Prospective Associations Between Infant Sleep at 12 Months and Autism Spectrum Disorder Screening Scores at 24 Months in a Community-Based Birth Cohort

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ABSTRACT

Background: Sleep problems have been associated with autism spectrum disorder (ASD) symptoms and diagnosis. However, past research has studied the simultaneous association of sleep problems with precursor ASD symptoms. Using data from a birth cohort, we estimate prospective associations between infant sleep characteristics at 12 months and later ASD screening scores at 24 months.

Methods: We obtained data from children (N = 1,096) and their mothers as participants in the Conditions Affecting Neurocognitive Development and Learning in Early Childhood longitudinal birth cohort study. Mothers were enrolled between 2006 and 2011, when they were 16–26 weeks pregnant. Using linear regression, we examined the influence of infant sleep characteristics (nighttime and daytime sleep, night wakings, and sleep onset latency) at 12 months on ASD screening scores at 24 months while controlling for other psychosocial characteristics.

Results: The number of night wakings was the only sleep characteristic at 12 months to be significantly associated with the development of early ASD symptoms at 24 months ($B = 0.097$, $P = .021$; 95% CI, 0.014 to 0.180). However, other competing risks, especially child socioemotional competence at 12 months ($B = 0.573$, $P < .001$; 95% CI, 0.361 to 0.785), showed stronger relative contributions in predicting ASD risk.

Conclusions: Infants with more sleep problems by 12 months, especially those waking more often during the night, showed an increased number of early ASD symptoms a year later. This study suggests that infant sleep characteristics could constitute one clinical sign of ASD risk, together with key psychosocial characteristics.

J Clin Psychiatry 2018;79(1):16m11127

To cite: Nguyen AKD, Murphy LE, Kocak M, et al. Prospective associations between infant sleep at 12 months and autism spectrum disorder screening scores at 24 months in a community-based birth cohort. *J Clin Psychiatry.* 2018;79(1):16m11127.

To share: https://doi.org/10.4088/JCP.16m11127

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An autism spectrum disorder (ASD) is estimated to occur in approximately 1 in 68 births.[1] Prevalence rates for sleep problems in children with ASD are higher than prevalence rates in children with typical development.[2–10] These findings suggest that preexisting sleep problems may be part of the ASD symptom constellation. Previous research has linked sleep problems with the emergence of associated developmental psychopathologies and behavior problems,[11–16] and, likewise, sleep problems could also exacerbate already existing symptoms of ASD. Regardless, developmental research on precursor ASD symptoms would benefit from more knowledge about the relationship between early childhood sleep and symptoms often associated with an eventual diagnosis of ASD.

Past research that links sleep problems and precursor ASD symptoms has been methodologically challenged. One important criticism of past studies is that children were often recruited when already diagnosed with ASD, which typically occurs after the age of 2 years.[17–20] Other research has observed a sleep-ASD relationship in 3- and 5-year-old children.[2,4,7,21,22] Studies rarely obtain data from children at or before 24 months, which can serve as precursor data. A British prospective study[23] that assessed 14,062 English-born children from 6 months to 11 years of age found a longitudinal relationship between parent-reported early childhood sleep patterns and ASD diagnosis. Better sleep could also be associated with less risk of ASD behaviors. From a preventive perspective, research on sleep characteristics and precursor ASD symptoms might help develop a better understanding of precursor symptoms to a later full-blown ASD symptomatology. Studies of the influence of sleep characteristics on the manifestation of precursor ASD behaviors should ideally occur earlier in development and examine a wider scope of outcomes. Early screening for sleep problems could make a significant contribution to the early diagnosis of ASD.

Normative infant sleep characteristics during the first year of life indicate that a total of 12 to 16 sleep hours per day for infants aged between 4 and 12 months is optimal.[24,25] A 12-month-old child is expected to sleep around 10 hours at night.[26,27] By 12 months, infants should be able to sleep through the night and sleep proportionately less during the day compared to earlier stages of their first year of life.

Large-scale screenings of ASD-type behaviors have been performed in community-based samples. Baron-Cohen et al[28] validated the Checklist for Autism in Toddlers (CHAT)[29] with approximately 16,000 British children aged 18 months. Their results yielded rates of nearly 100% on test specificity.[28] Specificity represents the ability of a test to correctly identify those without a condition, while sensitivity refers to the ability of the test to correctly

Clinical Points

- Sleep problems are associated with autism spectrum disorder (ASD) symptoms and diagnosis, but it is unknown if they emerge together or if sleep disturbance is a precursor to ASD.
- Night wakings are a clinical sign of ASD risk, but expected socioemotional competence at the end of the first year appears to be a stronger predictor.
- If infants show low socioemotional competence and wake often at night, clinicians should consider providing access to early intervention.

identify those with the condition. The Modified Checklist for Autism in Toddlers (M-CHAT) was then created as an extension of the CHAT; it incorporates 9 parent-report questions from the original CHAT and an additional 14 discriminatory symptoms.[30] Research has documented an association between M-CHAT screening scores and eventual ASD diagnosis. In American children, the M-CHAT has a sensitivity of 0.87 and a specificity of 0.99.[30] In Canadian children, it has a sensitivity between 0.77 and 0.92 and a specificity between 0.27 and 0.43.[31] The M-CHAT also has solid internal reliability.[30,32] Even in a non-Western cultural context, the M-CHAT significantly correlates with the Childhood Autism Rating Scale ($r = 0.581$), indicating good concurrent validity.[33] Its scores have been found to be significantly higher in children later diagnosed with ASD compared with typically developing children.[33] In a similar study, Wong et al[34] relied on a checklist that integrates elements from the CHAT and the M-CHAT with 125 Chinese participants. Results from Wong et al[34] suggested specificity rates between 0.77 and 0.91 depending on the number of failed questions either in each separate part or in total, yielding sensitivity rates between 0.74 and 0.93.

By using large-scale screening tools, studies are able to focus on the number of ASD risk behaviors per person rather than diagnosis prevalence in a given population. This is especially relevant as clinical symptoms associated with neurodevelopmental disorders are continuously distributed to various degrees in the general population.[35]

The purpose of this study was to estimate, using a birth cohort, prospective associations between infant sleep characteristics at 12 months and later ASD screening scores at 24 months. The prospect of finding associations between potentially nonnormative infant sleep characteristics and later ASD screening scores is appealing as infant sleep characteristics may serve as one of the earliest behavioral signs of atypical neurodevelopment. It was expected that daytime sleep duration at 12 months might be positively correlated with ASD screening scores at 24 months. Conversely, night sleep duration at those particular early ages was expected to be negatively correlated with ASD screening scores. It was also expected that the number of night wakings and sleep onset latency (ie, the length of time it takes to go from full wakefulness to sleep) at the end of the first year of life would be positively correlated with ASD screening scores taken a year later. Finally, the combined influence of sleep quality at age 12 months was expected to predict ASD screening scores at 24 months.

METHODS

Participants

Participants were recruited for the Conditions Affecting Neurocognitive Development and Learning in Early Childhood (CANDLE) longitudinal birth cohort study, funded by the Urban Child Institute (UCI) in Shelby County, Tennessee. The UCI CANDLE study is designed to examine a wide range of maternal and infant characteristics associated with early childhood development from the second trimester of pregnancy to age 3 years. Following informed consent, healthy pregnant women in Memphis and surrounding Shelby County were recruited at the Regional Medical Center at Memphis, several local hospitals, and health care providers associated with the University of Tennessee Health Science Center (64.1% African-American, 34.2% Caucasian, 1.6% others; Table 1). Mothers were enrolled between 2006 and 2011, when they were 16–26 weeks pregnant. Data collection was limited to 1 child per family. The institutional review boards at the University of Montreal and the University of Tennessee Health Science Center, Memphis, approved this research.

Measures

Predictor: infant sleep characteristics (12 months). The Brief Infant Sleep Questionnaire (BISQ)[36] was administered to assess infant sleep characteristics at 12 months. Research assistants administered the questionnaire to parents, who then provided details on infant sleep over the past week. The BISQ shows strong Pearson correlations for repeated measures on nighttime sleep duration ($r = 0.82$), daytime sleep duration ($r = 0.89$), number of night wakings ($r = 0.88$), and sleep onset latency ($r = 0.95$) as singular predictors of sleep quality. The number of sleep hours and the number of night wakings on the BISQ have been shown to be the best predictors distinguishing between clinical and control groups.[36] As a parent self-report instrument, the BISQ achieves results that are similar to those of studies that use objective measures and other subjective reports.[36]

For this study, night sleep duration (between 7:00 PM and 7:00 AM), mean number of night wakings, daytime sleep duration (between 7:00 AM and 7:00 PM), and sleep onset latency at bedtime are the variables of interest. Sleep onset latency at bedtime accounts only for the times when parents put the child to sleep in the evening. Those predictors were mainly measured in hours and thus were continuous, with a range of 3 to 12 hours of nighttime sleep, 0 to 8 hours of daytime sleep, and 0 to 6 hours of sleep onset latency. The number of night wakings ranged from 0 to 7 and was also considered continuous.

Outcome: ASD screening scores (24 months). The M-CHAT[37] was administered by a trained examiner to assess ASD-type child behaviors at 24 months. The scale consists of 23 items that are answered by "yes" or "no." Each answer determines whether there is a possible ASD-type behavior (1 for a failed item) or no sign (0) according to the answer key for each item. The cognitive examiners, who often were licensed psychologists or advanced psychology graduate students under the supervision of psychologists, were then tasked to proceed with a follow-up interview of each item that was scored as "failed" by interviewing the mother to elaborate or confirm answers.[38] This instrument has a good internal consistency coefficient (α = .85).[30] Kleinman et al[32] reported that the M-CHAT alone yielded a positive predictive value of 0.36 for American children. That positive predictive value was also found in a study from Spain.[39] In a follow-up study, the positive predictive value for ASD was as low as 0.28 in low-risk children for whom the M-CHAT was administered at age 16–23 months.[40] Nevertheless, the M-CHAT screening result was positive for a majority of children who were eventually diagnosed with ASD, language delay, or a global developmental delay.[40] For the current study, the primary screening score was the total number of failed items. Greater M-CHAT scores indicated more ASD-type child behaviors, hereafter referred to as greater ASD risk.

Control variables: mother and child (reported at the time of enrollment, at birth, or at 12 months). Mothers reported on (1) highest academic achievement at the time of enrollment, which was dichotomized by high school diploma or above (coded as 0) or no high school diploma (coded as 1); (2) ethnic background (non–African-American coded as 0; African-American coded as 1); and (3) marital status at the time the child was 12 months old. The latter variable was dummy-coded to differentiate between married/cohabitating mothers (coded as 0) and single mothers (coded as 1).

Using the information from the labor and delivery form, girls were coded as 0, and boys were coded as 1. Data on the exact percentile of birth weight for gestational age value were registered in the neonatal summary form. This measure determines whether the child is deemed as small for gestational age (SGA) based on American intrauterine gender-specific growth curves, compiled by Olsen et al.[41] According to the recommended cutoff point for SGA, weights below the 10th percentile were coded as 1, while percentiles equal or above the 10th percentile were coded as 0.

The Brief Infant Toddler Social Emotional Assessment (BITSEA)[42] identifies children who are at risk of experiencing socioemotional and behavioral problems. The BITSEA consists of 42 questions (of which 11 questions comprise the socioemotional competence component and 31 questions comprise the behavior problems component). Possible responses are 0 (rarely/false), 1 (sometimes/a little true), and 2 (always/very true).[42] Total scores range from 0 to 84 points. The 11 items on the Competence scale cover elements such as sustained attention, compliance, mastery motivation, prosocial peer relations, empathy, imitation/play skills, and social relatedness. The BITSEA yields excellent test-retest reliability, very good interrater reliability, and adequate internal consistency (α = .79 for the problem scale; α = .65 for the competence scale).[43,44] The BITSEA sufficiently discriminates between 24-month-old children with and without problems (sensitivity = 0.84; specificity = 0.90).[45] The BITSEA is seen as a valid tool for early detection of psychosocial problems in children at 24 months, but is not sufficiently valid to support identification of psychosocial problems below 24 months. Nevertheless, the BITSEA socioemotional competence scores represent a valuable screening component for ASD in children aged younger than 42 months as those scores are lower for children with ASD.[46] The screening accuracy for an eventual ASD diagnosis is significant for the socioemotional competence scale (AUC = 0.93; 95% CI, 0.91 to 0.95). The screening accuracy of the Competence scale is significantly better for girls (AUC = 0.97; 95% CI, 0.95 to 0.98) than boys (AUC = 0.91; 95% CI, 0.88 to 0.94).[47] Socioemotional competence scores at 12 months were dummy-coded as either below the 15th percentile (coded as 1) or not (coded as 0), according to the cutoff point in the BITSEA manual.[42]

Data Analytic Strategy

The unique contribution of each sleep component in predicting M-CHAT scores was subsequently assessed using ordinary least squares linear regression. A number of mother and child characteristics were included as possible confounders, as competing explanations, and to control for omitted variable bias.[48–55] Consequently, the regression model was adjusted for potentially confounding variables such as maternal education, maternal ethnic background, maternal marital status, sex of the child, birth weight for gestational age, and child socioemotional competence scores.

This longitudinal study required numerous data sources and follow-ups. As such, we expected children to have a percentage of incomplete data, at random, on 1 or more variables. Incomplete data percentages ranged from 0.09% to 11.59% (Supplementary eTable 1). Missing data may potentially bias estimated associations regardless of the analysis method used. Multiple imputation promises bias reduction while increasing precision.[56] Thus, to correct for attrition bias, we estimated randomly distributed incomplete data by conducting multiple imputation using SPSS statistical analysis software.

RESULTS

At 12 months, children slept a mean of 9.35 hours (SD = 1.429; range, 3–12) per night and 2.49 hours (SD = 1.374; range, 0–8) during the day, woke up 0.61 times per night (SD = 0.903; range, 0–7), and took 0.30 hours to go to sleep in the evening (SD = 0.340; range, 0–6). These averages are slightly lower than the expected ranges suggested by Hirshkowitz et al,[24] Paruthi et al,[25] Ferber,[26] and Weissbluth.[27]

Table 1 reports the descriptive statistics for the predictors (as an index and by components), outcome, and control variables.

Table 2 reports the bivariate correlations between the predictors, outcome, and control variables. Higher M-CHAT scores were associated with increases in night wakings

Table 1. Descriptive Statistics for the Outcome, Predictor, and Control Variables

Variable	N	Score Range	Mean	SD
Continuous measures				
No. of M-CHAT items failed (total number)	1,096	0–10	0.69	1.182
No. of sleep hours at night at 12 mo	1,096	3–12	9.35	1.429
No. of daytime sleep hours at 12 mo	1,096	0–8	2.49	1.374
No. of night wakings at 12 mo	1,096	0–7	0.61	0.903
Sleep onset latency at bedtime at 12 mo (hours)	1,096	0–6	0.30	0.340
Discrete measures				
Sex of the child	1,096	0–1	0.506	0.500
Boys	555			
Girls	541			
Maternal education at enrollment	1,096	0–1	0.909	0.288
Completed high school (coded 1)	996	0–1		
Did not complete high school (coded 0)	100			
Maternal marital status at 12 mo	1,096	0–1	0.594	0.491
Married/cohabitating (coded 1)	651			
Single (coded as 0)	445			
Maternal ethnic background at enrollment	1,096	0–1	0.641	0.480
African-American (coded 1)	703			
Caucasian (coded 0)	375			
Others (coded 0)	18			
BITSEA socioemotional competence scores at 12 mo	1,096	0–1	0.117	0.321
Equal/above 15th percentile (coded 0)	968			
Below 15th percentile (coded 1)	128			
Birth weight for gestational age	1,096	0–1	0.073	0.260
Equal/above 10th percentile (coded 0)	1,016			
Below 10th percentile (coded 1)	80			

Abbreviations: BITSEA = Brief Infant Toddler Social Emotional Assessment, M-CHAT = Modified Checklist for Autism in Toddlers.

Table 2. Bivariate Correlation Matrix Between Outcome, Predictors, and Control Variables[a]

	1	2	3	4	5	6	7	8	9	10	11
1. No. of M-CHAT items failed	1.00										
2. No. of night sleep hours	–0.12***	1.00									
3. No. of daytime sleep hours	–0.02	–0.05	1.00								
4. No. of night wakings	0.09**	–0.28***	–0.09**	1.00							
5. Sleep onset latency at bedtime	0.10***	–0.24***	–0.07*	0.12***	1.00						
6. Sex of the child	0.05	–0.03	0.00	0.08**	–0.00	1.00					
7. Maternal education	0.11***	–0.16***	–0.01	0.05	0.02	0.02	1.00				
8. Maternal marital status	0.15***	–0.29***	–0.14***	0.09**	0.15***	–0.01	0.17***	1.00			
9. Maternal ethnic background	0.18***	–0.40***	–0.12***	0.05	0.16***	0.02	0.14***	0.47***	1.00		
10. Socioemotional competence scores	0.16***	–0.04	0.02	–0.01	–0.03	0.08**	0.01	0.04	0.05	1.00	
11. Birth weight for gestational age	0.03	–0.09**	–0.02	0.06	0.04	0.04	0.06	0.08*	0.09**	0.03	1.00

[a]Spearman correlations are used for variables 1 to 5. Pearson correlations are used for variables 6 to 11.
*$P \leq .05$.
**$P \leq .01$.
***$P \leq .001$.
Abbreviation: M-CHAT = Modified Checklist for Autism in Toddlers.

($r_s = 0.09$, $P = .002$), sleep onset latency time at bedtime ($r_s = 0.10$, $P = .001$), and decrease in night sleep hours ($r_s = –0.12$, $P = .001$). M-CHAT scores were also significantly higher in cases in which mothers did not complete high school ($r = 0.11$, $P < .001$), were single ($r = 0.15$, $P < .001$), or were of African-American descent ($r = 0.18$, $P < .001$) and in which children had BITSEA socioemotional competence scores below the 15th percentile at 12 months ($r = 0.16$, $P < .001$). Number of daytime sleep hours was not significantly associated with M-CHAT scores ($r_s = –0.02$, $P = .501$). Bivariate correlations showed mostly similar results when the data were not corrected for attrition bias (Supplementary eTable 2).

Table 3 presents the unstandardized coefficients for the adjusted relationship between the 4 sleep characteristics at 12 months and the total failed items on the M-CHAT at 24 months. Only an increase in the number of night wakings significantly predicted later M-CHAT scores. An increase in the number of night wakings corresponded to a 7.0% increase in total failed items on the M-CHAT ($B = 0.097$, $P = .021$; 95% CI, 0.014 to 0.180) (Table 3). Several control variables significantly predicted total failed items on the M-CHAT: maternal education ($B = 0.343$, $P = .005$; 95% CI, 0.102 to 0.584), maternal ethnic background ($B = 0.298$, $P = .001$; 95% CI, 0.127 to 0.468), and BITSEA socioemotional competence scores ($B = 0.573$, $P < .001$;

Table 3. Infant Sleep Characteristics at 12 Months as Indicators of the Autism Spectrum Disorder Screening Scores at 24 Months

	Unstandardized Coefficients		95% CI		
Predictor	*B*	SE	Lower	Upper	β
No. of sleep hours at night	0.014	0.030	−0.044	0.072	0.016
No. of sleep hours in the day	−0.010	0.027	−0.064	0.044	−0.011
No. of night wakings	0.097*	0.042	0.014	0.180	0.070
Sleep onset latency	0.165	0.111	−0.053	0.382	0.045
Sex of the child	0.062	0.070	−0.075	0.198	0.026
Maternal education	0.343**	0.123	0.102	0.584	0.084
Maternal marital status	0.144	0.082	−0.016	0.304	0.060
Maternal ethnic background	0.298***	0.087	0.127	0.468	0.121
Socioemotional competence scores	0.573***	0.108	0.361	0.785	0.156
Birth weight for gestational age	−0.025	0.134	−0.287	0.238	−0.005
R^2	0.074				

*$P \leq .05$.
**$P \leq .01$.
***$P \leq .001$.

95% CI, 0.361 to 0.785) (Table 3). The number of hours slept during the night ($B = 0.014$, $P = .641$; 95% CI, −0.044 to 0.072), the number of daytime sleep hours ($B = -0.010$, $P = .712$; 95% CI, −0.064 to 0.044), and sleep onset latency at bedtime ($B = 0.165$, $P = .138$; 95% CI, −0.053 to 0.382) were associated to nonsignificant changes in total failed items on the M-CHAT. Maternal marital status at age 12 months significantly predicted total failed items on the M-CHAT ($B = 0.213$, $P = .017$; 95% CI, 0.038 to 0.388) before correction for attrition bias was applied (Supplementary eTable 3). However, that influence became nonsignificant after the correction.

DISCUSSION

Parents often refer to sleep problems in their children as a source of stress for the whole family. This is especially so in families with children who have symptoms associated with developmental psychopathologies. Childhood sleep problems have been associated with anxiety, depression, somatic complaints, socioemotional problems, and neurodevelopmental disorders.[2–16] Sleep problems are more frequent in children with precursor ASD symptoms, and these can begin early in childhood. This study sought to estimate prospective associations between infant sleep characteristics at 12 months and later ASD screening scores at 24 months in a community sample, with the goal of determining whether sleep characteristics could represent an early behavioral sign of ASD risk.

We found that the number of night wakings made a unique contribution to predicting subsequent ASD-type behaviors. Twelve-month-olds who woke more often during the night were more likely to have higher M-CHAT scores a year later than their counterparts who woke less often. At first, this finding suggests that infant sleep characteristics could represent an early sign of nonnormative brain development. However, other confounding variables (maternal education, maternal ethnicity, and socioemotional competence scores) made stronger unique contributions to predicting ASD screening scores than infant sleep predictors. In particular, the socioemotional competence characteristics (which comprise sustained attention, compliance, mastery motivation, prosocial peer relations, empathy, imitation/play skills, and social relatedness) made the most important relative contribution of all, followed by maternal ethnicity and then by maternal education.

Limitations and Strengths of the Study

This study is not without limitations. First, one major limitation is the use of a shared data source. In this case, mothers provided the data for both the predictors and the outcome at 2 different time points. Sadeh[57] found that parent reports on child sleep tend to overestimate total sleeping time by 14 minutes but also underestimate the total number of night wakings. Second, the M-CHAT outcome scores in this study might not provide a precise level of ASD risk, because a follow-up interview procedure was not administered for failed items. When a follow-up interview was included, positive predictive value of the M-CHAT increased from 0.36 to 0.74.[32] That finding is confirmed in a study[58] in which M-CHAT positive predictive value increased from 0.06 to 0.54 for ASD and from 0.11 to 0.98 for any diagnosis with developmental concerns in a general population sample. A third limitation is the lack of information on maternal socioemotional competence as a confounding variable in the relationship between sleep and precursor ASD symptoms. It appears that parental personality, mental health, and related cognitions and emotions contribute to parental behaviors and thus ultimately influence infant sleep.[59,60] It is plausible that a limited sense of parental self-efficacy could lead to more involvement between parents and children at bedtime. As such, infants who fall asleep with more parental involvement are more likely to wake more often and stay awake for longer times.[61] However, the links are transactional in that poor infant sleep may influence parental behaviors and vice versa.[60]

Notwithstanding such limitations, the strength of this longitudinal study is its ability to examine the unique contribution of infant sleep at the end of their first year of life on later developmental risk. Future research is warranted on the association between socioemotional competence in infants and autism symptoms in older children. Research on whether infant sleep characteristics predict the appearance of neurodevelopmental psychopathologies other than ASD between ages 3 and 5 years is also warranted. Given that more than 20% of children are affected by developmental psychopathology with impairment during the transition to formal schooling,[62] identification of behavioral markers and enrichment of socioemotional competence might lessen the functional impairment associated with this prevalence.

Submitted: August 4, 2016; accepted July 10, 2017.

Published online: January 2, 2018.

Potential conflicts of interest: All authors have no conflicts of interest to disclose; no financial relationships relevant to this article to disclose; and no competing interests.

Funding/support: None.

Supplementary material: See accompanying pages.

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Supplementary material follows this article.

THE JOURNAL OF
CLINICAL PSYCHIATRY
THE OFFICIAL JOURNAL OF THE AMERICAN SOCIETY OF CLINICAL PSYCHOPHARMACOLOGY

Supplementary Material

Article Title: Prospective Associations Between Infant Sleep at 12 Months and Autism Spectrum Disorder Screening Scores at 24 Months in a Community-Based Birth Cohort

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DOI Number: 10.4088/JCP.16m11127

List of Supplementary Material for the article

1. **eTable 1** Descriptive Statistics for the Outcome, Predictor, and Control Variables Without Correction for Attrition Bias
2. **eTable 2** Bivariate Correlation Matrix Between Outcome, Predictors, and Control Variables Without Correction for Attrition Bias
3. **eTable 3** Unstandardized and Standardized Coefficients for the Adjusted Relationship Between Infant Sleep Characteristics at 12 Months as Indicators of the ASD Screening Scores at 24 Months Without Correction for Attrition Bias

Disclaimer

This Supplementary Material has been provided by the author(s) as an enhancement to the published article. It has been approved by peer review; however, it has undergone neither editing nor formatting by in-house editorial staff. The material is presented in the manner supplied by the author.

Supplementary Material

eTable 1: Descriptive statistics for the outcome, predictor, and control variables without correction for attrition bias.

Variable	N	Score range	Mean	SD
Continuous measures				
Number of M-CHAT items failed (total number)	1096	0 – 10	.693	1.182
Number of sleep hours at night at 12 months	969	3 – 12	9.38	1.429
Number of daytime sleep hours at 12 months	969	0 – 8	2.50	1.374
Number of night wakings at 12 months	970	0 – 7	.61	.903
Sleep onset latency at bedtime at 12 months (hours)	970	0 – 6	.29	.340
Discrete measures				
Sex of the child	1094	0 – 1	.506	.500
• Boys	554			
• Girls	540			
• Missing	2			
Maternal education at enrollment	1095	0 – 1	.909	.288
• Completed HS (coded 1)	995			
• Did not complete HS (coded 0)	100			
• Missing	1			
Maternal marital status at 12 months	1003	0 – 1	.602	.490
• Married/Cohabitating (coded 1)	603			
• Single (coded as 0)	399			
• Missing	94			
Maternal ethnic background at enrollment	1094	0 – 1	.641	.480
• African-American (coded 1)	701			
• Caucasian (coded 0)	375			
• Others (coded 0)	18			
• Missing	2			
BITSEA socio-emotional competence scores at 12 months	1006	0 – 1	.128	.334
• Equal/above 15th percentile (coded 0)	878			
• Below 15th percentile (coded 1)	128			
• Missing	94			
Birth weight for gestational age	1059	0 – 1	.076	.264
• Equal/above 10th percentile (coded 0)	979			
• Below 10th percentile (coded 1)	80			
• Missing	37			

eTable 2: Bivariate correlation matrix between outcome, predictors, and control variables without correction for attrition bias.

	1	2	3	4	5	6	7	8	9	10	11
1) Number of M-CHAT items failed	1.00										
2) Number of night sleep hours	-.10***	1.00									
3) Number of daytime sleep hours	-.02	-.04	1.00								
4) Number of night wakings	.09**	-.28***	-.10**	1.00							
5) Sleep onset latency at bedtime	.10**	-.21***	-.08*	.10**	1.00						
6) Sex of the child	.05	-.03	.00	.08*	.00	1.00					
7) Maternal education	.12***	-.14***	-.01	.04	.03	.02	1.00				
8) Maternal marital status	.16***	-.28***	-.14***	.09**	.15***	-.01	.16***	1.00			
9) Maternal ethnic background	.17***	-.38***	-.11***	.05	.16***	.02	.14***	.47***	1.00		
10) Socio-emotional competence scores	.18***	-.05	.02	-.01	-.03	.09**	.02	.05	.07*	1.00	
11) Birth weight for gestational age	.02	-.09**	-.02	.07*	.04	.04	.06*	.09**	.10**	.03	1.00

Notes: asterisks reflect level of significance: * p ≤ .05; ** p ≤ .01; *** p ≤ .001. Spearman correlations are used for variables 1 to 5. Pearson correlations are used for variables 6 to 11.

eTable 3: Unstandardized and standardized coefficients for the adjusted relationship between infant sleep characteristics at 12 months as indicators of the ASD screening scores at 24 months without correction for attrition bias.

Predictor	Unstandardized coefficients		95% C.I.		
	B	SE	Lower	Upper	Beta
Number of sleep hours at night	.020	.030	-.039	.079	.024
Number of sleep hours in the day	-.007	.028	-.062	.047	-.009
Number of night wakings	.095*	.043	.011	.179	.073
Sleep onset latency	.187	.112	-.033	.406	.055
Sex of the child	.068	.075	-.080	.215	.029
Maternal education	.295*	.142	.016	.574	.067
Maternal marital status	.213*	.089	.038	.388	.088
Maternal ethnic background	.247**	.092	.066	.428	.102
Socio-emotional competence scores	.594***	.114	.371	.818	.167
Birth weight for gestational age	-.030	.144	-.312	.252	-.007
R-square	.078				

Note: * p ≤ .05; ** p ≤ .01; ***: p ≤ .001.