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Original Article

Associations of sleep-related behaviors and the sleep environment at infant age one month with sleep patterns in infants five months later

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ABSTRACT

Objective: To characterize family and environmental correlates of sleep patterns that may contribute to differences in infant sleep.
Methods: We studied 313 infants in the Rise & SHINE (Sleep Health in Infancy & Early Childhood study) cohort. Our main exposures were the parent-reported sleep environment, feeding method and sleep parenting strategies at infant age one month. The main outcomes were nighttime sleep duration, longest nighttime sleep and number of awakenings measured by actigraphy at age six months. We used multivariable linear regression models to examine associations, and secondarily also explored the role of sleep-related environmental exposures in mediating previously observed associations of racial/ethnicity and parental education with infant sleep characteristics.
Results: In adjusted models, a non-dark sleep environment (versus an always dark sleep location) and taking the baby to parent's bed when awake at night (versus no co-sleeping) were associated with 28 (95% CI, −45, −11) and 18 (95% CI, −33, −4) minutes less sleep at night, respectively. Bottle feeding at bedtime was associated with 62 (95% CI, 21, 103) minutes additional longest nighttime sleep period. Exploratory mediation analyses suggested a modest mediating role of a non-dark sleep environment on racial/ethnic and educational differences in sleep duration.
Conclusions: Infant sleep duration was positively associated with a dark sleep environment and a focal feed at bedtime while taking the baby to the parent's bed was associated with reduced infant sleep. Modifying the sleep environment and practices may improve infant sleep and reduce sleep health disparities.

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1. Introduction

There is large inter-individual differences in infant sleep development, the sources of which are poorly understood. Caregivers perceptions of their infant's short sleep or frequent awakenings can be causes of concern [1,2]. In addition, good sleep can promote behavioral outcomes, neurocognition and healthy body weight [3–6]. Infant sleep problems are a major source of stress to parents and a significant predictor of maternal depression [6,7]. Parents often try different strategies to improve their children's sleep, gleaning information from sources including parenting books, websites, social media and advice from family and friends. Nonetheless, few of them are evidence-based or specifically address sleep across diverse population groups. To equip clinicians and parents as well as researchers with adequate knowledge about

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infant sleep development, it is crucial to understand what to expect from infant sleep under different circumstances.

Few studies, however, have investigated the risk and protective factors of sleep outcomes (eg adequate sleep quantity and quality of sleep) in infants using objective sleep measurements and the results are controversial [1]. Dias et al. recently conducted a systematic review on associated infant, parental and environmental factors with infant-sleep wake behaviors during the first 12 months of life. The authors pointed out a number of methodological problems in the literature, including the grouping of different ages, exclusive use of parent-report, the use of different definitions of sleep-wake variables and inadequate discussion of potential confounding variables [9].

Our group recently reported findings demonstrating racial/ethnic differences in sleep emerge between one month and six months, with reduced sleep durations in Hispanic/Latinx and Black infants compared to whites [10–12]. These differences may be due to the disproportion of social disadvantage experienced by members of racial/ethnic minorities, as well as potential differences in cultural practices related to sleep [13].

A significant racial/ethnic difference in sleep practices is a higher co-sleeping rate in African-Americans and Asian families [14,15]. Moreover, children from historically disadvantaged groups often experience a suboptimal sleep environment (eg too noisy or too bright) – both of which can disturb sleep [16].

The primary objective of our study was to examine multilevel – environmental and family – characteristics and strategies at infant age one month associated with infant sleep duration and continuity five months later. Second, we explored the extent to which environmental- and family-level characteristics were mediators of previously identified racial/ethnic and sociodemographic differences in sleep duration and continuity in early life. We hypothesized that a suboptimal sleep environment and active physical comforting (eg bed-sharing and rocking) at one month would influence infant sleep development and be associated with shorter nighttime sleep and more sleep disruptions at six months, whereas strategies encouraging the infant's autonomy (eg low parental involvement at bedtime) would be associated with the development and maintenance of longer and more consolidated night time sleep [17,18]. In addition, we hypothesized that racial/ethnic disparities seen in sleep outcomes would be partially mediated by differences in parental bedtime involvement and environmental factors.

2. Material and methods

2.1. Participants

Study subjects were participants in Rise & SHINE (Sleep Health in Infancy & Early Childhood), a prospective cohort study that recruited mother-infant dyads at birth from the newborn unit of Massachusetts General Hospital in Boston, MA, USA. The overall goals of the study are to examine associations between sleep patterns and growth in early life. Full-term singletons with no genetic or congenital abnormalities and their biological mothers without diagnosed chronic medical or mental conditions were eligible to participate in this study. Other eligibility criteria included mother's fluency in English or Spanish, mother's age of at least 18 years old, and the family living within 40 miles without plans to move from the area within the study period.

Signed informed consent was obtained from all the participating families during enrollment. After obtaining informed consent, we performed in-person visits at one month and six months to obtain infant actigraphy and parental surveys. The study was approved by Mass General Brigham Office of Research.

We approached 1459 eligible mother-infant dyads, 433 of whom agreed to participate. Of these, 313 completed surveys for sleep strategies at one month and had valid sleep data (≥3 nights of actigraphy) at a 6-months visit. Demographic information was collected at enrollment from mothers. Compared to the non-participants, the analytic sample (N = 313) included a higher percentage of White and Asian infants, a lower percentage of African American and Hispanic infants, and a higher percentage of infants with college-educated mothers.

2.2. Measurements

2.2.1. Exposures

At one month, we surveyed parents for their infant's sleep environment and sleep-related parenting practices. We used questions from validated questionnaires to collect these data, including three questions on sleep environment (light, noise, and TV in bedroom), two questions on feeding methods (feeding mode and feeding practices to sleep) [19] and four questions on sleep-related parenting strategies during sleep initiation and awakenings: soothing technique at sleep (feeding, being rocked/held, or in bed or crib alone/near parent) [20], bed-sharing [21], taking the infant to parent bed [22], need of a special object [23], and strategies for putting baby back to sleep (nursing, picking up, using a pacifier, patting, checking in without touching, or letting infant fall back asleep) [20] (Table S1).

2.2.2. Outcomes

Our main outcomes at 6-months were measures of 1) *sleep quantity* assessed by infant actigraphy: a) total night sleep duration, and b) longest nighttime sleep period; and 2) *sleep fragmentation:* number of nighttime awakenings. At the 6-months home visits, the coordinators instructed mothers how to use an actigraph and complete a paper-based, 24-h, 7-day sleep diary [24]. In the sleep diary, parents recorded sleep periods, wake, sleep in motion (eg asleep in the stroller) and actigraph "off" periods, providing annotations using a time-line shown as 5-min intervals for the period overlapping the actigraphy monitoring.

A Philips Actiwatch 2 (Philips Healthcare, Andover, MD, USA) was placed on the infants' left ankle for seven continuous days after the home visit. Data were recorded in 30-sec epochs at a sampling rate of 32 Hz, and analyzed at the low activity threshold settings of 80 counts for wake detection [25]. A trained research assistant, blinded to other clinical data, identified rest and active intervals using caregiver-completed sleep diary and observation of a sharp decrease/increase of activity. Sleep and active intervals were then determined using the commercially available algorithms for Actiwatch 2, Respironics Actiware 6 (Version 6.0.9, Philips/Respironics) scoring algorithm. Please see Yu et al. and Quante et al. for a detailed protocol of our actigraphy scoring and description of derived sleep measures [11,26].

Sleep intervals were determined by the combination of information from the diary and the activity pattern on the actigraph [27]. The night and day sleep intervals were defined as between 7:00 pm - 7:59 am and 8:00 am - 6:59 pm, respectively, reflecting the cutoffs in the sleep questionnaire we used for nighttime and daytime sleep periods. Our main outcomes included 1) *sleep quantity:* a) night sleep duration (sum of all sleep epochs within the rest intervals that at least partially overlapped the hours between 07:00 pm and 07:59 am) and b) longest nighttime sleep (sum of sleep epochs within the rest interval with the most consecutive sleep epochs during the nighttime); and 2) *fragmentation:* nighttime awakenings, the number of episodes of wakefulness showing a sharp increase of activity for longer than 5 min between intervals of nighttime sleep. A detailed description of the

sleep variables can be found here [11,26]. Average values were calculated across measurement days. Six months actigraphy data lost due to technical failure, parent non-adherence or artifacts was 2% (eight out of 323 records). In the analytical sample, the average number of valid nights with six months actigraphy data was 7.3 (SD 1.2).

2.2.3. Covariates

Sociodemographic and other individual-level covariates were collected via a combination of maternal report and electronic health record abstraction at enrollment. Infant sex, gestational age at delivery, and birthweight were abstracted from infants' electronic health records, while maternal age and parity were abstracted from mothers' electronic health records. Mothers self-reported their infant's race and ethnicity, their own race and ethnicity, their highest level of education and their annual household income. In addition, marital status was self-reported from mothers during the one-month study visit.

2.3. Statistical analysis

We first examined unadjusted associations between infant sleep patterns at six months and aspects of the sleep environment, sleep strategies and infant feeding practices at one month. We then fit separate multiple linear regression models for each exposure-outcome pair, adjusted for potential confounders. Confounders were selected on the basis of prior literature reports and included maternal age, education, household income, infant race/ethnicity, and gestational age [28]. We checked the variance of inflation factors and found no strong multi-collinearity.

We conducted an exploratory analysis to examine the potential mediating roles of sleep strategies and environment in observed sleep disparities. Outcomes were average nighttime total sleep and longest sleep; exposures were race/ethnicity (white, Asian, Black/Hispanic), household income (<$80k, $80-199k, >$200k) and maternal education (less than bachelor's, bachelor's, graduate); potential mediators included: pacifier use, baby held while fell asleep, sharing a bed, baby put to bed with bottle, baby sleep in dark, take baby to parent bed. We combined data from Black and Hispanic infants due to the small sample size of Black infants. We further adjusted for infant age, infant weight at one month of age, sex and mother's average sleep on weekdays. For each outcome-exposure-mediator triplet, we adopted the mediation framework of Vander Weele and Robinson to estimate the direct disparity (DD) and mediated disparity (MD) in sleep outcome [29]. We conducted complete-case analyses only. We report bootstrap confidence intervals and p-values for tests of no mediated disparity (across all exposure levels).

3. Results

Characteristics of the maternal, infant and household characteristics by tertiles of average nightly sleep duration are shown in Table 1. Infants had a mean (SD) age of 6.4 (0.6) months at the 6-months visit and a little over the half of infants were female. In our sample, 42% of the infants were Non-Hispanic White, 7% Non-Hispanic Black, 34% Hispanic, and 17% Asian. Over half of the parents had a college degree and 61% of infants lived in a household with an income of greater than $80,000 per year. At 6 months, the average nightly sleep duration measured by actigraphy was 8.8 (1.1) hours and the longest sleep period at night was 460 (100) minutes. Infants had on average 1.1 (1.1) nocturnal awake periods (see Table 1).

In multivariable analyses adjusted for maternal age, education, income, infant race/ethnicity, and gestational age, infants who never or only sometimes had a dark sleeping location at age one month slept 28 (95% CI, −45, −11) minutes less at night, and their longest nocturnal sleep period was 39 (95% CI, −65, −13) minutes shorter compared to infants who always had a dark room at night. “Taking the baby to parent bed when being awake at night” was associated with 18 (95% CI, −33, −4) minutes shorter average nighttime sleep and 25 (95% CI, −48, −3) minutes shorter longest sleep period. Unexpectedly, infants who were formula or mixed fed had 35 (95% CI, −68, −3) minutes and 18 (95% CI, −35, −1) minutes shorter nighttime sleep compared to exclusive breast feeding. Mixed feeding was also associated with more nighttime awakenings and 34 (95% CI, −59, −8) minutes shorter longest sleep periods. On the other hand, feeding a bottle of formula or breast milk at bedtime was associated with a more than 62 (95% CI, 21, 103) minutes longer longest sleep period. Infant “need of a special object” was associated with a 48 (95% CI, −93, −4) minutes decrease in nightly sleep duration, whereas infants whose parents followed a strategy of checking without touching had 15 (95% CI, 1, 30) minutes longer nightly sleep duration. Infants who had a television in their bedroom had more nighttime awakenings [0.3 (95% CI, 0.0, 0.6)] (Table 2).

The results of the exploratory mediation analyses showed that both sleep strategies and sleep environment characteristics partially mediated observed racial/ethnic and educational differences in sleep outcomes previously observed in this cohort. For example, a non-dark sleep location partly mediated associations of shorter longest nighttime sleep duration with Asian, Black/Hispanic infants and for infants whose mothers were not college graduates (see Tables 3 and 4). For example, 11 min (95% CI: −21, −3) of shorter longest nighttime sleep in Black/Hispanic infants could be attributed to non-dark sleep environment in Black/Hispanic infant ($p = 0.03$).

4. Discussion

In this study of 313 infants followed from birth to six months, we found that a non-dark sleep environment and taking the infant to parent's bed during night awakenings were associated with less infant sleep at night, while checking on the baby without touching was associated with longer and more continuous sleep. Bottle feeding (formula or breast milk) at bedtime was associated with more continuous sleep, whereas exclusive breast feeding was favorable for both sleep quantity and quality (fewer awakenings).

These results suggest that both bedtime strategies as well as the sleep environment—both of which are modifiable—may significantly influence infant nocturnal sleep. Specifically, we found that a non-dark sleep environment was associated with about half an hour less nighttime sleep and about 40 min shorter longest sleep period in 6-months-old infants, measured by actigraphy. Taking a waking baby to the parent's bed at night was associated with about 20 min shorter nighttime sleep, whereas use of bottle feeding at bedtime resulted in an additional hour of the longest sleep episode. The study identifies the potential negative effects of sleeping in a non-dark environment, which is consistent with the known role of light as the primary extrinsic synchronizing cue for our circadian system [30]. Notably, the first weeks of life are a formative period for the infant circadian system [31,32]. Additionally, light has acute alerting effects and suppresses melatonin, especially in children [33,34]. These findings are consistent with a study from Japan of 1302 1-month-old infants and mothers dyads demonstrating that infant nighttime sleep duration was shorter in infants with irregular light-off times [35]. Animal studies also indicate that constant light disrupts the biological clock development, resulting in less consolidated and more fragmented sleep phases [36]. A non-dark sleep environment may also be an indicator of other suboptimal sleep conditions. A prospective study of 1226 mother-infant pairs in

Table 1
Maternal, infant, and household characteristics in the first 6 months according to actigraphy-measured terciles of average night time sleep duration. Data from 313 Participants in the Rise & SHINE study.

Characteristic	Overall N = 313	Tercile 1 (<510 min) N = 104	Tercile 2 (≥ 510 and < 557 min) N = 105	Tercile 3 (≥557 min) N = 104
Parental and Household Characteristics	**Mean (SD) or N (%)**			
Maternal age (years) at enrollment	32.8 (4.9)	31.6 (5.5)	32.9 (4.8)	33.8 (4.1)
Parity at enrollment				
≥ 1	193 (61.7)	66 (63.5)	68 (64.8)	59 (56.7)
0	120 (38.3)	38 (36.5)	37 (35.2)	45 (43.3)
Marital status (n = 4 missing)				
Married or cohabitating	220 (71.2)	65 (63.7)	73 (70.9)	82 (78.8)
Other	89 (28.8)	37 (36.3)	30 (29.1)	22 (21.2)
Maternal Education				
≥College graduate	230 (73.5)	65 (62.5)	76 (72.4)	89 (85.6)
<College graduate	83 (26.5)	39 (37.5)	29 (27.6)	15 (14.4)
Household Income				
Less than $80,000 per year	114 (36.4)	50 (48.1)	46 (43.8)	18 (17.3)
$80,000 - $199,000 per year	106 (33.9)	32 (30.8)	29 (27.6)	45 (43.3)
$200,000 per year or more	85 (27.2)	20 (19.2)	27 (25.7)	38 (36.5)
Don't know/missing	8 (2.6)	2 (1.9)	3 (2.9)	3 (2.9)
Race/ethnicity (n = 3 missing)				
White	145 (46.8)	35 (34.0)	41 (39.8)	69 (66.3)
Black	18 (5.8)	5 (4.9)	11 (10.7)	2 (1.9)
Asian	48 (15.5)	21 (20.4)	16 (15.5)	11 (10.6)
Hispanic	99 (31.9)	42 (40.8)	35 (34.0)	22 (21.1)
Infant Characteristics				
Infant age at 6-months visit (yrs)	0.5 (0.1)	0.5 (0.1)	0.5 (0.1)	0.5 (0.1)
Gestational age at delivery (wk)	39.5 (1.0)	39.3 (1.1)	39.6 (1.0)	39.7 (1.0)
Birth weight for gestational age z-score	−0.2 (0.9)	−0.3 (0.9)	−0.3 (0.9)	−0.2 (0.8)
Female	159 (50.8)	56 (53.8)	52 (49.5)	51 (49.0)
Race/ethnicity				
Non-Hispanic White	131 (41.9)	29 (27.9)	40 (38.1)	62 (59.6)
Non-Hispanic Black	23 (7.3)	7 (6.7)	13 (12.4)	3 (2.9)
Non-Hispanic Asian	54 (17.3)	24 (23.1)	17 (16.2)	13 (12.5)
Hispanic	105 (33.5)	44 (42.3)	35 (33.3)	26 (25.0)
Actigraphy Sleep Measures at 6 Months				
Nighttime Sleep Duration (mins/night)	526.0 (66.8)	454.7 (59.4)	533.3 (12.3)	590.0 (22.2)
Number of nighttime awakenings	1.1 (1.1)	1.5 (1.2)	1.1 (1.1)	0.8 (0.8)
Longest night sleep (mins)	459.8 (99.9)	369.7 (81.4)	470.9 (62.6)	538.6 (70.9)

the Project Viva birth cohort found that infants who lived in more urbanized neighborhoods had 20 min short sleep duration. The authors proposed that the exposure to light, noise, air pollution and higher temperature underlies the relationship between urbanicity and sleep duration [37]. Indeed, we found modest evidence of mediation by non-dark sleep environment in sleep health disparities. Here, introducing light-blocking window shades and eliminating blue light emitting electronics might be effective intervention strategies for a more consolidated sleep.

The American Academy of Pediatrics recommends room-sharing but not bed-sharing in order to reduce the risk of sudden unexpected infant death [38]. Nevertheless, about 60% of our study participants reported bed-sharing for at least one night per week. In our study, bed-sharing was associated with 20 min shorter nighttime sleep documented by actigraphy. This is in line with previous reports using parent reports of infant sleep (rather than actigraphy) in co-sleeping infants [39,40]. For example, Mindell et al. reported on data from an app-based parental survey of infant sleep for more than 10,000 infants aged 6–12 months from six different countries. Parents reported better sleep outcomes (earlier bedtimes, shorter time to fall asleep, longer and more consolidated sleep) for infants sleeping in a separate room compared to infants who room- or bed-share [41]. On the other hand, a longitudinal Israeli study of 153 families, using both objective and subjective measures of sleep demonstrated no significant differences in objective sleep measures between bed-sharing and solitary sleeping infants at ages three and six months. Of note, bed-sharing mothers in the Israeli study reported more infant awakenings than mothers in the solitary sleeping group [42].

The shorter night sleep duration seen in bed-sharing infants might be explained by the fact that mothers who choose bed-sharing in response to their infant's sleep problems may be responding to infants who have more problems sleeping—ie, bringing the baby to the parent's bed is an effect rather than a cause of the infant's shorter sleep. Alternatively, bed-sharing may reduce the infant's abilities to self-soothe.

In contradiction to bed-sharing, checking on the baby after awakening at night without touching was associated with 15 min additional nighttime sleep duration and a 27 min period of longest night sleep. This strategy belongs to the extinction-based behavioral interventions that aim to condition the infant to fall asleep in the absence of bodily contact. A cluster randomized clinical trial with behavioral interventions based on extinction compared to usual care for infants with sleeping problems (ages eight to 10 months, N = 328) found fewer sleeping problems in the intervention group two to four months later [43]. However, differences between groups were no longer present at the five-year-follow-up study [44]. While extinction strategies demonstrate positive short-term effects, many families have difficulties incorporating them into long-term sleep habits [45].

The introduction of objects such as a blanket or doll are popular strategies for parents to help their infants feel safe without parent's presence, although they are a known risk factor for sudden unexpected infant death [38]. In our study, the need of a special object was associated with 48 min less nighttime sleep duration. Again, it

Table 2
Multivariable Linear Regression Models for Sleep Patterns at 6 Months. Data from 313 Participants in Rise & SHINE. Adjusted for maternal age, education, household income, infant race/ethnicity, and gestational age.

Characteristic	Nighttime Sleep Duration (Minutes)	Number of Nighttime Awakenings	Longest Night Sleep (Minutes)
	β (95% CI)		
Sleep Environment at 1 Month			
Dark room at night			
Never/Sometimes	**−28.0 (−44.7, −11.2)**	0.1 (−0.2, 0.4)	**−38.9 (−64.5, −13.2)**
Always	Ref	Ref	Ref
Quiet room at night			
Never/Sometimes	−4.0 (−22.2, 14.3)	0.1 (−0.2, 0.4)	−27.2 (−54.9, 0.6)
Always	Ref	Ref	Ref
Television in bedroom where child sleeps			
Yes	−2.7 (−18.0, 12.6)	**0.3 (0.04, 0.6)**	−16.9 (−40.2, 6.4)
No	Ref	Ref	Ref
Sleep Strategies at 1 Month			
Bedsharing			
≥ 1 night per week	−14.2 (−30.1, 1.7)	−0.1 (−0.4, 0.2)	−23.9 (−48.1, 0.4)
Never	Ref	Ref	Ref
Taking baby to parent bed			
≥ 1 night per week	**−18.2 (−32.8, −3.6)**	0.1 (−0.1, 0.4)	**−25.2 (−47.5, −2.8)**
Never	Ref	Ref	Ref
Special object			
≥ 1 night per week	**−48.1 (−92.8, −3.5)**	0.1 (−0.7, 0.8)	−50.6 (−119.0, 17.9)
Never	Ref	Ref	Ref
Strategies to put baby back to sleep			
Nurse baby			
Yes	21.7 (−31.7, 75.1)	0.2 (−0.7, 1.1)	−13.8 (−95.4, 67.9)
No	Ref	Ref	Ref
Pick up baby			
Yes	7.9 (−9.2, 25.0)	0.01 (−0.3, 0.3)	20.2 (−5.8, 46.3)
No	Ref	Ref	Ref
Pacifier			
Yes	2.0 (−13.5, 17.5)	0.1 (−0.2, 0.3)	−8.4 (−32.0, 15.2)
No	Ref	Ref	Ref
Pat gently			
Yes	1.2 (−13.0, 15.5)	0.1 (−0.2, 0.3)	−0.4 (−22.1, 21.4)
No	Ref	Ref	Ref
Check in but not touch			
Yes	**15.3 (0.9, 29.7)**	−0.03 (−0.3, 0.2)	**26.7 (4.7, 48.7)**
No	Ref	Ref	Ref
Let baby fall back asleep			
Yes	−8.6 (−27.0, 9.8)	−0.1 (−0.4, 0.2)	3.5 (−24.7, 31.7)
No	Ref	Ref	Ref
Infant Feeding Practices at 1 Month			
Feeding practice at 1 month			
Mixed feeding	**−17.6 (−34.5, −0.7)**	**0.4 (0.1, 0.7)**	**−33.5 (−59.2, −7.8)**
Formula feeding	**−35.4 (−67.8, −3.1)**	0.1 (−0.5, 0.6)	−24.9 (−74.0, 24.1)
Exclusive breast feeding	Ref	Ref	Ref
Baby put to bed with a bottle of formula, breast milk, etc.			
Only occasionally at bedtimes	3.8 (−21.7, 29.3)	−0.1 (−0.5, 0.3)	32.2 (−6.2, 70.7)
At most naps	17.4 (−23.9, 58.7)	−0.5 (−1.2, 0.2)	61.8 (−0.4, 124.0)
At most night bedtimes	8.9 (−18.4, 36.2)	**−0.6 (−1.0, -0.1)**	**62.0 (20.9, 103.1)**
At most bedtimes, including naps	12.9 (−8.5, 34.2)	−0.2 (−0.5. 0.2)	**42.5 (10.4, 74.6)**
Never	Ref	Ref	Ref

is possible that the special object is not the sleep disturber but rather its use reflects parental response to their infant's sleep problem. However, given the prevalence of use of nighttime objects, further research should address whether their use attenuates self-soothing or otherwise disturbs infant sleep.

Many infants are fed just prior to sleep. The belief is that this practice will reduce awakenings due to hunger. In our study, bedtime feeding was associated with 63 min longer sleep. The literature is inconclusive with regard to this finding. A recent French study including 11,783 infants aged 1 year old found that feeding to fall asleep was more prevalent in infants with short sleep duration, sleep onset difficulties and frequent night awakenings [46]. In a small study of 26 parents and their infants, a focal feed between 10 pm and 12 am helped infants to sleep through the night along with other strategies like re-swaddling and diapering [47]. Interestingly, feeding -specifically to help fall asleep-had no effect on sleep outcomes in our study. Overall, it seems that a scheduled bedtime feed helps infants sustain longer sleep episodes, whereas we have no evidence that feeding back to sleep is a useful sleep strategy. Notably, exclusive breastfeeding was associated with longer nighttime sleep duration and also more consolidated sleep in our study. These results are in contrast with previous findings showing that breastfed infants awaken more times during the night at six months and have shorter nighttime sleep periods [48–50]. However, previous studies almost exclusively relied on self-reported data, with potential biased reporting associated with over-estimation of infant sleep duration reported by formula-feeding mothers [51].

The strength of our study includes its prospective study design and relatively large sample size, the use of objective sleep measures by actigraphy and the assessment of various associated factors with infant sleep-wake behavior. However, some study limitations need to be recognized. We analyzed information on exposures and

Table 3
Mediation analysis of nighttime sleep duration. Adjusted for infant sex, age weight.

Sleep strategy - Mediator	Exposure – Sociodemographic Characteristics	Mediated Disparity (95% CI)	p-value	Direct Disparity (95% CI)
Dark room at night	Asian	−5 (−13; 0)	0.05	−24 (−44; −3)
	Black/Hispanic	−7 (−15; −1)		−32 (−50; −15)
Bedsharing	Asian	2 (−5; 9)	0.05	−31 (−49; −12)
	Black/Hispanic	−12 (−22; −3)		−27 (−46; −10)
Taking baby to parent bed	Asian	−1 (−7; 4)	0.07	−28 (−46; −10)
	Black/Hispanic	−8 (−15; −2)		−32 (−47; −16)
Baby put to bed with a bottle of formula, breast milk, etc.	Asian	0 (−3; 3)	0.93	−29 (−48; −10)
	Black/Hispanic	1 (−3; 6)		−40 (−58; −23)
Dark room at night	$200,000 per year or more	7 (−5; 24)	0.24	40 (14; 63)
	$80,000 - $199,000 per year	4 (0, 10)		27 (8; 47)
Bedsharing	$200,000 per year or more	2 (−9; 14)	0.07	45 (23; 66)
	$80,000 - $199,000 per year	19 (4; 36)		12 (−14; 40)
Taking baby to parent bed	$200,000 per year or more	0 (−7; 7)	0.08	47 (27; 66)
	$80,000 - $199,000 per year	10 (2; 19)		21 (−1; 43)
Baby put to bed with a bottle of formula, breast milk, etc.	$200,000 per year or more	−1 (−5; 3)	0.56	48 (29; 67)
	$80,000 - $199,000 per year	−2 (−6; 1)		33 (15; 53)
Dark room at night	≥ College graduate	**6 (2; 12)**	**0.02**	**31 (13; 50)**
Bedsharing	≥ College graduate	8 (0; 17)	0.07	29 (8; 50)
Taking baby to parent bed	≥ College graduate	5 (−1; 11)	0.12	32 (12; 52)
Baby put to bed with a bottle of formula, breast milk, etc.	≥ College graduate	−2 (−6; 1)	0.24	39 (21; 57)

"White", "Less than $80,000" and "Less than college graduate" are the referent groups for race, income and education analyses. DD = direct disparity and MD = mediated disparity.

Table 4
Mediation analysis of average longest sleep. Adjusted for infant sex, age weight.

Sleep strategy - Mediator	Exposure – Sociodemographic Characteristics	MD (95% CI)	p-value	DD (95% CI)
Dark room at night	Asian	**−7 (−19; 1)**	**0.03**	−33 (−71; 4)
	Black/Hispanic	**−11 (−21; -3)**		−28 (−50; −3)
Bedsharing	Asian	5 (−3; 18)	0.05	−46 (−85; −9)
	Black/Hispanic	−16 (−29; −3)		−23 (−48; 3)
Taking baby to parent bed	Asian	**1 (−8; 11)**	**0.04**	−41 (−79; −5)
	Black/Hispanic	**−12 (−21; −4)**		−27 (−50; −4)
Baby put to bed with a bottle of formula, breast milk, etc.	Asian	1 (−5; 10)	0.93	−42 (−78; −7)
	Black/Hispanic	−1 (−6; 4)		−38 (−62; −13)
Dark room at night	$200,000 per year or more	10 (−5; 27)	0.17	53 (22; 82)
	$80,000 - $199,000 per year	7 (0, 18)		35 (9; 63)
Bedsharing	$200,000 per year or more	7 (−9; 25)	0.20	55 (25; 87)
	$80,000 - $199,000 per year	13 (−3; 31)		28 (0; 59)
Taking baby to parent bed	$200,000 per year or more	6 (−4; 19)	0.08	56 (27; 86)
	$80,000 - $199,000 per year	12 (2; 25)		30 (2; 58)
Baby put to bed with a bottle of formula, breast milk, etc.	$200,000 per year or more	−1 (−9; 4)	0.52	64 (36; 92)
	$80,000 - $199,000 per year	−3 (−10; 1)		45 (19; 72)
Dark room at night	≥ College graduate	**10 (3; 19)**	**0.02**	**31 (7; 57)**
Bedsharing	≥ College graduate	10 (−1; 21)	0.09	31 (6; 57)
Taking baby to parent bed	≥ College graduate	7 (−1; 15)	0.11	34 (10; 60)
Baby put to bed with a bottle of formula, breast milk, etc.	≥ College graduate	−5 (−12; 1)	0.09	45 (22; 70)

"White", "Less than $80,000" and "Less than college graduate" are the referent groups for race/ethnicity, income and education analyses. DD = direct disparity and MD = mediated disparity.

outcomes at only one time point each, namely during the 1-month and 6-months study visit, respectively. Some associations may reflect confounders or reverse causal associations. The mediation analyses were conducted for exploratory purposes only due to limited power to estimate both direct and mediated disparities for every outcome-exposure-mediator triplet. However, they suggest several factors associated with the sleep environment (particularly a dark sleep environment) that can be further addressed in future sleep disparity research.

Conclusion

In summary, we found that both the sleep environment (eg, dark room at night) and parental bedtime strategies (eg, taking the baby to parent bed and bedtime feeding) were associated with infant sleep duration. A non-dark sleep location partly mediated associations of shorter longest nighttime sleep duration with racial/ethnic and racial/ethnic disparities. These factors are changeable and may be influenced by resources, stress etc. especially in the context of disparities and can be introduced to intervention programs.

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CRediT authorship contribution statement

Mirja Quante: Conceptualization, Methodology, Writing – original draft, Visualization. **Glen W. McGee:** Methodology, Software, Formal analysis, Writing – review & editing. **Xinting Yu:** Methodology, Writing – review & editing. **Tayla von Ash:** Methodology, Writing – review & editing. **Mandy Luo:** Software, Formal analysis, Data curation. **Emily R. Kaplan:** Investigation. **Michael Rueschman:** Software, Validation. **Sebastien Haneuse:**

Supervision, Writing – review & editing. **Kirsten K. Davison:** Funding acquisition, Writing – review & editing, Project administration. **Susan Redline:** Funding acquisition, Writing – review & editing, Project administration. **Elsie M. Taveras:** Conceptualization, Methodology, Writing – review & editing, Supervision, Project administration, Funding acquisition.

Conflict of interest

SR received consulting fees from Eisai Inc, Eli Lilly Inc and Apnimed Inc and a grant from Jazz Pharma unrelated to this topic.

The ICMJE Uniform Disclosure Form for Potential Conflicts of Interest associated with this article can be viewed by clicking on the following link: https://doi.org/10.1016/j.sleep.2022.03.019.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.sleep.2022.03.019.

References

[1] Field T. Infant sleep problems and interventions: a review. Infant Behav Dev 2017;47:40–53.
[2] Paavonen EJ, Saarenpää-Heikkilä O, Morales-Munoz I, et al. Normal sleep development in infants: findings from two large birth cohorts. Sleep Med 2020;69:145–54.
[3] Hemmi MH, Wolke D, Schneider S. Associations between problems with crying, sleeping and/or feeding in infancy and long-term behavioural outcomes in childhood: a meta-analysis. Arch Dis Child 2011;96:622–9.
[4] Seehagen S, Konrad C, Herbert JS, et al. Timely sleep facilitates declarative memory consolidation in infants. Proc Natl Acad Sci U S A 2015;112:1625–9.
[5] Bathory E, Tomopoulos S. Sleep regulation, physiology and development, sleep duration and patterns, and sleep hygiene in infants, toddlers, and preschool-age children. Curr Probl Pediatr Adolesc Health Care 2017;47:29–42.
[6] Taveras EM, Rifas-Shiman SL, Oken E, et al. Short sleep duration in infancy and risk of childhood overweight. Arch Pediatr Adolesc Med 2008;162:305–11.
[7] Blunden SL, Thompson KR, Dawson D. Behavioural sleep treatments and night time crying in infants: challenging the status quo. Sleep Med Rev 2011;15:327–34.
[9] Dias CC, Figueiredo B. Sleep-wake behaviour during the first 12 months of life and associated factors: a systematic review. Early Child Dev Care 2020;190:2333–65.
[10] Ash T, Taveras EM, Redline S, et al. Contextual and parenting factors contribute to shorter sleep among hispanic/latinx compared to non-hispanic white infants. Ann Behav Med 2020;55(5):424–35.
[11] Yu X, Quante M, Rueschman M, et al. Emergence of racial/ethnic and socioeconomic differences in objectively measured sleep-wake patterns in early infancy: results of the Rise & SHINE study. Sleep 2020 Mar 12;44(3):zsaa193.
[12] Ash T, Davison KK, Haneuse S, et al. Emergence of racial/ethnic differences in infant sleep duration in the first 6 Months of life. Sleep Med X 2019:100003.
[13] Patrick KE, Millet G, Mindell JA. Sleep differences by race in preschool children: the roles of parenting behaviors and socioeconomic status. Behav Sleep Med 2016;14:467–79.
[14] Salm Ward TC, Ngui EM. Factors associated with bed-sharing for African American and White mothers in Wisconsin. Matern Child Health J 2015;19:720–32.
[15] Ball HL, Moya E, Fairley L, et al. Infant care practices related to sudden infant death syndrome in South Asian and White British families in the UK. Paediatr Perinat Epidemiol 2012;26:3–12.
[16] Wilson KE, Miller AL, Lumeng JC, et al. Sleep environments and sleep durations in a sample of low-income preschool children. J Clin Sleep Med 2014;10:299–305.
[17] Sweeney BM, Signal TL, Babbage DR. Effect of a behavioral-educational sleep intervention for first-time mothers and their infants: pilot of a controlled trial. J Clin Sleep Med 2020;16:1265–74.
[18] Rouzafzoon M, Farnam F, Khakbazan Z. The effects of infant behavioural sleep interventions on maternal sleep and mood, and infant sleep: a randomised controlled trial. J Sleep Res 2021;30:e13344.
[19] Centers for disease control and prevention. https://www.cdc.gov/breastfeeding/pdf/ifps/ifps_ii/month2/month2gop.pdf; 2007.
[20] Sadeh A, Mindell JA, Luedtke K, et al. Sleep and sleep ecology in the first 3 years: a web-based study. J Sleep Res 2009;18:60–73.
[21] Keller MA, Goldberg WA. Co-sleeping: help or hindrance for young children's independence? Infant Child Dev 2004;13:369–88.
[22] Morrell JMB. The infant sleep questionnaire: a new tool to assess infant sleep problems for clinical and research purposes. Child Psychol Psychiatr Rev 1999;4:20–6.
[23] Owens JA, Spirito A, McGuinn M. The Children's Sleep Habits Questionnaire (CSHQ): psychometric properties of a survey instrument for school-aged children. Sleep 2000;23:1043–51.
[24] Barr RG, Kramer MS, Boisjoly C, et al. Parental diary of infant cry and fuss behaviour. Arch Dis Child 1988;63:380–7.
[25] Sadeh A. Assessment of intervention for infant night waking: parental reports and activity-based home monitoring. J Consult Clin Psychol 1994;62:63–8.
[26] Quante M, Hong B, Ash T, et al. Associations between subjectively and objectively measured sleep duration and timing in infants at age 6 months. Sleep 2020 Apr 9;44(4):zsaa217.
[27] Schoch SF, Jenni OG, Kohler M, et al. Actimetry in infant sleep research: an approach to facilitate comparability. Sleep 2019;42.
[28] Lederer DJ, Bell SC, Branson RD, et al. Control of confounding and reporting of results in causal inference studies. Guidance for authors from editors of respiratory, sleep, and critical care journals. Ann Am Thorac Soc 2019;16:22–8.
[29] VanderWeele TJ, Robinson WR. On the causal interpretation of race in regressions adjusting for confounding and mediating variables. Epidemiology 2014;25:473–84.
[30] Moore-Ede MC, Czeisler CA, Richardson GS. Circadian timekeeping in health and disease. Part 1. Basic properties of circadian pacemakers. N Engl J Med 1983;309:469–76.
[31] Duffy JF, Wright Jr KP. Entrainment of the human circadian system by light. J Biol Rhythm 2005;20:326–38.
[32] Jenni OG, Deboer T, Achermann P. Development of the 24-h rest-activity pattern in human infants. Infant Behav Dev 2006;29:143–52.
[33] Cajochen C. Alerting effects of light. Sleep Med Rev 2007;11:453–64.
[34] Higuchi S, Nagafuchi Y, Lee S-i, et al. Influence of light at night on melatonin suppression in children. J Clin Endocrinol Metabol 2014;99:3298–303.
[35] Iwata S, Fujita F, Kinoshita M, et al. Dependence of nighttime sleep duration in one-month-old infants on alterations in natural and artificial photoperiod. Sci Rep 2017;7:44749.
[36] Ohta H, Mitchell AC, McMahon DG. Constant light disrupts the developing mouse biological clock. Pediatr Res 2006;60:304–8.
[37] Bottino CJ, Rifas-Shiman SL, Kleinman KP, et al. The association of urbanicity with infant sleep duration. Health Place 2012;18:1000–5.
[38] Moon RY. SIDS and other sleep-related infant deaths: evidence base for 2016 updated recommendations for a safe infant sleeping environment. Pediatrics 2016;138.
[39] Adams S, Jones D, Esmail A, et al. What affects the age of first sleeping through the night? J Paediatr Child Health 2004;40:96–101.
[40] Touchette É, Petit D, Paquet J, et al. Factors associated with fragmented sleep at night across early childhood. Arch Pediatr Adolesc Med 2005;159:242–9.
[41] Mindell JA, Leichman ES, Walters RM. Sleep location and parent-perceived sleep outcomes in older infants. Sleep Med 2017;39:1–7.
[42] Volkovich E, Ben-Zion H, Karny D, et al. Sleep patterns of co-sleeping and solitary sleeping infants and mothers: a longitudinal study. Sleep Med 2015;16:1305–12.
[43] Hiscock H, Bayer J, Gold L, et al. Improving infant sleep and maternal mental health: a cluster randomised trial. Arch Dis Child 2007;92:952–8.
[44] Price AM, Wake M, Ukoumunne OC, et al. Five-year follow-up of harms and benefits of behavioral infant sleep intervention: randomized trial. Pediatrics 2012;130:643–51.
[45] Etherton H, Blunden S, Hauck Y. Discussion of extinction-based behavioral sleep interventions for young children and reasons why parents may find them difficult. J Clin Sleep Med 2016;12:1535–43.
[46] Messayke S, Franco P, Forhan A, et al. Sleep habits and sleep characteristics at age one year in the ELFE birth cohort study. Sleep Med 2020;67:200–6.
[47] Pinilla T, Birch LL. Help me make it through the night: behavioral entrainment of breast-fed infants' sleep patterns. Pediatrics 1993;91:436–44.
[48] Hysing M, Harvey AG, Torgersen L, et al. Trajectories and predictors of nocturnal awakenings and sleep duration in infants. J Dev Behav Pediatr 2014;35:309–16.
[49] Figueiredo B, Dias CC, Pinto TM, et al. Exclusive breastfeeding at three months and infant sleep-wake behaviors at two weeks, three and six months. Infant Behav Dev 2017;49:62–9.
[50] Ramamurthy MB, Sekartini R, Ruangdaraganon N, et al. Effect of current breastfeeding on sleep patterns in infants from Asia-Pacific region. J Paediatr Child Health 2012;48:669–74.
[51] Rudzik AEF, Robinson-Smith L, Ball HL. Discrepancies in maternal reports of infant sleep vs. actigraphy by mode of feeding. Sleep Med 2018;49:90–8.