

Sleep/Wake Patterns Derived from Activity Monitoring and Maternal Report for Healthy 1- to 5-Year-Old Children

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Study Objectives: To describe behavioral sleep/wake patterns of young children from actigraphy and mothers' reports, assess age-group and sex differences, describe daytime napping, and investigate the impact of family demographic variables on sleep-wake measures.

Design: Cross-sectional sample of children wore actigraphs for 1 week; mothers kept concurrent diaries.

Setting: Children studied in their homes.

Participants: 169 normal healthy children in 7 age groups (12, 18, 24, 30, 36, 48, and 60 months old); 84 boys and 85 girls.

Interventions: N/A.

Measurements and Results: Nocturnal sleep/wake measures estimated from activity recordings using a validated algorithm; mothers' reports of nocturnal sleep/wake patterns and daytime naps obtained from concurrent diaries. Bedtimes and sleep start times were earliest and time in bed and sleep period times were longest for 12-month-old children. Rise time, sleep end time, and nocturnal sleep minutes did not differ across age

groups. Actigraphic estimates indicated that children aged 1 to 5 years slept an average of 8.7 hours at night. Actigraph-based nocturnal wake minutes and wake bouts were higher than maternal diary reports for all age groups. Daytime naps decreased monotonically across age groups and accounted for most of the difference in 24-hour total sleep over age groups. Children in families with lower socioeconomic status had later rise times, longer time in bed, more nocturnal wake minutes and bouts, and more night-to-night variability in bedtime and sleep period time. Children with longer naps slept less at night.

Conclusions: Individual differences in sleep/wake measures reflect characteristics of children, parents, or parent-child interactions.

Keywords: Children, sleep/wake patterns, actigraphy, developmental, ontogeny, naps, diary

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INTRODUCTION

YOUNG CHILDREN'S SLEEP FEATURES PROMINENTLY IN PARENTS' DEVELOPMENTAL CONCERNS. NEVERTHELESS, REMARKABLY FEW OBJECTIVE DATA EXIST on the sleep/wake patterns of preschool-aged children, and most reports were published before 1980. The collection of objective sleep studies of preschool-aged children includes differences in procedures, settings, length of recordings, age groups examined, and so forth.¹⁻¹¹ Generalizations arising from these reports, therefore, may not adequately capture the nature of young children's sleep. Societal changes and parental expectations may also impact children's sleep, and the available normative data may no longer reflect current sleep patterns.

The availability of norms for younger children is important to assist parents, teachers, physicians, psychologists, and other health professionals in understanding the sleep/wake patterns of normal children and children whose sleep is considered problematic. A major concern to many parents of young children, for example, is night waking, which is reported with greater preva-

lence in preschool-aged children than would be expected based on polysomnographic data.¹²⁻¹⁴ Furthermore, Sadeh et al. recently reported that school-aged children with fragmented sleep (based on actigraphic estimates of night waking) showed lower performance on neurobehavioral functioning measures and also had higher rates of parent-reported behavior problems than children with less night waking.¹⁵

Finally, investigation of the extent to which children's sleep is influenced by child, parent, and sociocultural variables, such as age, sex, parent characteristics, and socioeconomic status may alert parents and clinicians to transient or mutable factors that have an impact on individual sleep/wake patterns.^{14,16-18} A rising concern about insufficient sleep of many teenagers and adults leads us to question whether the youngest members of families are also affected.

Activity monitoring has become fairly common in sleep research and provides a tool to address some of these issues. Actigraph monitors are now small, lightweight, and unobtrusive devices capable of collecting time-based activity data over extended intervals, and algorithms are available to estimate sleep and wake from these activity data.¹⁹⁻²² We have demonstrated previously that miniature actigraphs and their associated sleep/wake scoring algorithms provide valid and reliable measures of behavioral sleep/wake patterns for normal infants, children, and adults within behaviorally documented nocturnal periods.¹⁹⁻²¹

The goals of this study were to describe behavioral sleep/wake patterns in the home for a cross-sectional sample of healthy normal children 1 to 5 years of age, to assess age group and sex differences for sleep/wake pattern measures, and to investigate the impact of child and family demographic variables on children's sleep/wake measures. We report data from actigraph recordings in conjunction with maternal diary reports of daytime and nocturnal

Disclosure Statement

This was not an industry supported study. Drs. Acebo, Sadeh, Seifer, Tzischinsky, Hafer, and Carskadon have indicated no financial conflicts of interest.

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sleep/wake patterns. These data add to the limited actigraphy database for this age range²²⁻²⁴ and provide additional normative data for children studied in the home that may be useful to researchers and clinicians. The data we report from maternal diaries provide measures that describe the broad outlines of the children's 24-hour sleep patterns and add to the maternal-report data for young children.

METHODS

Data for this report were drawn from a cross-sectional study that obtained up to 7 nights of actigraph recordings on children living at home with sleep-wake schedules selected by the family. All procedures were approved by the E.P. Bradley Hospital Institutional Review Board for the Protection of Human Subjects, and parents provided informed consent for participants. Parents received \$20 and children a small toy or t-shirt for their participation.

Participants

Boys and girls ages 12 to 60 months took part in this project. Potential participants from the greater Providence, Rhode Island, area were located from a variety of sources (e.g., newspaper advertisements, recruiting by a commercial survey firm, word of mouth), screened, and recruited into groups of children, based on age, in months: 12 (n = 24, 12 boys), 18 (n = 29, 16 boys), 24 (n = 22, 12 boys), 30 (n = 21, 9 boys), 36 (n = 21, 12 boys), 48 (n = 24, 11 boys), and 60 (n = 28, 12 boys) months (with 2-week age windows on either side for 12- to 30-month-old children and 1 month on either side for 48- and 60-month-old children). Only a single child from any family participated.

Of the 169 children (84 boys and 85 girls) who completed the study, 154 were Caucasian, 3 African American, 1 Asian American, 1 Hispanic, and 10 of mixed racial descent. Ninety-five percent of the children lived with both natural parents. Sixty-eight (40%) of the children were first born. Mothers' mean age was 31.5 ± 5.2 years, and fathers' was 34.0 ± 6.1 years. Families were rated on the Hollingshead Four Factor Index of Social Status,²⁵ on which lower numbers indicate more education and higher-status occupations; 21% were rated Class I, 40% Class II, 27% Class III, 10% Class IV, and 2% were Class V. Fifty additional participants aged 12 to 60 months were enrolled but were dropped from the study for a variety of reasons, including medical illness at the time of recording (n = 20), child's refusal to wear the actigraph (n = 11), technical problems (n = 10), mother's noncompliance with procedures (n = 3), and discovery of exclusion criteria (see below) after assessments were complete (n = 6).

Parents were asked a series of questions to determine eligibility during a telephone screening interview and the initial home visit as described below. Inclusion required that the child was born full term without medical complications and presently living full time with the biologic mother and that the mother could understand the study requirements and read and write English. Children were excluded if parents reported major genetic, medical, psychological or behavioral problems, or "serious sleep problems." A serious sleep problem was defined as a positive response to the question "Does your child have a serious sleep problem?" and thus was mother determined. Also excluded were children whose parents reported mental health problems (such as recent treatment or hospitalization for mental illness; diagnosis of depression, mania, or

anxiety; or presence of psychotic symptoms) or sleep disorders (such as sleep apnea or narcolepsy) in the child's first-degree relatives and children taking medications that might affect sleep or alertness. Because the actigraph records motion, children who routinely coslept with parents or siblings were not included in the study, although some brief periods of cosleeping did occur and were documented by mothers, usually at the end of the night. We do not have complete information on the total number of potential participants approached. Advertisements stressed the need for healthy children without sleep problems, and the screening was done in multiple stages. The brief, initial phone prescreening interview queried about sleep problems, and those who responded affirmatively were not followed further. Finally, the inclusive screening interview by telephone sought information about the full range of inclusion and exclusion criteria.

Procedures

A telephone interview with a parent provided information about the study and screened for eligibility. Eligible participants were scheduled for a home visit. The initial home visit included an interview with the mother to obtain demographic and health information, placement of the actigraph on the child, and instructions on actigraph care and use. Mothers were given a diary and instructed in its use to keep track of the child's bedtimes, rise times, naps, and periods asleep, as well as times when the actigraph was off or exposed to external motion (such as car rides). A booklet of additional questionnaires (data not reported here) was left for parents to complete during the week.

The child wore the actigraph for approximately 7 days. Mothers were instructed to keep the actigraph on the child continuously, removing it only during times it could get wet (bathing or swimming) or subjected to shock. We used mini-actigraphs (AMA-32 Mini-Act, Ambulatory Monitoring Inc., Ardsley, NY), weighing 57 g, set for 1-minute recording epochs, zero-crossing mode, and movement detection sensitivity of 0.1g/rad per second. Mothers of children younger than age 36 months placed the actigraph on the child's left ankle; for children 36 months or older, the actigraph was placed on the nondominant (by mother's report) wrist. Placement of the actigraph on the ankles of the youngest children was necessary to prevent excessive notice and handling and to prevent children from accidentally hitting themselves with the device. All previous actigraph validation studies of these youngest children have used ankle placement.^{20,26} The device was moved to the wrist at age 36 months because of concern for breakage as the children became more mobile and able to generate greater force with their legs. Although hand dominance may not be fully developed until 4 to 5 years of age,²⁷ we queried mothers for their best estimate so that they would feel comfortable that the actigraph would not interfere with the child's dominant hand.

During the week of data collection, research staff telephoned mothers in the middle of the week to ask about any problems, illnesses, or special events and to remind them about the second home visit. The second home visit was made at the end of the week to check the diary and questionnaires for completeness and to collect the actigraph and forms. Upon return to the laboratory, the actigraph was downloaded, the record was checked against the mother's diary, and a follow-up phone call was made to resolve any discrepancies or to ask about missing data.

Measures

Diary Measures

We used a typical diary for logging sleep schedules with additional instructions to record events that might lead to artifacts in the actigraph record, such as actigraph “off” times and times of external motion.^a Mothers were asked to indicate by arrows when the child was put in bed for the night and taken out of bed in the morning and to fill in 30-minute “bubbles” to indicate times they believed the child was asleep. Mothers were instructed to fill in the diary by coding the boxes and circling the segment that most closely matched the time the event started and ended. They were explicitly asked not to “split a circle or a box into a smaller time segment.” Thus, if a nap began at 9:20 AM and lasted until 10:00, the mother was expected to fill in the 9:30-10:00 circle, resulting in a 30-minute nap recorded for an actual 40-minute nap. If a nap began at 9:10 AM and lasted until 10:00, the mother was expected to fill in the 9-9:30 circle and the 9:30-10:00 circle, resulting in a recorded 1-hour nap for an actual 50-minute nap. We expected this procedure to result in randomly distributed overestimates and underestimates from the mothers. Figure 1 illustrates one 24-hour portion of the diary. Measures derived from the diary included: Bedtime, defined as the beginning time of the 30-minute interval denoting when the child was put down in bed for the night; Rise Time, the beginning time of the 30-minute interval denoting when the child was taken out of bed in the morning; Time in Bed, the number of hours between reported Bedtime and Rise Time; Reported Wake Minutes, the summed time of 30-minute intervals in which mothers indicated that the child was awake between sleep onset at night and sleep offset in the morning; Nap Sleep Minutes, the summed time of 30-minute intervals denoting sleep outside of the nighttime sleep period; and Number of Naps, the number of discrete intervals of continuous sleep (separated by at least one 30-minute interval of wake) reported by mother outside of the nighttime sleep period.

Actigraphy Measures

Nocturnal sleep/wake measures were estimated from actigraphic data using the validated Sadeh actigraph scoring algorithm.¹⁹⁻²¹ Each nightly record was scored for the portion indicated as nighttime sleep by the diary report. Specifically, the algorithm was applied during portions of the record encompassing 30 minutes before reported Bedtime through 30 minutes after reported Rising Time. The actigraph variables assessed for this report are defined below and illustrated in Figure 1. All final scoring required reasonable correspondence between the mother’s completed diary and the actigraph record. For example, a mother was questioned about the discrepancy if she recorded a diary bedtime of 8:00 PM but continuous sleep was identified by the algorithm as starting at 6:30 PM. If no reasonable explanation was offered, the night was considered unscorable. This constraint was implemented to avoid making the assumption that low activity identified as sleep by the algorithm was sleep when not confirmed by mother’s report or if the mother was uncertain (e.g., could not remember, monitor may have been off, etc.). This method is conservative but important to avoid errors of overestimation.

Variables derived for analysis from the Sadeh sleep-scoring al-

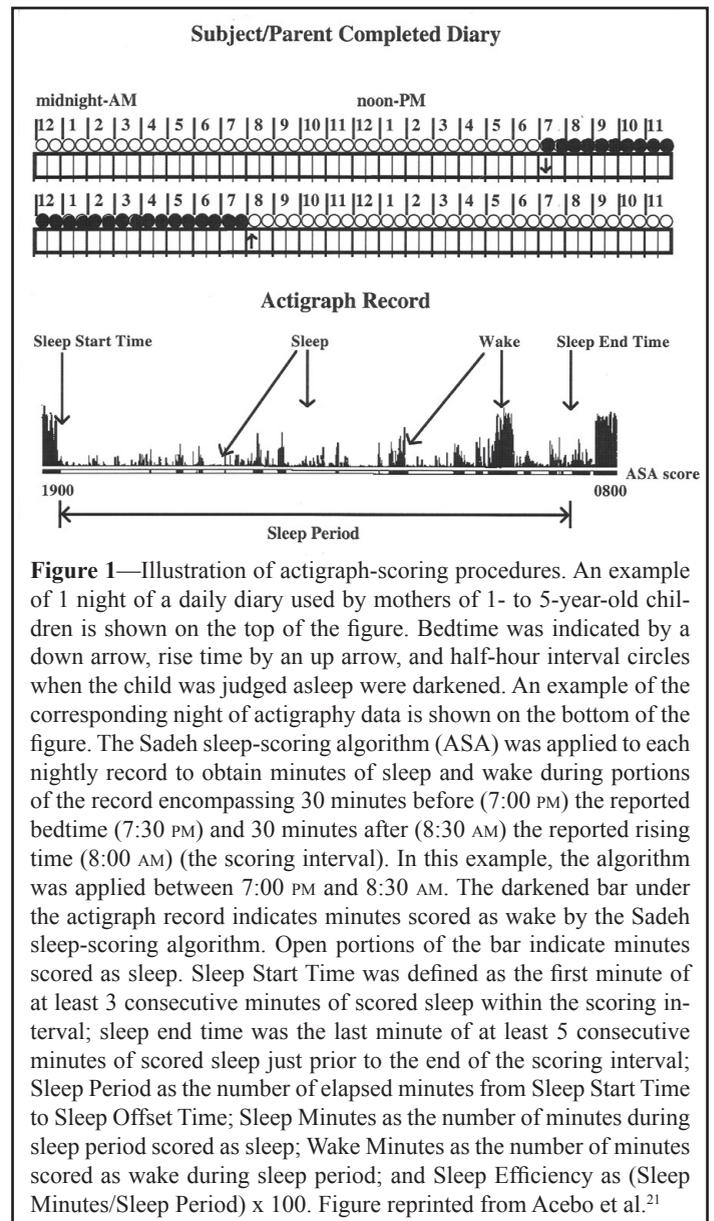


Figure 1—Illustration of actigraph-scoring procedures. An example of one night of a daily diary used by mothers of 1- to 5-year-old children is shown on the top of the figure. Bedtime was indicated by a down arrow, rise time by an up arrow, and half-hour interval circles when the child was judged asleep were darkened. An example of the corresponding night of actigraphy data is shown on the bottom of the figure. The Sadeh sleep-scoring algorithm (ASA) was applied to each nightly record to obtain minutes of sleep and wake during portions of the record encompassing 30 minutes before (7:00 PM) the reported bedtime (7:30 PM) and 30 minutes after (8:30 AM) the reported rising time (8:00 AM) (the scoring interval). In this example, the algorithm was applied between 7:00 PM and 8:30 AM. The darkened bar under the actigraph record indicates minutes scored as wake by the Sadeh sleep-scoring algorithm. Open portions of the bar indicate minutes scored as sleep. Sleep Start Time was defined as the first minute of at least 3 consecutive minutes of scored sleep within the scoring interval; sleep end time was the last minute of at least 5 consecutive minutes of scored sleep just prior to the end of the scoring interval; Sleep Period as the number of elapsed minutes from Sleep Start Time to Sleep Offset Time; Sleep Minutes as the number of minutes during sleep period scored as sleep; Wake Minutes as the number of minutes scored as wake during sleep period; and Sleep Efficiency as (Sleep Minutes/Sleep Period) x 100. Figure reprinted from Acebo et al.²¹

gorithm for nighttime sleep included: Sleep Start Time, defined as the time of the first of at least 3 consecutive minutes of sleep; Sleep End Time, the time of the last of at least 5 consecutive minutes of sleep; Sleep Period, the elapsed interval (in hours) from Sleep Start Time to Sleep End Time; Sleep Time, amount (in hours) of Sleep Period scored as sleep (indicated by open area on the Sadeh sleep-scoring algorithm score bar in Figure 1); Wake Minutes, the number of all minutes scored as wake during the Sleep Period (indicated by solid areas on the Sadeh sleep-scoring algorithm score bar in Figure 1); Sleep Efficiency, the percentage of the Sleep Period spent asleep ($[\text{Sleep Time}/\text{Sleep Period}] \times 100$); Minutes Longest Continuous Sleep, the number of minutes of the longest interval scored as continuous sleep within the Sleep Period; and Mean Activity, the average number of activity counts per minute during Sleep Period time. (Activity counts could range from 0 to 280 within each minute.)

Minute-by-minute scores from the algorithm for each night were also submitted to a smoothing routine to provide measures of night waking that represented more than very brief arousals and thus would better reflect waking that could be problematic for mothers. Variables obtained from smoothed scores included the Number of Smoothed Wake Bouts, defined as the number of

^aA copy of the diary may be obtained from the first author.

Table 1—Diary Report Measures According to Sex and Age Group

Diary Measure	Sex	Age Group, mo						
		12	18	24	30	36	48	60
Bedtime, PM*†	Boys	7:53 (35)	8:43 (44)	9:09 (91)	8:46 (20)	8:52 (47)	8:31 (41)	8:47 (41)
	Girls	8:41 (54)	8:40 (47)	8:42 (33)	9:00 (47)	8:40 (70)	9:17 (46)	8:35 (20)
Rise Time, AM	Boys	7:19 (85)	7:38 (59)	7:32 (29)	7:11 (46)	7:20 (34)	7:24 (28)	7:11 (44)
	Girls	7:22 (50)	7:35 (64)	7:19 (44)	7:34 (48)	7:19 (68)	7:47 (35)	7:25 (35)
Time in Bed, h‡	Boys	11.4 (1.4)	10.9 (.9)	10.4 (.6)	10.4 (.9)	10.5 (.8)	10.9 (.5)	10.4 (.6)
	Girls	10.9 (.9)	10.9 (1.0)	10.6 (.5)	10.6 (.6)	10.6 (.5)	10.5 (.6)	10.8 (.4)

Data are presented as mean (SD). Significant effects from analysis of variance; significant differences from posthoc tests.

*Age group ($F_{6,155} = 2.27, P = .04$); 12 mo < 24 mo, 30 mo, 48 mo, 60 mo

†Sex-by-Age-group interaction ($F_{6,155} = 2.84, P = .01$); 12-mo girls > 12-mo boys; 48-mo girls > 48-mo boys

‡Age group ($F_{6,154} = 2.27, P = .04$); 12 mo < 24 mo, 30 mo, 48 mo, 60 mo

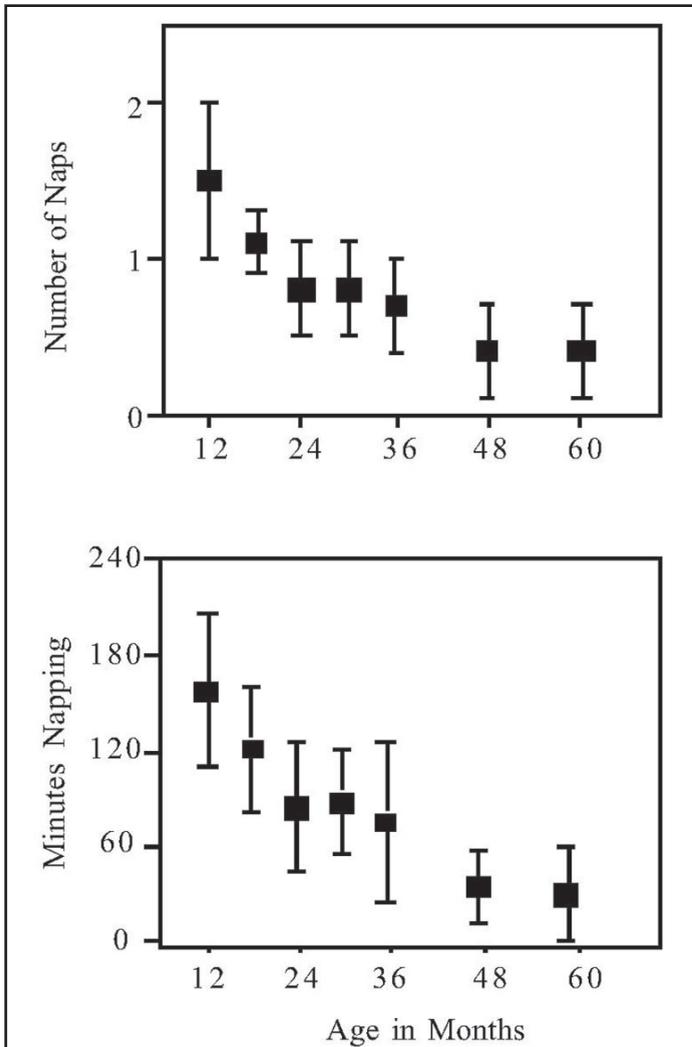


Figure 2—Measures of napping from maternal diary reports. Vertical lines depict SD. Mothers filled in 30-minute “bubbles” (see Figure 1) to indicate times the child was asleep during naps outside of the nighttime sleep period. Data were averaged over days for individual children. Mean number of naps (top panel) ($F_{6,124} = 26.8, P < .001$) and mean duration of naps (bottom panel) ($F_{6,124} = 22.2, P < .001$) differed significantly between age groups for children whose mothers reported naps. The pattern of differences was 12 months > 18 months and 24 months; 18 months > 24 months; 36 months > 48 months.

bouts of wake longer than 3 minutes within the Sleep Period and Smoothed Wake Minutes, the number of minutes of the Sleep Period scored as wake within Smoothed Wake Bouts.

Data Analysis

Individual nights were not scored as usable data if the child was sick or taking medications, the child slept with another person for the entire night, the actigraph was off or not working for all or part of the night, the diary indicated unusual external motion that would mask sleep (such as sleeping in a car or swing), the diary was not completed properly, or the actigraph data did not correspond sufficiently with the mother’s diary to identify sleep start and end times. At least 5 nights were scored for 91% of participants; 76% had at least 6 nights scored. No participant had fewer than 4 nights scored.

Nightly data for each actigraph and diary measure were averaged over nights for individual children for each measure. These individual weekly means were the units of analysis in multivariate analyses of variance with age group and sex as between-subject factors, followed by posthoc *t* tests. Alpha was set at .05. We first report the data obtained from the mothers’ diaries, followed by data from the actigraph recordings. Group mean values for data described below are presented in Tables 1 to 2 and Figures 2 to 4. In some instances, we also report lowest and highest individual mean data to illustrate the range of values in this sample.

RESULTS

Diary Measures

We found significant main effects for age group for reported Bedtime, reported Time in Bed, Number of Naps, and Nap Sleep Minutes (Table 1 and Figure 2). Sex was not a significant main-effect source of variance for any of the diary measures. An age-group-by-sex interaction was significant for reported Bedtime.

The age-group main effect for reported Bedtime and Time in Bed are accounted for by earliest average bedtimes and longest average Time in Bed for 12-month-old children versus children at 24, 30, 48, and 60 months (from posthoc *t* tests, $P \leq .05$). Bedtimes and Time in Bed for children 18 months and older did not differ on average. The significant age-group-by-sex interaction reflects later Bedtimes for 12- and 48-month-old girls than boys ($P < .02$). For individual children, the earliest individual mean Bedtime (averaged across all nights) was 6:30 PM in a 36-month-old girl; the latest individual mean Bedtime was 10:50 PM in a 12-month-old girl.

We did not find age group, sex, or interaction differences for Rise time reported by the mothers. The overall mean Rise time was 7:24 AM, and average Rise time was not different among the

Table 2—Actigraph Measures According to Sex and Age Group

Actigraph Measure	Sex	Age Group, mo						
		12	18	24	30	36	48	60
Sleep Start Time, PM*†	Boys	8:04 (34)	8:57 (44)	9:28 (31)	8:50 (43)	9:12 (43)	8:59 (36)	9:10 (44)
	Girls	8:51 (55)	9:04 (49)	9:02 (41)	9:22 (47)	9:10 (80)	9:43 (41)	9:02 (26)
Sleep End Time, AM	Boys	6:52 (70)	7:14 (53)	7:16 (29)	6:51 (43)	7:02 (32)	7:07 (27)	6:54 (52)
	Girls	7:02 (52)	7:17 (55)	7:02 (49)	7:26 (49)	7:10 (65)	7:31 (33)	7:04 (44)
Sleep Period Time, h‡	Boys	10.8 (1.0)	10.3 (.7)	9.8 (.4)	10.0 (.8)	9.8 (.6)	10.1 (.2)	9.7 (.6)
	Girls	10.2 (.8)	10.2 (.8)	10.0 (.5)	10.1 (.6)	10.0 (.7)	9.8 (.6)	10.0 (.5)
Sleep Time, unsmoothed	Boys	8.5 (.8)	8.8 (.6)	8.9 (.6)	8.8 (.9)	8.4 (.8)	9.0 (.7)	8.6 (.8)
	Girls	8.4 (.9)	8.8 (.5)	9.1 (.6)	9.0 (.8)	8.7 (.7)	8.5 (.8)	8.9 (.8)
Wake Bouts, smoothed§	Boys	7.6 (2.0)	5.3 (1.9)	3.8 (1.4)	4.3 (2.6)	4.6 (1.7)	4.4 (2.2)	4.8 (1.7)
	Girls	5.6 (2.0)	4.6 (1.6)	3.5 (1.4)	3.9 (1.1)	4.8 (1.8)	4.6 (1.0)	4.3 (1.5)
Sleep Efficiency, %	Boys	79.5 (6.2)	85.9 (4.5)	91.3 (3.4)	88.5 (7.7)	85.8 (5.3)	88.7 (6.4)	87.9 (4.9)
	Girls	82.8 (7.0)	86.6 (5.5)	91.0 (3.7)	89.8 (5.6)	87.0 (4.6)	86.9 (4.7)	88.6 (4.5)
Longest Continuous Sleep, min¶	Boys	104 (26)	149 (43)	184 (57)	179 (80)	156 (53)	153 (48)	143 (35)
	Girls	142 (48)	155 (62)	205 (43)	183 (50)	167 (52)	158 (36)	153 (35)

Data are presented as mean (SD). Significant effects from analysis of variance; significant differences from posthoc tests.

*Age group ($F_{6,155} = 3.64, P = .002$); 12 mo < 18 mo

†Sex by Age group interaction ($F_{6,155} = 2.34, P = .03$); 12-mo girls > 12-mo boys; 48 mo girls > 48 mo boys

‡Age group ($F_{6,155} = 2.91, P = .01$); 18 mo > 24 mo

§Age group ($F_{6,155} = 6.77, P < .001$); 12 mo > 18 mo, 24 mo; 18 mo > 24 mo

||Age group ($F_{6,155} = 7.98, P < .001$); 12 mo < 18 mo, 24 mo; 18 mo < 24 mo

¶Age group ($F_{6,155} = 5.24, P < .001$); 12 mo > 18 mo, 24 mo; 18 mo < 24 mo; 24 mo > 36 mo, 48 mo, 60m; 30 mo > 36 mo, 48 mo, 60 mo

age groups. Wide individual differences on this measure are evident in the large variability, as reflected in the SD. The earliest individual mean Rise time was 5:22 AM in a 12-month-old boy; the latest individual mean Rise time was 10:42 AM in an 18-month-old girl.

Mothers' reports of night waking were low at all ages. Only 45 mothers (27%) reported episodes of Wake during any night; only 13 mothers (8%) reported episodes of Wake on more than 1 night. For children between 1 and 3 years old, 71% of mothers reported no night waking on any night. For 5-year-old children, 82% of mothers reported no night waking. No significant age group, sex, or interaction effects were found for reported amount of night waking for children whose mothers reported night waking ($n=45$); their average reported night waking was 12 ± 10 minutes, which represents less than one 30-minute interval per night.

Daytime naps reported by mothers showed significant age-related patterns (Figure 2). A monotonic decrease in diary-reported daytime naps occurred across age groups. This finding was evident for both Number of Naps and Nap Sleep Minutes. Posthoc comparisons indicated significant decreases between 12, 18, and 24 months, then again between 36 and 48 months for both measures. The number (percentage) of mothers for each age group who reported naps decreased over age groups (12 months = 23 [96%]; 18 months = 29 [100%]; 24 months = 22 [100%]; 30 months = 20 [95%]; 36 months = 17 [81%]; 48 months = 15 [62%]; 60 months = 12 [43%]). Furthermore, 82% (95) of children older than 18 months were not taking any naps on some (65 children) or all (30 children) days.

Actigraph Measures

The main effect for sex was not significant for any actigraph variable (Table 2 and Figure 3). We found significant age-group effects for Sleep Start Time, Sleep Period Time, number of Wake Bouts during the night, Sleep Efficiency, and Longest Continuous Sleep episode. The only significant interaction was found for

Sleep Start Time.

The major feature of the age-group difference for Sleep Start Time was a later average time in the 18-month group versus the 12-month group but no additional differences among the older groups. The significant sex-by-age-group interaction reflects Sleep Start Times that are later for girls at 12 and 48 months ($P < .02$) than boys. The earliest individual mean Sleep Start was 6:43 PM in a 36-month-old girl; the latest individual mean Sleep Start was 11:00 PM in a 36-month-old girl.

Sleep Period Time differed by age group. Posthoc analysis indicated no difference between 12- and 18-month-old children, a significant decrease between 18 and 24 months, and no differences among groups of children aged 24 months and older. No main effects or interactions were found for Sleep End Time or nocturnal sleep time. The overall mean Sleep End Time was 7:08 AM. Mean nocturnal Sleep Time for the entire sample estimated from activity data indicated that children slept an average of 8.7 hours nightly. The shortest individual mean nocturnal Sleep Time was 7 hours in a 12-month-old girl; the longest individual mean Sleep Time was 10.4 hours in a 30-month-old girl.

Unsmoothed and smoothed nocturnal Wake Minutes were strongly correlated ($r = .99, P < .001$), with the same pattern of differences over age groups (See Figure 3). Smoothed estimates of nocturnal Wake were lower than the unsmoothed estimates (by about 12 minutes on average) as would be expected, but differences between the 2 measures were not significant (from t tests) for any age group or over the entire sample. Actigraph-estimated nocturnal Wake (unsmoothed) decreased from about 2 hours on average in the 12-month group to a low of 53 minutes in the 24-month-old children and then increased to reach stable mean values greater than 1 hour in the 30-month and older groups (group mean values: 30 months = 65 minutes; 36 months = 82 minutes; 48 months = 73 minutes; 60 months = 69 minutes). Mean activity counts also differed by age group, with a similar pattern to Wake minutes (Figure 3).

As noted above, mothers reported night waking in the dia-

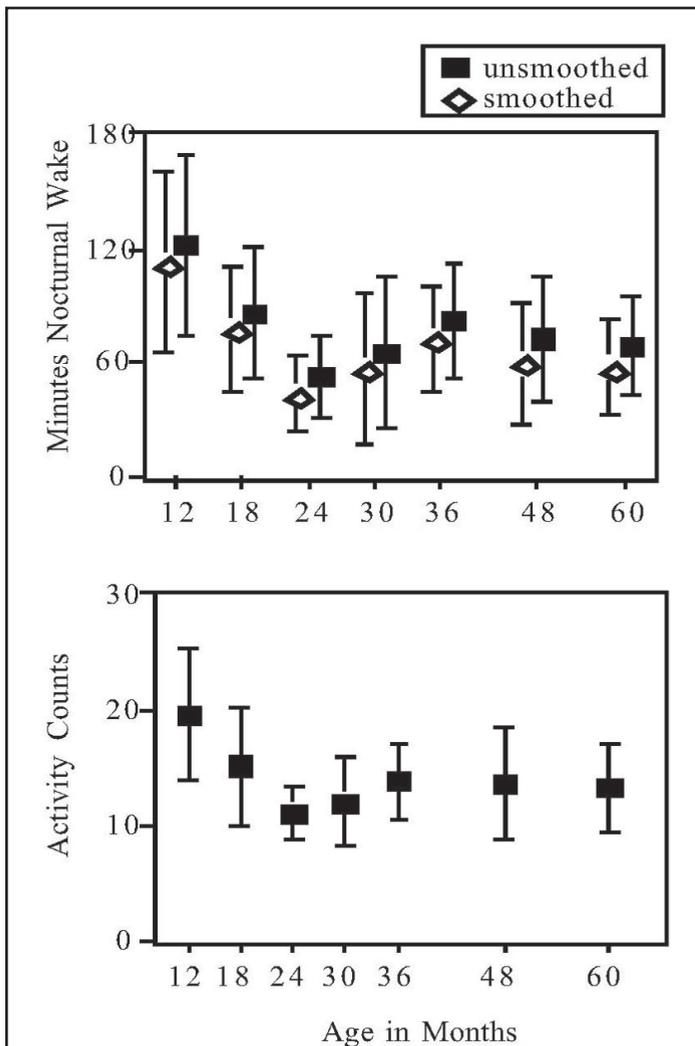


Figure 3—Both unsmoothed and smoothed mean (SD) minutes of nocturnal wake in the top panel differed significantly between age groups (unsmoothed $F_{6,155} = 9.47, P < .001$; smoothed $F_{6,155} = 10.44, P < .001$). For both measures, posthoc tests indicated 12 months > 18 months, 24 months, 30 months, 36 months, 48 months, and 60 months; 18 months > 24 months, 30 months, and 60 months; 24 months < 12 months, 18 months, 36 months, 48 months, and 60 months. Mean (SD) number of activity counts per minute in the bottom panel showed a similar pattern over age group ($F_{6,155} = 8.92, P < .001$). Posthoc tests indicated 12 months > 18 months, 24 months; 18 months > 24 months.

ries for only 45 children. Actigraph measures of nocturnal Wake Minutes for these children were significantly correlated with average mother-reported night-waking minutes ($r = .42, P = .004$ for unsmoothed Wake Minutes; $r = .40, P < .006$ for smoothed Wake Minutes). On the other hand, neither the smoothed nor unsmoothed actigraph Wake Minutes differed when comparing children whose mothers did or did not report night waking on their diaries.

The mean number of smoothed Wake Bouts differed by age group. Posthoc analysis indicated significant differences between 12-, 18-, and 24-month groups, with fewer wake bouts in each successive age group. No differences were found between groups of children 24 months of age or older. Sleep Efficiency is the complement of the actigraph Wake Minutes measure. As with Wake Minutes, the main effect for age was significant, with differences only between the 12-, 18-, and 24-month groups. The mean length of the Longest Continuous Sleep episode differed by age group,

Table 3—Sleep-Pattern Measures for Children According to Socioeconomic Status

Measure	Socioeconomic Status			
	I (n=34)	II (n=68)	III (n=45)	IV and V (n=20)
Risetime, AM (min)*	7:16 (43)	7:22 (46)	7:29 (45)	7:50 (71)
Time in Bed, h*	10.5 (.7)	10.7 (.7)	10.7 (.8)	11.2 (1.1)
Wake time, min— unsmoothed†	64 (31)	78 (38)	81 (39)	105 (44)
Wake Bouts, no.— smoothed†,‡	4.0 (1.6)	4.7 (2.0)	5.0 (1.9)	5.6 (1.9)
Longest Continuous Sleep, min— unsmoothed†	176 (56)	161 (54)	153 (48)	132 (29)
Sleep Efficiency, %†,§	89.3 (4.8)	87.3 (6.0)	86.8 (5.8)	83.4 (6.4)

Data are presented as mean (SD).

*From diary.

†From actigraphy.

‡Bouts of wake longer than 3 minutes.

§Defined as (Sleep Minutes/Sleep Period) x 100.

with longer episodes in each successive age group between 12, continuous Sleep than the 24- and 30-month-old children.

Daytime Naps and Night Sleep

We were interested in whether nocturnal sleep/wake measures were related to the reported length of daytime naps for children who napped once or more during the week. We performed a hierarchical regression analysis for each sleep/wake measure with age and sex entered on the first step and Nap Sleep Minutes on the second step. Significant increments to R^2 for Nap Sleep Minutes were evident for Sleep Period Time (R^2 increment = .12, $P < .001$), nocturnal Sleep Time (R^2 increment = .10, $P < .001$), and Sleep End Time (R^2 increment = .08, $P < .001$). Thus, among nappers, children who had longer mean Nap Sleep Minutes had shorter nighttime sleep periods, slept less at night, and woke earlier in the morning than children with lower mean nap durations. Nap Sleep Minutes was not related to Sleep Start time, nocturnal Wake Minutes, or Sleep Efficiency.

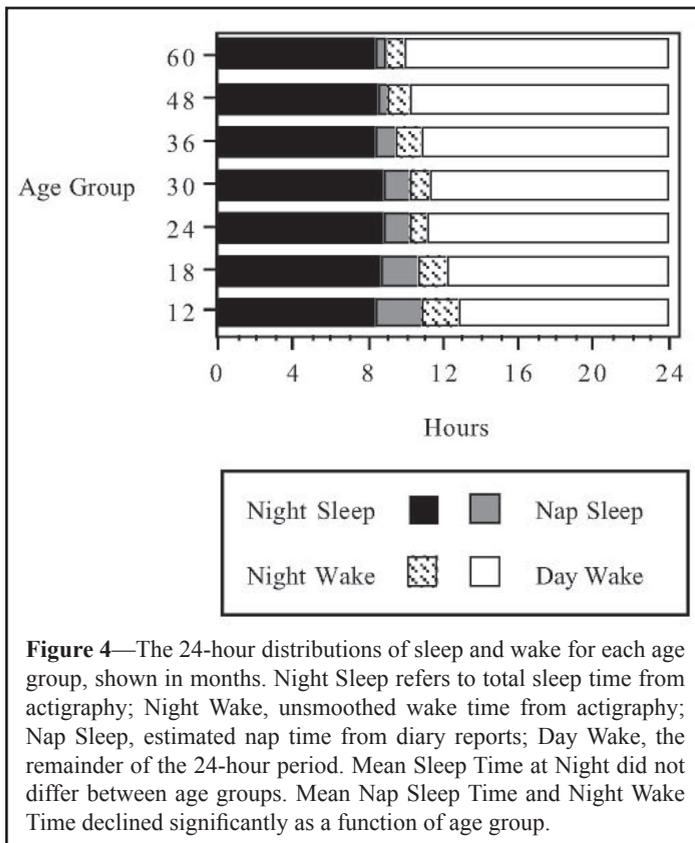
Mean (SD) nocturnal Sleep Time was shorter for nappers versus nonnappers in the 48-month-old group (nappers, 506 (41) minutes; nonnappers, 552(37)), and in the 60-month-old group (nappers, 502 (44) minutes; nonnappers, 540 (45)).

Night-to-Night Variability

We assessed age and sex differences in the degree of variability over nights in individual children. For each sleep measure and each child, the coefficient of variation (CV) was computed as SD divided by the Mean. We found no main effects for sex for any measure. We found significant main effects for age group for Wake Minutes and Sleep Efficiency such that CVs were higher in the 36-month-old group than other age groups. Significant sex-by-age-group interactions were found for Bedtime and nocturnal Sleep Time, with boys higher at some ages and girls higher at others, but no consistent pattern of differences.

Twenty-Four-Hour Sleep/Wake Patterns

Figure 4 illustrates the 24-hour distribution of sleep and wake



for each age group from actigraphy estimates for nocturnal sleep and wake and mothers' report for daytime nap sleep. The figure reflects the significant decline in Nap Sleep time and Night Wake across age groups, as described above.

Family or Parent Demographic Variables

To assess the influence of socioeconomic status (SES) and parental age on sleep/wake measures, we performed a hierarchical regression analysis for each sleep/wake measure with age and sex entered on the first step, Hollingshead ratings of SES on the second step, and parental age variables on the final step. Significant increments to R^2 for SES were evident for reported Rise Time (R^2 increment = .03, $P = .03$), reported Time in Bed, actigraph nocturnal Wake Minutes (R^2 increment = .06, $P < .001$), Wake Bouts (R^2 increment = .05, $P = .004$), Longest Continuous Sleep (R^2 increment = .05, $P = .002$), and Sleep Efficiency (R^2 increment = .05, $P = .002$). Thus, after controlling for age and sex, children in families with a lower SES were taken out or got out of bed later in the morning, spent longer times in bed, had more nocturnal Wake, more Wake Bouts, shorter Longest Continuous Sleep Bouts, and lower Sleep Efficiency (see Table 3). Age, sex, and SES together accounted for 34% to 41% of total variance for actigraph nocturnal wake and sleep efficiency, respectively. In addition, we found trends ($P = .06$) for longer Sleep Period times and later Sleep End times with lower SES. We did not find significant associations with socioeconomic status for Reported Bedtime, Sleep Start time, Reported nocturnal Wake Minutes, Nap Sleep Minutes, or nocturnal Sleep Time. Increments to R^2 for parental age measures were not significant for any of the sleep/wake measures.

Regression analyses of the variability measures (CV) revealed significant increments to R^2 for reported Bedtime (R^2 increment = .07, $P = .001$), Sleep Start Time (R^2 increment = .05, $P = .003$),

and Sleep Period (R^2 increment = .03, $P < .02$). Thus, after controlling for age and sex, children in families with lower SES had more nightly variability in Bedtimes, Sleep Start times, and Sleep Period times.

DISCUSSION

Our data from this cross-sectional study indicate age-related changes in at-home nocturnal sleep as estimated by actigraphy across ages 1 to 5 years, with most differences between the 12-, 18-, and 24-month groups. Actigraph estimates of nocturnal sleep and wake were remarkably stable among groups 24 to 60 months old. On the other hand, the average length of mother-reported daytime naps declined quite sharply from an average of 2.5 hours per day in the 1-year-old group to 30 minutes in the subgroup (43%) of 5-year-old children who still napped. Furthermore, estimated total 24-hour sleep averaged 9 to 9.5 hours in our 4- and 5-year-old children, as compared with the greater than 10 hours typically described for this age group.²⁸⁻³¹ Other striking features of these data include high amounts of nocturnal Wake as estimated by actigraphy and a wide range of individual differences in measures of sleep and in sleep patterning within each age group. Our results indicate that family SES was a significant contributor to sleep/wake pattern variation: children in families with higher SES tended to be out of bed earlier in the morning, spent less time in bed during the night, and had less nocturnal waking, higher sleep efficiency, and longer continuous sleep bouts. Night-to-night variability was lower, on average, in families with higher SES for Bedtimes, Sleep Start times, and Sleep Period times. We speculate that parents in higher SES groups may be more likely to keep scheduled bedtimes for their children but are unable to avoid waking them early.³² The shortened Time in Bed may reflect the time pressures faced by higher SES families and may account for increased Sleep Efficiency and longer continuous Sleep Bouts in these children. Finally, nocturnal sleep duration among nappers was negatively related to daytime nap duration, and 4- and 5-year old nappers slept less at night than children the same ages who did not nap.

The age-related changes we report for nocturnal sleep/wake measures are surprisingly few and small. For example, reported Time in Bed showed an average difference of about 18 minutes between the 12-month group and the 18-month group, with no significant differences between groups aged 18 months and older. Similarly, Sleep Start Time was earlier and Sleep Period longer in the youngest group, though again the average differences were modest (about 30 minutes). Although average times were "practically" similar among groups, individual differences were quite substantial.

The overall similarities between actigraph measures and mother-reported measures may arise from our requirement that the diary report and actigraph record be consistent in order to retain the record for analysis. Our procedures rely on the diary reports to set nightly windows for scoring actigraphy records; thus, nights of actigraphy that could not be reconciled with diary reports were dropped from analysis. Likewise, nights of diary data that were not supported by actigraph data were dropped from analysis. This process is equivalent to excluding from analysis sections of polysomnography records that have artifact or dropout in 1 or more signals. We believe that using this "quality control" resulted in best-case measures from both actigraphy and diary procedures.

To some extent, this mutual selection process may limit the generalizability of both types of measures should they be compared with results from either technique alone. On the other hand, because each procedure provided validation for the other, our results might also be seen as optimal estimates from the 2 methodologies.

When we compare our actigraph sleep data with polysomnography studies, the in-lab studies generally report more nocturnal sleep (9-11 hours compared with 8.7 in our sample) and less nocturnal wake (less than 60 minutes compared with twice that much in our 12-month-old sample).^{8,11,33} An exception is the study by Kahn and colleagues in 1973,⁷ in which measures of sleep time were comparable to our estimates for younger children. Thus, Total Nocturnal Sleep Time was 8.9 hours for 2- to 4-year-old children, and Daytime Nap Sleep averaged 108 minutes; Total Nocturnal Sleep Time for 4- to 6-year-old children was 9.6 hours. Several explanations may account for the discrepancies between our results and those from most laboratory studies, including several differences in study design. In-lab sleep studies published in the 1970s and 1980s typically recorded sleep based upon "usual" (otherwise unspecified) schedules as estimated by mothers. These "usual" schedules may have been "ideal" schedules that optimized the typical pattern. On the other hand, "usual" sleep expectations may have changed over time. The older studies also may have included fewer children with working mothers. In addition, procedures for some of the in-lab studies included withholding daytime naps; therefore, children may have been somewhat sleep deprived. Thus, procedural differences may account in part for differences between home-based and laboratory studies.

Parental attitudes about sleep and sleep schedules also may have changed over the last several decades,³⁴ reducing expectations for "usual" sleep needs of children. Evidence is accumulating that sleep length is declining in adults and adolescents in the United States³⁵; perhaps our data indicate a similar secular trend for younger children. For example, Iglowstein and colleagues³¹ have shown cohort differences in mother-reported sleep times of Swiss children.

Changes in adult and adolescent sleep patterns are commonly attributed to lifestyle,³⁵⁻³⁸ and parental life styles and attitudes may also influence how they regulate their children's sleep. The associations among SES and measures of bedtime variability, Nocturnal Wake, Rise Time and Time in Bed support this speculation. Children whose parents have technical and professional occupations had less nightly variability in Bedtime and Time in Bed, but they also spent less Time in Bed, had less nocturnal wake, and were out of bed earlier in the morning. These results may reflect differences in parents' attitudes or availability, including attention to scheduling regular sleep periods, variable work hours, and variable financial, social, and time pressures.³² We cannot determine from our results whether the decreased nocturnal Wake in children of families with a higher SES indicates higher "quality" of sleep or consolidation of nocturnal sleep dictated by the shortened Time in Bed.

The results of this study highlight the importance of additional studies of sleep in the home to address such issues as how well maternal reports reflect children's sleep behaviors. Thus, do more night wakings measured by actigraphy versus maternal report indicate motor development or differences in children's "signaling" wakefulness to mothers.³⁹⁻⁴¹ Of interest is that actigraphy estimates of nocturnal waking are consistent with both clinical experience

and survey data,^{12,14,42} which indicate high rates of regular night waking (up to 33%) in preschool-aged children.⁴³ Recent findings from actigraph studies in older children indicate that significant sleep fragmentation may continue into later childhood.¹⁴

Our results on night-to-night variability of sleep measures indicate the potential usefulness of sleep-variability measures to index regulatory functioning in individual children and in families. Night-to-night variability in sleep patterns has been associated with difficulties in other domains in older children.⁴⁴⁻⁴⁶ The increased average night-to-night variability for several variables in the 36-month-old children raises the possibility that this age is a time of reorganization in the sleep/wake system. This finding bears replication and further assessment as a potential family stressor.

These cross-sectional data document prominent age-related differences in reported daytime naps. Consistent with the literature, total 24-hour sleep decreased over successive age groups, as shown in Figure 4. Unlike previous studies, however, decreased napping accounted for most of this change. The age-related differences for nap measures are consistent with Weissbluth's⁴⁷ longitudinal data for napping over the preschool-age years, and correlations between nap duration and nocturnal sleep are consistent with results from studies based on maternal and teacher reports.^{48,49} In addition, our data are consistent with others in highlighting large individual variation in napping behavior.^{47,50} Napping is thus another area that merits further study. Children differ in the number of years they continue to nap, yet few data exist on daytime sleep in preschool-aged children or consequences of its disruption, both for daytime functioning and consequent nighttime sleep.

One limitation of this study is that the sample predominantly represents white, middle-class children in urban and suburban Rhode Island. In addition, we did not obtain detailed information about daycare and kindergarten attendance by these children and could not assess the impact of these practices on sleep and sleep scheduling. The associations we found between sleep/wake measures and SES highlight the importance of performing larger and more broadly representative studies to fulfill clinical and research needs for normative sleep/wake data for young children. Another potential limitation of our study is that actigraph placement varied across age groups. The Sadeh sleep-scoring algorithm used in our study was validated for 1-year-old children wearing the actigraph on the ankle and for older children and adolescents wearing the actigraph on nondominant wrists.^{19,20} In spite of occasional reports that actigraph measures differ as a function of placement site,⁵¹ our algorithm has been shown to be relatively insensitive to placement differences.¹⁹ We did not investigate age differences in the amount of movement just before and after sleep episodes, although we found age differences in activity counts during sleep. It is possible that changes in the amount or duration of movement as children grow and develop could affect the validity of actigraph estimates of sleep, wake, and sleep-period timing. Additional validation studies of this methodology in young children are necessary to address these issues.

A final limitation of the study is the relatively small sample size for each age group and the associated limited power for the number of analyses reported here. Additional studies of preschool-aged children are needed to determine whether more subtle age-related changes occur, and longitudinal evaluations would be valuable. We are confident, however, that the differences we

detected are meaningful because they were coherent in maternal report and actigraph measures.

In conclusion, large individual differences on most measures may highlight the flexibility of the developing sleep/wake system and the potential importance of sleep/wake variables as indicators of biobehavioral functioning within the child, the parent-child system, or both. Associations between SES and sleep/wake measures illustrate the impact of family characteristics on the regulation of sleep and wakefulness in children. A great deal more research is needed in preschool-aged children to determine whether children are getting the sleep they need and how sleep affects developmental outcomes.

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