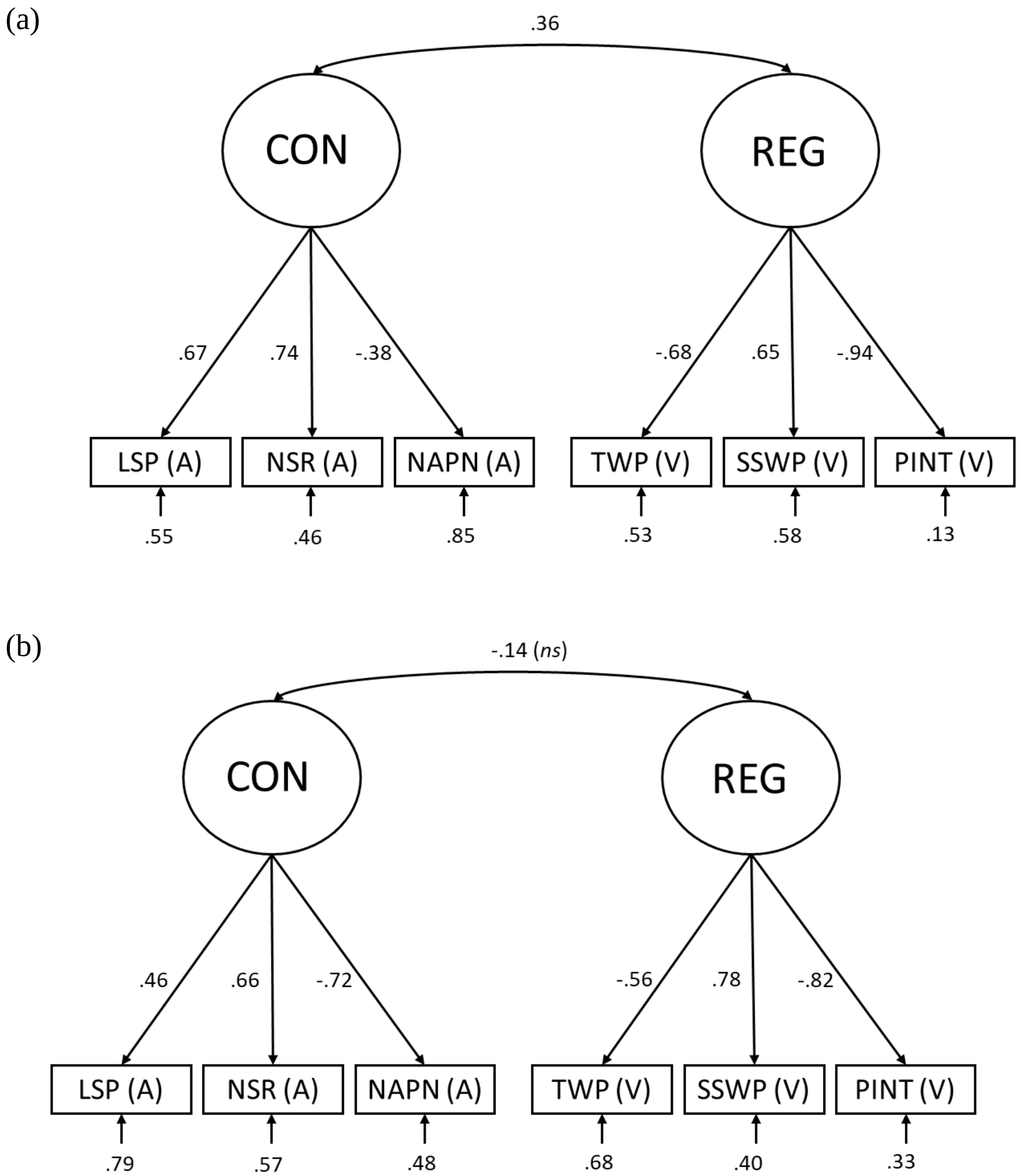


*Figure 2*. Final measurement model at (a) 3 months and (b) 6 months. CON = consolidation; REG = regulation; LSP = longest sleep period; NSR = nighttime sleep ratio; NAPN = number of daytime naps; TWP = total wake proportion; SSWP = proportion of self-soothed wakings; PINT = number of parental interventions; A = actigraphy; V = videosomnography; ns = non-significant ($p$ > .05).

(a)

(b)

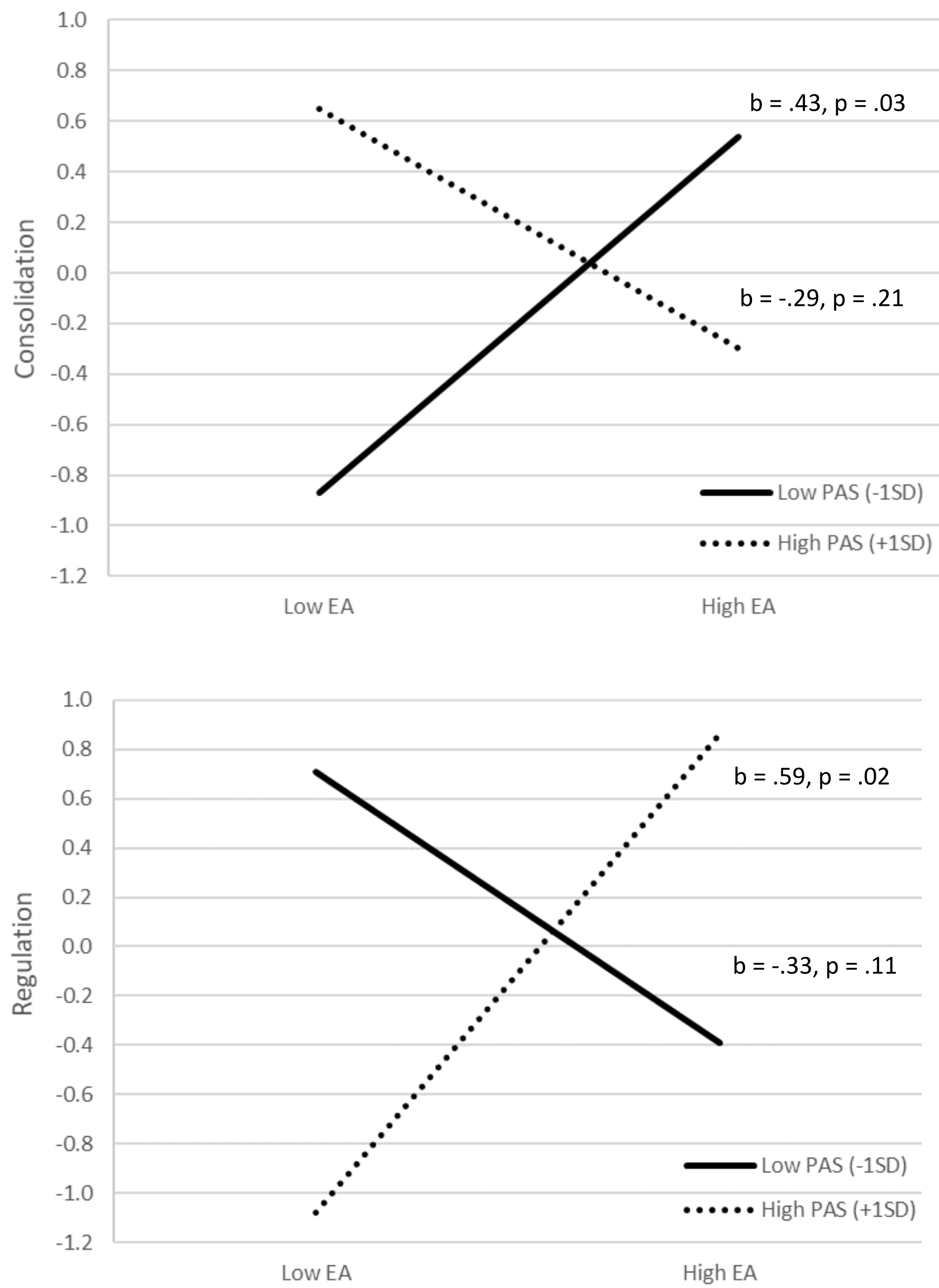


*Figure 3.* Interaction between child positive emotionality/surgency (PAS) and maternal emotional availability (EA) at 3 months predicts (a) infant sleep consolidation and (b) regulation at 6 months.

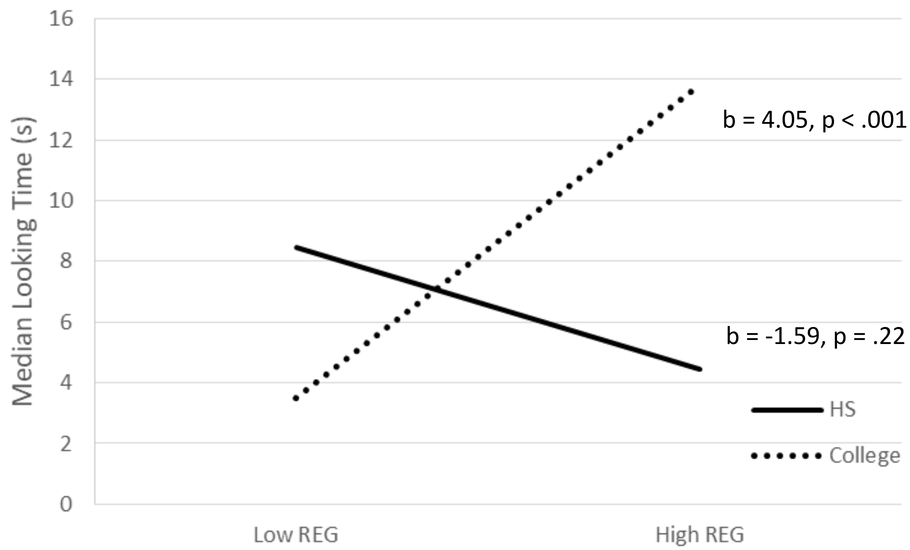


*Figure 4.* Interaction between child sleep regulation and maternal education in predicting infant attention. s = seconds; HS = high school degree; College = college degree; REG = regulation.

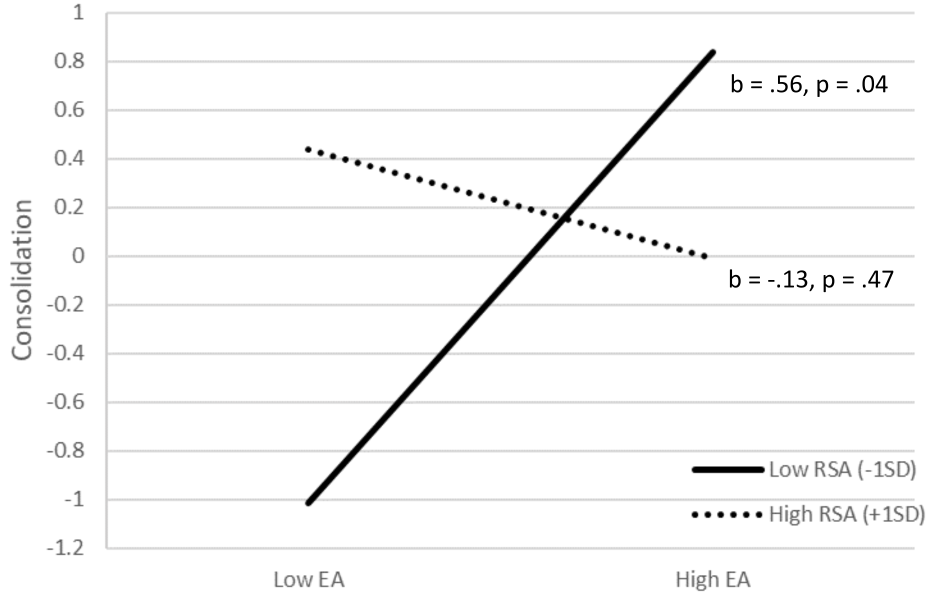


*Figure 5.* Interaction between child baseline respiratory sinus arrhythmia (RSA) and maternal emotional availability (EA) in predicting infant sleep consolidation.

# APPENDIX A: ADDITIONAL TABLES

Table A1. Variables derived from each sleep assessment method.

| Variable Name (*Abbreviation*) | Definition | Hypothesized Construct | Relation to Construct |
|---|---|---|---|
| **Actigraphy** | | | |
| Total sleep time (*TST*) | Amount of sleep during sleep period | Consolidation | Positive |
| Total wake time (*TWT*) | Amount of wake during sleep period | Regulation | Negative |
| Efficiency (*EFF*) | Ratio of time asleep to time in bed | Regulation | Positive |
| Night wakings (*NW*) | Number of periods of wakefulness > 5 min | Regulation | Negative |
| Longest sleep period (*LSP*) | Longest continuous sleep period | Consolidation | Positive |
| Number of daytime naps (*NAPN*) | Number of daytime sleep periods | Consolidation | Negative |
| Duration of daytime naps (*NAPD*) | Total duration of daytime sleep periods | Consolidation | Negative |
| Nighttime sleep ratio (*NSR*) | Ratio of nighttime sleep to total (24-h) sleep | Consolidation | Negative |
| **Videosomnography** | | | |
| Total sleep proportion (*TSP*) | Proportion of sleep time in observation period | Consolidation | Positive |
| Total wake proportion (*TWP*) | Proportion of sleep time in observation period | Regulation | Negative |
| Longest sleep period (*LSP*) | Longest continuous sleep period | Consolidation | Positive |
| Night wakings (*NW*) | Number of periods of wakefulness | Regulation | Negative |
| Self-soothed wakings (*SSW*) | Number of wakings that do not receive parent intervention | Regulation | Positive |
| Parental interventions (*PINT*) | Number of parent responses to infant during observation period | Regulation | Negative |
| **Sleep Diaries** | | | |
| Number of daytime naps (*NAPN*) | Number of daytime sleep periods | Consolidation | Negative |
| Duration of daytime naps (*NAPD*) | Total duration of daytime sleep periods | Consolidation | Negative |
| Night wakings (*NW*) | Number of reported wake periods | Regulation | Negative |
| Sleep period duration (*SPD*) | Time from sleep onset to morning wake | Consolidation | Positive |

Table A2. Correlation among all consolidation variables at 3 months

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. TST (A) | - | | | | | | | | | |
| 2. LSP (A) | .77* | - | | | | | | | | |
| 3. NAPN (A) | -.13 | -.22* | - | | | | | | | |
| 4. NAPD (A) | -.19 | -.22* | .34* | - | | | | | | |
| 5. NSR (A) | .54* | .48* | -.35* | -.92* | - | | | | | |
| 6. TSP (V) | .13 | .20 | .03 | -.09 | .15 | - | | | | |
| 7. LSP (V) | .08 | -.01 | .14 | .17 | -.09 | .51* | - | | | |
| 8. SPD (D) | .18 | .11 | -.05 | -.07 | .13 | -.22* | -.22* | - | | |
| 9. NAPN (D) | .07 | .08 | .22 | -.05 | .10 | -.06 | .05 | .12 | - | |
| 10. NAPD (D) | -.07 | .04 | .16 | .17 | -.17 | -.12 | -.08 | .13 | .57* | - |

*Note*. $^*p < .05$. TST = total sleep time; LSP = longest sleep period; NAPN = number of daytime naps; NAPD = duration of daytime naps; NSR = nighttime sleep ratio; TSP = total sleep proportion; SPD = sleep period duration; A = actigraphy; V = videosomnography; D = sleep diaries.

Table A3. Correlation among all consolidation variables at 6 months

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| 1. TST (A) | - | | | | | | | | | |
| 2. LSP (A) | .72* | - | | | | | | | | |
| 3. NAPN (A) | -.22* | -.33* | - | | | | | | | |
| 4. NAPD (A) | -.16 | -.11 | .41* | - | | | | | | |
| 5. NSR (A) | .43* | .31 | -.47* | -.94 | - | | | | | |
| 6. TSP (V) | .02 | .04 | -.16 | -.14 | .16 | - | | | | |
| 7. LSP (V) | .10 | .20 | -.08 | -.04 | .08 | .51* | - | | | |
| 8. SPD (D) | -.04 | -.09 | .15 | .05 | -.05 | .08 | -.03 | - | | |
| 9. NAPN (D) | .11 | .03 | .16 | .14 | -.09 | -.12 | -.15 | .13 | - | |
| 10. NAPD (D) | .01 | -.10 | .09 | .34* | -.32* | .06 | -.04 | .13 | .35* | - |

*Note*. *$p$ < .05. TST = total sleep time; LSP = longest sleep period; NAPN = number of daytime naps; NAPD = duration of daytime naps; NSR = nighttime sleep ratio; TSP = total sleep proportion; SPD = sleep period duration; A = actigraphy; V = videosomnography; D = sleep diaries.

Table A4. Correlation among all regulation variables at 3 months

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1. TWT (A) | - | | | | | | | |
| 2. EFF (A) | -.38* | - | | | | | | |
| 3. NW (A) | .14 | -.57* | - | | | | | |
| 4. TWP (V) | -.02 | -.17 | .13 | - | | | | |
| 5. NW (V) | .19 | -.17 | .19 | .15 | - | | | |
| 6. SSWP (V) | .09 | .19 | -.23 | -.43* | -.03 | - | | |
| 7. PINT (V) | .02 | -.26 | .29* | .64* | .41* | -.60* | - | |
| 8. NW (D) | .01 | -.11 | .20 | .20 | -.01 | -.39* | .15 | - |

*Note*. *$p < .05$. TWT = total wake time; EFF = efficiency; NW = night wakings; TWP = total wake proportion; SSWP = proportion of self-soothed wakings; PINT = number of parental interventions; A = actigraphy; V = videosomnography; D = sleep diaries.

Table A5. Correlation among all regulation variables at 6 months

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|---|---|---|---|---|---|---|---|---|
| 1. TWT (A) | - | | | | | | | |
| 2. EFF (A) | -.59* | - | | | | | | |
| 3. NW (A) | -.30* | -.18 | - | | | | | |
| 4. TWP (V) | -.23 | .15 | .18 | - | | | | |
| 5. NW (V) | -.15 | .10 | .05 | .44* | - | | | |
| 6. SSWP (V) | .20 | .02 | -.28* | -.37* | -.27* | - | | |
| 7. PINT (V) | -.27* | .20 | .07 | .75* | .55* | -.52* | - | |
| 8. NW (D) | .06 | -.03 | .36* | .31* | .10 | -.20 | .12 | - |

*Note*. *$p$ < .05. TWT = total wake time; EFF = efficiency; NW = night wakings; TWP = total wake proportion; SSWP = proportion of self-soothed wakings; PINT = number of parental interventions; A = actigraphy; V = videosomnography; D = sleep diaries.

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