A Review of the Effects of Sleep During the First Year of Life on Cognitive, Psychomotor, and Temperament Development

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During the first year of life, infants spend most of their time in the sleeping state. Assessment of sleep during infancy presents an opportunity to study the impact of sleep on the maturation of the central nervous system (CNS), overall functioning, and future cognitive, psychomotor, and temperament development. To assess what is currently known regarding sleep during infancy and its effects on cognitive, psychomotor, and temperament development, we assessed the relevant literature published over the last several decades. To provide a foundation for a more in-depth understanding of this literature, we preface this with an overview of brain maturation, sleep development, and various assessment tools of both sleep and development during this unique period. At present, we do not have sufficient data to conclude that a causal relationship exists between infant sleep and cognitive, psychomotor, and temperament development. Caution should be used in predicting outcomes, as the timing and subjectivity of evaluations may obviate accurate assessment. Collectively, studies assess a wide array of sleep measures, and findings from one developmental period cannot be generalized readily to other developmental periods. Future studies should follow patients longitudinally. Additionally, refinements of existing assessment tools would be useful. In view of the relatively high reported pediatric prevalence of cognitive and behavioral deficits that carry significant long-term costs to individuals and society, early screening of sleep-related issues may be a useful tool to guide targeted prevention and early intervention.

Keywords: Infant sleep, cognitive, psychomotor, and temperament development

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SLEEP IS ESSENTIAL TO HUMAN LIFE AND INVOLVES BOTH PHYSIOLOGIC AND BEHAVIORAL PROCESSES. DURING THE FIRST YEAR OF LIFE, INFANTS SPEND most of their time in the sleeping state. Sleep is recognized not simply as a resting state, but as a state that involves intense brain activity.[1] Assessment of sleep during infancy presents an opportunity to study the impact of sleep on the maturation of the central nervous system (CNS), overall functioning, and future cognitive, psychomotor, and temperament development.[2]

To date, most studies that relate sleep and development have been performed either in animals, adults, or older children. In children, a number of studies relate various sleep measures and sleep patterns to hyperactivity, shortened attention span, and cognitive and behavioral deficits.[3-8] In view of the limited research conducted in infants, the findings in studies involving animals, adults, and older children are often applied to infants.[9]

To assess what is currently known regarding sleep during infancy and its effects on development, we assessed the relevant literature published over the last several decades; studies were obtained using PubMed. Inclusion criteria were studies that evaluated both sleep and development during the first year of life. To provide a foundation for a more in-depth understanding of this literature, we preface this with an overview of brain maturation, sleep development, and various assessment tools of both sleep and development during this unique period.

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OVERVIEW

Brain Maturation

The first year of life is a time of substantial change in the development of both the human brain and sleep. The relationship between the two is vital, as the control of sleep and the sleep-wake cycle are regulated by the CNS.[10]

Under normal circumstances, the maturation of the prenatal brain follows a specific sequence. This embryologic process begins in the brainstem, and progresses to the cerebellum, and then to the cerebrum.[11] On the cellular level, overlapping stages of neuronal proliferation, migration, differentiation, and early aspects of maturation occur prenatally. Dendritic arborization and synapse formation begin prenatally and extend prolifically into the postnatal period. This is followed by synaptic pruning, which creates efficient and specialized neural circuits in a topographic- and system-specific manner. As demonstrated on magnetic resonance imaging (MRI), postnatal brain development involves decreasing water content, increasing lipid and protein content due to myelination, and differentiation of grey/white matter.[11-16] Development of the CNS continues into adulthood, but the most dramatic changes occur during the first 2 years of life.[17]

A fundamental system that controls the sleep-wake cycle is the *circadian timing system*. This system, located in the suprachiasmatic nuclei (SCN) of the anterior hypothalamus, demonstrates rhythmicity and oscillations for close to 24 hours.[18,19] SCN neurogenesis has been detected in humans as early as 18 weeks' conceptional age (CA).[20] Using immunocytochemistry, the maturation of the SCN has been shown to continue throughout the first year of life. Although changes in circadian rhythms occur into late adulthood, they are less dramatic than during infancy.[21,22]

Another essential process involved in brain maturation is *brain plasticity*, which is the genetically determined ability of the infant brain to change its structure and function in response to the environment.[23,25] Studies have shown that when young animals are REM- and NREM-sleep deprived, there is a loss of brain plasticity; this loss is characterized by smaller brains, diminished learning, and negative long-term behavioral effects.[25,26]

Endogenous stimulation is another important component of early neurosensory development. Such stimulation refers to discharges from neurons within the neurosensory system that may not be related to the immediate environmental circumstances of the child, but appear to be essential for axon growth and targeting.[27] These discharges create various connections between sensory organs and essential brain structures.[27] Healthy development depends on endogenous stimulation. Specifically, this includes the visual, auditory, somatesthetic, olfactory, and limbic systems, as well as the hippocampus, pons, brainstem, and midbrain. Endogenous stimulation occurs only during REM sleep, and interference with REM sleep can lead to the abnormal development of these systems and structures in animal models.[23] REM sleep deprivation, for example, results in underdevelopment of the central visual system because no connection is made between retinal ganglion cells and the lateral geniculate nucleus.[24]

Sleep spindles and *K-complexes* also are suspected to be important for normal brain maturation as they are thought to play a role in the development of the cerebral cortex as well as processes of memory and learning**.**[28,29] Sleep spindles and K-complexes are EEG characteristics that appear as distinct sleep stages emerge in the first few months of life.[28] Spindles are produced from rhythmic spike bursts in GABAergic neurons that arise from synchronized activities in neuronal networks that link the thalamus to the cortex.[28,30] K-complexes result from the depolarization and hyperpolarization of cortical neurons.[28] Both features have been clearly characterized, and their abnormal appearance on EEG, especially spindles, may reflect significant underlying anomalies in brain activity.

The Development of Sleep

Sleep during infancy is markedly different from sleep later in childhood and adulthood. A comprehensive and evidence-based review was published by the Pediatric Task Force of the American Academy of Sleep Medicine in 2007. This review provides details on the age-related development of the polysomnographic features of sleep in neonates and infants. It also assesses the reliability and validity of these features, and alternative methods of measurement.[31] Another detailed review, published by de Weerd et al. in 2003, describes the development of sleep during the first months of life.[32]

In the newborn period, the model infant sleeps 16-17 hours per day.[33] By 6 months of age, sleep often decreases to 13-14 hours per day, and the longest sleep period is about 6 hours on average.[33,34] By 1 year of age, the longest sleep period increases to about 8-9 hours on average.[35] Importantly, and too often overlooked in popular parenting books, is the fact that these values represent only rough averages using fallible measurement techniques. It is likely that healthy sleep duration can cover a much broader range for a given child from night to night and across children of the same age.

Sleep states in infants can be termed REM/NREM sleep after 2 months of age. Before this age, terminology for sleep states is different. What later develops into REM sleep is initially classified as active sleep (AS); NREM as quiet sleep (QS); and a final stage of sleep is referred to as indeterminate sleep (IS). NREM can be further subdivided into stages 1, 2, and slow wave sleep in most infants beyond the age of 4-6 months. In IS, some elements of both REM and NREM are seen.[36]

In very young infants, behavioral observations are required to distinguish sleep states due to the subtle differences in EEG characteristics. These include electromyographic (EMG) tone, phasic twitches, rapid eye movements, and respiratory regularity.[37] Prior to 32 weeks CA, sleep is undifferentiated. After 32 weeks CA, rapid eye movements and phasic muscle twitches identify AS. By 40 weeks CA, all the EEG and behavioral correlates of AS, QS, and wakefulness are present.[31,38]

At full term, the background EEG pattern during AS is continuous, with activity from all frequency bands.[32] Rapid eye movements are frequent. Other movements such as sucking, fine twitches, tremors, grimaces, smiles, and limb movements are also observed.[39] Heart rate and respiration occur irregularly during AS, and chin EMG is either very low or highly unstable.[37,40]

The background EEG pattern during QS of a full-term infant is characterized by bursts of θ (4-7 Hz) and δ (0.5-2 Hz) activity intermingled with periods of α (8-13 Hz) and β (> 12 Hz) activity. These bursts, termed *tracé alternant*, last from 3–10 seconds, and alternate with periods of lower amplitude.[32] There is minimal movement observed during QS, and heart rate and respiration are more regular than during AS.[33,39]

The transition from neonatal sleep to infantile sleep is usually completed by 52 weeks CA.[42] Sleep onset in the newborn period is through AS, and is close to 50% of total sleep time.[35] During the first year, the percentage of AS decreases in total time and as a percentage of total sleep time, whereas the amount of QS increases.[43] By 6 months of age, AS occupies approximately 30% of total sleep time.[42] As with AS, the percentage of IS shows a steady decline over the first few months; by 6 months, it is no longer identifiable.[32]

The appearance of the sleep spindle on polysomnography (PSG) hallmarks the transition to infantile sleep. Sleep spindles are bursts of 11–15 Hz, seen primarily over the central regions of the head, and are a polysomnographic feature of stage 2 NREM sleep.[40] They are usually present by 8 to 11 weeks of age in full-term infants.[44] During the first year post-delivery, spindles become more synchronous, about 50% by 6 months of age and 70% by 1 year.[45] In children with CNS abnormalities, however, spindles are often asynchronous beyond 12 months of age, and may represent a unilateral decrease in electrical activity in the brain.[10]

K-complexes are another characteristic feature seen on EEG during stage 2 sleep. A K-complex appears as an initial surface-negative 50–100 μV wave that is 200 msec in duration, and is followed by a 30–50 μV surface-positive wave that is 300–500 msec in duration.[31] K-complexes can first be seen at 5 months of age, and are usually present by 6 months.[46]

One of the last major developments that take place in the sleep of an infant during the first year of life is the development of *stages 1, 2, and slow wave sleep*. Slow wave sleep is characterized by δ frequencies, and can typically be seen on EEG by 4 to 4.5 months of age.[37,47-49] Stages 1, 2 and slow wave sleep should be clearly distinguishable by 5 to 6 months of age.[27]

Methods of Sleep Assessment

Overnight polysomnography (PSG) is the most comprehensive method for assessing sleep in infancy. It is, for example, the only reliable way to acquire EEG data or a full respiratory montage. However, other modalities are also used because they can be more cost-effective, less disruptive to sleep, and used for more prolonged periods of time. Also, despite clearly defined rules for scoring polysomnographic studies, there is variability among scorers. Using a specifically designed system to score sleep in term and pre-term infants, Stefanski et al. reported inter-scorer agreement of 87% in coding EEG patterns.[50] Crowell et al. tested for levels of agreement in scoring PSGs in trained investigators and in technologists before and after a training program.[51] They found the κ (kappa coefficient: measure of inter-rater agreement) for EEG among the trained investigators was 0.56. The κ for technologists increased from 0.52 to 0.76 after training. For sleep states, Hoppenbrouwers et al. found that agreement for scoring IS was 50%, whereas agreement for scoring awake, AS, and QS was > 80%.[52]

Actigraphy is another method that provides important information regarding sleep. The actigraph continuously records limb movements that are scored by computer into states of sleep or wake.[53] Using actigraphy, sleep-state monitoring was consistent with PSG.[54] In infants up to 6 months of age, agreement rates between actigraphy and PSG for determining sleep/wake patterns were 89% to 94%. The predictive value for determining sleep was 97%, with sensitivities between 91% and 96%.[55] Actigraphy has the advantage of recording across days or weeks in the child's natural sleep settings, but it is generally limited to a single "channel" of information (movement). In addition, it is susceptible to artifacts that result in movement despite the occurrence of sleep (e.g., sleeping on someone or in a moving vehicle) or in a lack of movement despite waking (e.g., unit malfunction or removal).

Other methods used in various laboratories to study sleep in young infants include: direct observations, time-lapse video recordings, and pressure-sensitive pads. Time-lapse video recording is non-intrusive and provides information about the infant's sleep environment; however, data can be obtained only while the infant is in the crib.[35,56] Pressure-sensitive pads (also known as motility monitoring) are also attractive because of the lack of instrumentation on the infant, but like video recording or PSG, data can be obtained only while the infant is in the crib.[57] Studies have been done for each of these techniques to demonstrate their reliability and validity; nevertheless, each technique has its own limitations and does not offer the comprehensive evaluation of PSG.[35,56-58] Thus, the choice of instrumentation is heavily dependent on the goals and resources of the investigator. Readers of the scientific literature should be aware of the potential for limitations of any given sleep assessment tool.

Methods of Cognitive and Temperament Assessment

An exhaustive review of the assessment tools used to characterize infant development extends beyond the current paper. The interested reader may wish to review a recent article by Zentner and Bates,[59] Lidz's comprehensive text,[60] or edited volumes by Teti,[61] Zeanah,[62] or DelCarmen-Wiggins and Carter[63] Here, we focus on the measures most commonly utilized in the infant sleep literature.

Among the several published assessment batteries for assessing cognitive development in infants, the most common method for assessing cognitive development during infancy is the Bayley Scale of Infant Development (BSID). This test is a standardized, norm-referenced test that was initially divided into two subscales: the Mental Scale and the Psychomotor Scale, which in the most recent (3rd) edition were supplemented by Social-Emotional and Adaptive Behavior subscales.[64,65] The BSID was adopted to aid in the diagnosis of developmental delay, establish eligibility for interventional services, follow a child's progress over time, and track outcomes in research studies.[66,67]

Although the BSID is an invaluable tool to assess general functioning in infancy, it also has limitations. One such limitation is the use of age-specific item sets. These item sets standardize assessments that are used to make comparisons across populations; however, there is potential for anomalous and inconsistent scores.[68] A second limitation is that alterations in the starting points of evaluations may lead to differences in scores across different settings.[66] A final limitation is the poor predictive validity (0.37) of a subnormal Mental Developmental Index (MDI) score on future cognitive function.[69] This prognostic limitation is also true for other infant development scales, and illustrates the challenges inherent both in the one-on-one assessment of infant cognition, and the dramatic individual differences that can occur in the timing of developmental spurts in healthy children. Despite these limitations, the BSID continues to be a vital research measure and has become a basis for comparing and understanding development in diverse groups of infants and children.[66]

Another aspect of development that is often used for outcome measures is temperament. Again, multiple measurement scales are available, but the most frequently used tools for assessing temperament include the Infant Temperament Questionnaire (ITQ) and the Early Infancy Temperament Questionnaire (EITQ). The ITQ was first published by Thomas et al., and later revised by Carey et al.[70,71] The EITQ was designed specifically for infants younger than 4 months of age. An advantage of these questionnaires is the ease in which they can be implemented on a large scale.[72] Assessments can, nevertheless, vary greatly across different cultures,[73,74] and questionnaires are often completed by the infant's family, which can introduce rater biases and other sources of measurement error. Although these tools have inherent limitations, they continue to be used to aid in the understanding of behavioral development in the infancy period, and can provide important information that complements the information obtained during one-on-one assessments.

ASSOCIATIONS BETWEEN SLEEP AND WAKING FUNCTIONING IN INFANTS

Sleep and Mental Development

Over the last several decades, a number of studies have focused on the degree to which sleep in infancy relates to mental development. Table 1 outlines the key aspects of studies that have attempted to correlate sleep and mental development, and summarizes the results of those studies.

Several reports suggest that normal sleep development may be linked to higher mental development scores. Evaluating preterm infants at 40 weeks CA, Beckwith et al.[75] assessed a number of varying EEG patterns that may play a role in later development. These EEG patterns were indicative of maturity and neurophysiological organization. Infants with higher *tracé alternant*, particularly during QS, scored significantly higher on their 4- and 9-month development assessments. These findings were based on 90 minutes of sleep time, with only the second 60 minutes being used for analysis. One possible limitation in this study is that the limited amount of recording time may not be a true reflection of an infant's sleep over a 24-hour period.

Another study that employed EEG-sleep analyses was done by Scher et al.[76] They performed EEGs in the neonatal period to compare neurodevelopmental outcomes of healthy preterm infants to outcomes in term infants. In the combined cohort of both preterm and term neonates, fewer arousals per minute and lower REMs per minute were predictive of lower MDI at 12 months of age. In their analyses, results were more significant prior to adjustment for prematurity. In all infants, lower socioeconomic class was also correlated with lower mental scores. Limitations recognized by the authors include a small sample size (n = 32) and an atypical representation of healthy premature neonates.

Anders et al.[77] evaluated high- and low-risk premature infants using time-lapse video recordings at multiple time points. They found that mental performance at 24 weeks of age was predicted by the developmental rate of the holding time index; this refers to QS periods early in the night. At 52 weeks of age, mental performance was predicted by greater stability of the longest sustained sleep period. These variables (holding time index and longest sleep period) of sleep-wake state organization reflect greater temporal organization and continuity.

CNS integrity and maturation of sleep-wake organization may also be demonstrated by other characteristics of sleep. Using actigraphy in 10-month old infants, Scher[78] showed that sleep efficiency positively correlated with the Mental Developmental Index (MDI). Consistent with this, higher motor activity and night waking negatively correlated with mental scores. Other measures of sleep that may have confounding effects were not reported.

Becker et al.[79] reported the associations between REM storms and developmental status. These REM storms refer to bursts of intense REMs that occur in active sleep and involve eye movement of very high amplitude. They are an immature inhibitory feedback mechanism in the CNS pathway responsible for sleep organization. In normal development, the reduction of REM storms during the first year of life reflects CNS maturation. Becker et al. demonstrated that REM storms at 6 months of age have a negative correlation with mental scores. While REM sleep is required for endogenous stimulation and subsequent axonal growth, the characteristic bursting pattern of REM storms represent a disturbance in the organization of the CNS.[79] In this study, sleep states and state-related behaviors were determined by using pressure transducers under the infant's crib pad and direct observations during sleep.

Using direct observations, Arditi-Babchuk et al.[80] evaluated sleep-wake states and REM in premature neonates; MDI was assessed at 6 months of age. Similar to the findings of Scher et al.,[76] a direct relationship was observed between REM activity and mental development at this time point. In contrast to the findings of Becker et al.,[79] however, they found no associations between REM storms and later development.

The quality of sleep may also be important. Using overnight PSG in 8-month old infants, Montgomery-Downs et al.[82] showed that snore-related arousals in the absence of apneas or hypopneas, are negatively correlated with mental scores. By using PSG, these authors were able to conclude that no other sleep-related abnormalities contributed to the mental score. Other authors have identified negative correlations between the quality of sleep and mental development. Gertner et al.[83] assessed sleep-wake states in premature infants using actigraphy at 32 and 36 weeks CA, respectively. At 6 months of age, higher mental scores were related to decreased total sleep percentage, decreased nighttime sleep percentage, and increased total nighttime activity level at 36 weeks CA, as compared to 32 weeks CA. The authors acknowledge that a major methodologic limitation of this study is that sleep was assessed using actigraphy. Although this technique has been validated in full-term newborns,[84] there is only one recent study validating its reliability in preterm infants.[85]

Age of Assessment and Mental Scores

While the literature points to an association between markers of healthy sleep and mental development, it is likely that developmental factors moderate those associations. Studies performed that assess sleep at different ages during the first year of life have led to varying results. For example, a report published by Freudigman et al.[81] challenges the notion of a straightforward or invariant relationship between sleep and mental development. Using a technique similar to that used by Becker et al.,[79] these investigators conducted sleep assessments on postnatal days 1 and 2. Results showed that longer sleep periods and less sleep-wake transition were indicative of lower development scores at 6 months of age. In their analyses, effects of mode of delivery (e.g., C-section) were assessed for all measures, and none were found. As the authors point out, one explanation for these findings is the physiologic instability engendered by the birth process. Interestingly, multiple statistically significant sleep variables measured on day 1 were predictive of later mental development; those same variables, however, were not significant on day 2. The authors also present another possible explanation for these findings, which is that longer sleep periods and less sleep-wake transition are an extension of a greater stress response to perinatal events that lead to greater vulnerability and a suboptimal developmental course.[81]

In the previously mentioned study conducted by Gertner et al.,[83] no correlations were found with sleep parameters assessed at 32 weeks CA; however, lower total time spent in night sleep and higher mean level of night activity at 36 weeks CA were predictive of higher mental scores at 6 months.

Borghese et al.[86] investigated ultradian and diurnal rhythms in premature infants. These authors assessed sleep at 36 weeks CA and 6 months of age; the MDI was assessed at 6 months of age. They found that cyclicity (a measure of ultradian and diurnal rhythms) measured at 36 weeks CA was negatively correlated with MDI, whereas cyclicity measured at 6 months of

Table 1—Key Aspects and Results of Studies Correlating Sleep and Mental Development

Author	N	Mode of Sleep Assessment	Timing of Sleep Assessment	Mode of Development Assessment	Timing of Development Assessment	Correlations Between Sleep Characteristics and Mental Development
1. Beckwith et al.[75]	53 premature infants	EEG	40 weeks CA	Gesell Developmental Scale	4, 9 months	*tracé alternant* during QS: 4 months, r = 0.32 9 months, r = 0.33 No significant association with QS
2. Scher et al.[76]	16 preterm infants + 16 term infants	EEG	1-2 weeks after birth, then monthly up to term age	BSID	12 months, 24 months	***No. of arousals, $r^2 = 0.6382$, Adj $r^2 = 0.6053$
3. Anders et al.[77]	24 premature infants	Time-lapse video recording	2, 4, 8, 20, 24, 36, 52 weeks' CA	BSID	24, 52 weeks' CA	Holding Time Index: 24 weeks conceptional age (CA), F = 5.9 Longest Sleep Period: 52 weeks CA, r = −0.40, F = 7.6
4. Scher[78]	50 healthy infants	Questionnaire, actigraphy	10 months	BSID	10 months	Sleep efficiency, r = 0.30 % of activity/minute of sleep, r = −0.30 # awakenings > 5 minutes, r = −0.37
5. Becker et al.[79]	29 healthy infants	EEG	6 months	BSID	1 year	REM Storms: Group 1, r = −0.65 Group 2, r = −0.88
6. Arditi-Babchuk et al.[80]	81 premature infants	Observation	34 weeks CA	BSID	6 months	Prediction of MDI at 6 months REM (β = 29, F = 5.96) No association between REM storms and MDI
7. Freudigman et al.[81]	36 healthy newborns	Motility Monitoring System	Postnatal days 1 & 2	BSID	6 months	Longest sleep period, r = −0.42 Sleep-wake transition time, r = 0.36
8. Montgomery-Downs et al.[82]	35 healthy infants	Overnight polysomnogram	8 months	BSID	8 months	Snore-related arousals, r = −0.43, $R^2 = 0.18$
9. Gertner et al.[83]	34 premature infants	Actigraphy	32 & 36 weeks CA	BSID	6 months	36 weeks CA: Total night mean activity level, r = 0.373 Total sleep %, r = −0.349 Total night sleep %, r = −0.405 No significant associations with sleep assessed at 32 weeks' CA No significant association with QS
10. Borghese et al.[86]	49 premature infants	Motility Monitoring System	36 weeks CA & 6 months	BSID	6 months	Active Sleep: 36 weeks CA, r = −0.44 6 months, r = 0.34 Cyclicity: 36 weeks CA, r = −0.40 6 months, r = 0.43 No significant association with QS
11. Whitney et al.[87]	100 premature infants	Motility Monitoring System	Weekly for 1st 5 weeks of life	BSID	1 year, then biannually until age 3	Neurodevelopmental group: > Time in waking active < Time in Active Sleep and QS < Active sleep bout length < Longest sleep period < State stability score
12. Shibagaki *et al.*[89]	27 infants*	Overnight polysomnogram	4 months-1 year	Tsumori-Inage Questionnaire	4 months-1 year	Developmental quotient, r = 0.88, $R^2 = 0.78$
13. Scher *et al.*[90]	100 infants**	Questionnaire	4-6 months, 10-12 months	Harris Infant Neuromotor Test	4-6 months, 10-12 months	Similar sleep patterns in infants with and without risks for developmental delays

*infants with developmental disabilities; **infants were divided into 4 groups based on risk for developmental delay ; ***unadjusted for prematurity

Key Aspects and Results of Studies Correlating Sleep and Mental Development. Study characteristics including number of infants, modes of sleep and development assessment, and timing of sleep and development assessments are provided. Significant correlations are provided between various sleep characteristics and mental development scores for each study as well.

Abbreviations: EEG = electroencephalogram; CA = conceptional age; BSID = Bayley Scale of Infant Development; QS = quiet sleep; r = correlation coefficient; R^2 = squared multiple correlation; F = variance ratio

Table 2—Correlations Between Sleep Characteristics and Psychomotor Development

1. Scher[78]	No significant association with motor development
2. Scher et al.[90]	No significant association between motor development and sleep fragmentation
3. Montgomery-Downs et al.[82]	No significant association with motor development
4. Freudigman et al.[81]	Mean sleep period, r = −0.53 Sleep-wake transition time, r = 0.39 Quiet Sleep, r = −0.50
5. Anders et al.[77]	Wakefulness at birth, r = 0.21 Out Of Crib Time, r = 0.42

Significant correlations are provided between various sleep characteristics and psychomotor development scores for each study are provided. Abbreviations: r = correlation coefficient

age was positively correlated to MDI scores. In this same study, the amount of AS at 36 weeks CA was negatively correlated to MDI, whereas the amount of AS at 6 months of age was positively correlated to MDI. In this case, associations were not present or absent at different developmental periods; rather, they actually changed direction. Further complicating matters, other reports have found no significant relationship between QS and mental status.[75,83,86]

Infants with Disabilities and Mental Scores

Although most research has been conducted in apparently healthy infants, several authors have compared the sleep patterns in infants with disabilities to their unaffected counterparts. Whitney et al.[87] showed that infants with neurodevelopmental, physical or minor mental problems had sleep patterns that deviated from patterns in infants without handicaps, with the neurodevelopmental group being the most different. This is consistent with the findings of Thoman et al.,[88] who showed that toddlers with developmental dysfunction showed developmental inconsistencies in sleep-state organization during the infancy period. In infants with developmental disabilities, Shibagaki et al.[89] found that 78% of the variance in the Development Quotient (DQ) was explained by a combined sleep measure that consisted of 12 parameters. Contrary to all these findings, a study conducted by Scher et al.[90] reported that sleep patterns were similar in infants with and without risks for developmental delays.

Sleep and Psychomotor Development

A recent review published by Pin et al.[91] examined the relationship between motor development and sleep position, excluding other sleep parameters. Table 2 summarizes the results of the studies that examined the relationship between sleep and psychomotor development.

Scher found no correlations between sleep-wake patterns or sleep difficulties and motor achievements in infants during the first year of life.[78,90] These findings are consistent with those of Montgomery-Downs et al., who reported that motor scores were not significantly associated with PSG measures.[82]

Others authors have reported significant associations with motor development and sleep. Freudigman et al.[81] showed that on day 1 of life, increased mean sleep period and decreased sleep-wake transition were predictive of lower motor scores, whereas on day 2 of life, increased amount of QS was predictive of lower motor scores. Anders et al.[77] found that infants who had more wakefulness at birth and those who showed declining rates in their out of crib time, performed better on psychomotor scales.

Sleep and Temperament

Temperament comprises genetically determined characteristics of an individual that interact with the surrounding environment. As defined in Thomas and Chess's oft-cited book, it consists of nine specific behaviors: activity, rhythmicity, approachability/withdrawal, adaptability, intensity, mood, distractibility, persistence, and sensory threshold.[92] Table 3 outlines the key aspects of studies that relate various sleep measures and temperament.

Sleep characteristics during the immediate newborn period have been used as predictors for later temperament. Novosad et al.[93] reported that various measures of sleep on days 1 and 2 of life had significant correlations with temperament at 8 months of age. Although the effects of the delivery method were controlled for in the statistical analysis, the sleep variables that yielded significant associations on the first day of life were different from those that appeared significant on the second day of life. As reported by Carroll et al.,[94] sleep/wake measurements are different during the first 2 days of life. The underlying cause of this is unclear; however, it is suggested that it may be an adaptive response to the birth process, resulting in the release of high levels of stress hormones.[94]

In 6-month-old infants with and without night waking, Carey[95] found a significant correlation between night waking and low sensory threshold. In young children with known night waking, Schaefer[96] observed that those with "easy" temperaments were significantly underrepresented, and those with "difficult" temperaments were overrepresented. The participants in Schaefer's study were diverse in age, ranging from 6 months to 3 years. This precludes accurate assessment of temperament in the infancy period.

Weissbluth[97] reported that children with "difficult" temperaments sleep less both during the day and night. Halpern et al.[98] found that infants who spent more of the night awake at 3 weeks of age were more irritable at 3 months. They also reported that 3-month-old infants with nighttime sleep difficulties were less approachable.

Assessing sleep (using sleep diaries and actigraphy) and temperament at several time points during the first year of life in infants, Spruyt et al.[99] showed that increased sleep is correlated with an "easy" temperament. This "easy" temperament was characterized by increased approachability, rhythmicity, adaptability, and low distractibility.

In 12-month-old infants, Scher et al.[100] found that rhythmicity was the sole temperament variable that demonstrated a consistent correlation with five designated sleep measures (sleep onset time, sleep duration, number of awakenings, activity level, and sleep efficiency). Although infants described as rhythmic went to sleep at an earlier hour and slept longer than infants who were not

Table 3—Key Aspects of Studies Correlating Sleep and Temperament Development

Author	N	Mode of Sleep Assessment	Timing of Sleep Assessment	Mode of Development Assessment	Timing of Development Assessment
1. Novosad et al.[93]	41 healthy newborns	Motility Monitoring System	Postnatal Day 1 & 2	RITQ	8 months
2. Carey[95]	60 infants*	Questionnaire	6 months	ITQ	6 months
3. Schaefer[96]	100 infants and children*	Questionnaire	6 months- 3 years	ITQ	6 months- 3 years
4. Weissbluth[97]	60 healthy infants	Questionnaire	< 8 months	ITQ	< 8 months
5. Halpern et al.[98]	21 healthy infants	Questionnaire	3 weeks, 3 months	EITQ	3 weeks, 3 months
6. Spruyt et al.[99]	20 healthy infants	Sleep Diaries, actigraphy	Monthly for first year of life	EITQ & RITQ	3, 6, and 11 months
7. Scher et al.[100]	30 healthy infants	Actigraphy	12 months	Carey Toddler Temperament Questionnaire	12 months
8. Keener et al.[101]	23 infants*	Time-lapse video recording	6 months	RITQ	6 months
9. Weissbluth et al.[104]	53 healthy infants	Pneumograms	3-5 weeks	RITQ	> 4 months
10. Kelmanson[105]	200 healthy infants	Maternal report	2-4 months	EITQ	2-4 months

*no data on medical history.
Study characteristics including number of infants, modes of sleep and development assessment, and timing of sleep and development assessments are provided.
Abbreviations: ITQ = Infant Temperament Questionnaire; EITQ = Early Infant Temperament Questionnaire; RITQ = Revised Infant Temperament Questionnaire

rhythmic, their sleep was more fragmented and less efficient. As the authors state, these results do not support a linkage between sleep-wake regulation in infancy and temperament.

There is very little information on the relationship between infant temperament and SDB or other clinically derived sleep pathology. Assessing sleep using pneumograms in healthy infants, Weissbluth et al.[104] found that increased apneic pauses and periodic breathing were associated with low temperament ratings. In healthy 2- to 4-month-old infants, Kelmanson[105] found that maternal-reported snoring and/or noisy breathing were present more often in infants with a negative mood while awake. Although maternal factors such as education, age, and smoking were taken into account in their results, this study did not objectively determine the presence or severity of breathing obstruction.

Temperament ratings provide information that bears a direct relationship to daily functioning and that is exceedingly difficult to measure using objective tests. These ratings are, however, subject to reporter biases and inaccuracies. This is highlighted in a study by Keener et al.,[101] which correlated sleep data obtained from time-lapse video recordings with parental reports of temperament at 6 months of age. Although these authors found significant correlations between sleep continuity and aspects of temperament, the temperament variables that correlated were different depending on whether questionnaires were completed by mothers versus fathers. Issues of rater biases and accuracy are not unique to temperament research. Several studies have reported limitations of parental reports on sleep-wake patterns as well.[32,102,103]

CONCLUSION

The first year of an infant's life is a time of significant change. Greater than half of the first year of life is spent in a sleeping state. The concomitant growth and development that occurs during this time is substantial. Although there is a large body of literature investigating the predictive value of sleep in older children and adults, gaps in knowledge exist in the relationship between sleep in infancy and later development. It is important to address these gaps, as sleep characteristics during this period may have predictive value for processes of neurobehavioral organization.[83] Assessing sleep during infancy can also help to clarify the interplay between sleep and intellectual disability in neurodevelopmental conditions.[106]

Sleep parameters measured as early as the first day of life have been used to predict later outcomes pertaining to cognitive, psychomotor, and temperament development. These predictions should, however, be used with caution as the timing and subjectivity of evaluations may obviate accurate assessment. Collectively, studies assess a wide array of sleep measures, and findings from one developmental period cannot be generalized readily to other developmental periods. Additionally, other factors that affect an infant's sleep (e.g., position, ambient temperature, co-sleeping, and cigarette smoke exposure) often create discrepancies that make comparisons difficult. Future studies will need to be more consistent in the sleep parameters they examine. They should also account for parental (e.g., education levels, postpartum depression) and environmental variables (e.g., socioeconomic status, household sleeping arrangements) that can affect their outcome measurements and obscure or moderate sleep-development associations.

Although the literature generally suggests an association between sleep and daytime functioning in infants, we currently do not have sufficient data to conclude that a causal relationship exists. While animal models suggest that extreme circumstances such as sustained REM sleep deprivation can alter neurodevelopment, such circumstances rarely, if ever, occur in otherwise healthy human infants. In humans, it is unclear whether: (1) sleep and cognition reflect overall maturational status; (2) quality and maturation of sleep determine cognitive achievements; or (3) some other relationship exists.[78] Given that sleep and the ability to interact with the environment change over the first year of life, it would be prudent to follow patients longitudinally. Once firm associations between specific aspects of infant sleep and developmental outcomes have been better established, it may be fruitful to examine whether interventions to target these sleep variables can impact development in at-risk children. There have been promising experimental trials of prenatal education for improved infant sleep,[107,108] but outcomes measured to date have focused primarily on maternal reports of mood and reported infant sleep behaviors, not development.

Further refinements of existing assessment tools would also be useful. If infant sleep and cognitive or behavioral development are related, the clinical and public health yield of such research may indeed be substantial. In view of the relatively high reported pediatric prevalence of cognitive and behavioral deficits that carry significant long-term costs to individuals and society, early screening of sleep-related issues may be a useful tool to guide targeted prevention and early intervention.

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