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Activity-Based Assessment of Sleep–Wake Patterns During the 1st Year of Life

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The aim of this study was to examine the validity of activity-based monitoring (actigraphy) for the assessment of sleep–wake patterns during the 1st year of life. Forty-one infants were directly observed for sleep–wake state determination by trained observers. Concomitant activity data obtained by actigraphs attached to the infants' ankles during the observation were matched on a minute-by-minute basis, and a scoring algorithm was developed for automatic identification of sleep–wake states. Overall, the automatic scoring algorithm for activity data reached 95.3% agreement rate with the observers' sleep–wake scoring. Distinction of quiet and active sleep reached agreement rates ranging from 54% to 87% at different ages. Significant night-to-night stability was found for several derived sleep–wake measures, and high variability was noted for other measures. It is concluded that actigraphy provides valid sleep–wake measures during the 1st year of life.

sleep states infant actigraph observations

Consolidation of sleep–wake cycles into a mature diurnal pattern is a major developmental task in infancy, involving highly complex biobehavioral processes (Sadeh & Anders, 1993). Parental reports indicate that this task is achieved by most infants during the 1st year of life; however, significant numbers of infants (20–30%) experience difficulties or delays in this process, chiefly in the form of multiple and/or prolonged night wakings. Such infants are often categorized as sleep-disturbed or night wakers (see Mindell, 1993, Richman, 1987, and Sadeh & Anders, 1993, for recent reviews).

Studies of infant sleep have employed a variety of research methods ranging from parental reports to sleep laboratory polysomnographic studies, each with its strengths and weaknesses. Several studies have demonstrated that parental knowledge of infant sleep is limited and inaccurate (Anders, Halpern, & Hua, 1992; Sadeh, 1994; Sadeh, Lavie, Scher, Tirosh, & Epstein, 1991). For example, parents are typically aware of their infant's night waking only when he or she "signals" (i.e., cries or calls for attention). Laboratory studies provide the most detailed information on infant sleep but are expensive, of limited duration, and deviate markedly from the infant's natural sleep environment. Direct behavioral observations may be made in the home but are labor-intensive and of relatively short duration (Thoman, Acebo, Dreyer, Becker, & Freese 1979). A variety of bedside or ambulatory methods have been developed to provide a more naturalistic and objective appraisal of sleep. These home-based methods include time-lapse video recordings (e.g., Anders & Sostek, 1976), pressure-sensitive mattress or static-charged mattress recordings (e.g., Thoman & Glazier, 1987), and a variety of other approaches that minimize direct instrumentation of the infant.

Continuous recording of activity—actigraphy—has been used in many fields of medicine and behavioral research (see Tryon, 1991, for review). Such monitoring has recently been adopted for assessing sleep patterns in adults, children, and infants (e.g., Cole, Kripke, Gruen, Mullaney, & Gillin, 1992; Sadeh, Alster, Urbach, & Lavie, 1989; Sadeh et al., 1991). The method involves relatively small activity monitors which use solid-state memory to store activity counts at frequent intervals (e.g., 1 min). Advantages of actigraphy for assessing behavior in infants and children include minimal disruption of ongoing behavior while obtaining continuous activity recordings for prolonged periods (7–10 days) and data collection in the child's natural environment. Meaningful sleep–wake

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measures can be derived from actigraphy. Such measures are highly correlated with polysomnography and have been validated in children and adults for defined sleep episodes (e.g., Cole 1992; Sadeh et al., 1989; Sadeh et al., 1991). Furthermore, actigraphic sleep measures reflect temporal (i.e., sleep–wake schedule) and qualitative (i.e., night-waking, sleep efficiency) aspects of sleep. Therefore, they facilitate economic identification of sleep disturbances and follow-up measurement for treatment interventions (e.g., Hauri & Wisby, 1992; Sadeh, 1994; Sadeh et al., 1989; Sadeh et al., 1991).

To date, actigraphic sleep measures have been based on the ability to distinguish minutes of sleep and wakefulness within behaviorally defined sleep episodes. A valid actigraphic determination of sleep states per se has not been demonstrated, principally because sleep state determinations in noninfant humans are generally not behaviorally distinguishable. In infants, by contrast, "active" and "quiet" sleep states have been characterized based upon different patterns of activity, respiration, eye movements, and facial expressions (Thoman, 1975). This observational state taxonomy was originally developed by Wolff (1959, 1966) and further extended and modified by Thoman and her colleagues (Thoman, 1975; Thoman, Korner, & Kraemer, 1976). Support for these state categories has been provided by demonstrating measurement reliability and validity (Denenberg & Thoman, 1981; Thoman et al., 1979; Thoman, Davis, & Denenberg, 1987; Thoman et al., 1976). This methodology has provided extensive normative data on infants and has been psychometrically assessed more fully than any other state classification scheme. Concordance between Thoman's observation taxonomy and polysomnography has not been directly assessed, although state measures from both techniques show the same developmental trends. The states in the taxonomy are assigned from observer judgments of the infant's behavior patterns with special attention given to the infant's eyes, face, skin coloring, movement, muscle tone, vocalization, and breathing. Judgments are based on the quality and patterning of behaviors, not just their presence or absence. Because motor behavior is a highly relevant marker for active sleep during the first months of life, we hypothesized that activity data alone might suffice for active and quiet sleep determination in young infants.

The aims of this study were (a) to assess the validity of actigraphic sleep–wake measures during the 1st year of life; (b) to determine whether actigraphic data alone could provide a valid distinction between active and quiet sleep states in infants during the first 6 months of life; and (c) to assess night-to-night reliability and stability of actigraphically derived nocturnal sleep parameters. Children were examined in the newborn period and at 3, 6, and 12 months of age. Night-to-night stability was examined in the 3-, 6-, and 12-month-olds only.

METHOD

Subjects

Forty-one healthy, normal infants participated in this study. Ten newborns were studied in the Rhode Island Women and Infants Hospital neonatal nursery during the 2nd or 3rd day after delivery. Eleven 3-month-old, 10 6-month-old, and 10 12-month-old infants were studied at home. Mothers were recruited at the hospital, through hospital medical records or by various advertising methods (posters, newspapers, etc.). Study procedures were fully explained to the mothers, and consent was obtained in accordance with procedures approved by the Hospital Institutional Review Board for Human Research. Exclusion criteria were (a) pregnancy or birth complications, (b) signs of stress or jaundice in the newborns, (c) inability to accommodate to the study procedures, (d) use of infant medication or medication with sedative effects taken by nursing mothers, and (e) illness during the study period.

Procedures

The actigraph validation study was based on 2.0- to 2.5-hour assessments by trained observers using direct observations. Newborn, 3-month, and 6-month infant observations were supplemented with respiration data collected with a sensor pad placed in the crib under the infant's body. Sleep–wake states were coded in 10-s epochs of observation/respiration according to the procedures described by Thoman (1975).

During the observation period, a miniature actigraph (AMA-32, Ambulatory Monitoring Inc., Ardsley, NY) was attached to the infant's left ankle. The actigraph is a programmable, computerized activity monitor with a piezoelectric sensor beam sensitive to accelerations above .01 g per rad/s and internal memory (32 k). Each detected movement is counted, and the total number of movements per minute is digitized and stored in the memory. The monitor weighs about 2 oz (56.70 gms) and measures 1.75 in. × 1.3 in. × 0.38 in. (4.45 cm × 3.30 cm × .97 cm). A velcro band was used to attach it to the child's ankle. In our study, the actigraphs collected data using a zero-crossing mode in 1-min epochs (filter setting mode 18). This epoch length was chosen because it provides excellent resolution, yet continuous monitoring for 7 to 10 days. After each recording session, the actigraph's data were downloaded using a special interface unit to an IBM-compatible PC. The resulting raw data files were then read and analyzed with a tailored software program (Sadeh et al., 1989; Sadeh et al., 1991).

The assessment of 3-, 6- and 12-month-old infants included two observations performed with a 1-week interval (see Figure 1 for examples of the raw data). During the interval between these two observations, mothers were asked to keep the actigraph on their infant's left ankle and to complete a daily log describing the infant's sleep–wake schedule. Newborns were available for only one concomitant observation/actigraphy session in the nursery. Because our chief interest was in younger infants for whom observation-based sleep-state determinations are most clear, we chose to pursue only limited assessment of a group of infants at age 12 months. Therefore, only one observation was made for the 1-year-olds.

Data Analysis

Data analysis occurred in two phases. The first phase focused on developing a scoring algorithm, and the second involved validity and reliability testing of the resulting scoring algorithm and the derived sleep–wake measures.

A total of 8,154 1-min epochs of concomitant actigraphic and observation-respiration data were analyzed for the entire sample. In the newborn, 3-month-, and 6-month-old infants, infant behavior and respiration were coded by trained observers for *wake*, *sleep–wake transition*, *active sleep*, *quiet sleep*, and *uncertain* according to Thoman (1975, 1990). Ten-s state codes were smoothed over 1-min intervals based on predominant state. In case of no predominant state, smoothing was based on the state that was unique or the state that was continuous with predominant state in the following minute.

Behavioral states were coded according to the following leading criteria:

- *Active Sleep*: The infant's eyes are closed, respiration is uneven and primarily costal in nature. Rapid eye movements (REMs) occur intermittently. Smiles, frowns, sucking, sighs, sobs, twitching, vocalizations, and related behaviors may be seen during active sleep;
- *Quiet Sleep*: The infant's eyes are closed, respiration is slow, regular, and primarily abdominal in nature. Motor activities such as occasional startles, rhythmic mouthing, and sighs are typical as well as short periods of tonic limb or body movement.
- *Wake*: Infant's eyes are usually open. Activity level is generally increased. Fussing or crying may be observed, and alert or drowsy arousal may characterize the infant.
- *Sleep–Wake Transition*: The infant is alternating between behaviors characterizing both wakefulness and sleep. There is usually generalized motor activity. Eyes may be closed or rapidly alternate between open and closed position.
- *Uncertain*: State could not be determined accurately. For example, respiration data were missing or mother's interactive behavior interfered with the ability of the observer to monitor the infant.

Interobserver reliability for states ranged from 78% to 99% (percent of exact 10-s epoch-by-epoch agreement) calculated by the following formula: number of agreements/(number of agreements + disagreements).

Observations of the 12-month-old infants were scored for sleep–wake only, based on prior experience of one of the authors (Acebo, 1987) indicating that activity or body movement alone is insufficient to differentiate between sleep states in this age group (an impression also supported by Thoman, personal communication, June, 1993).

Epochs scored as uncertain or sleep–wake transitions from the observations (5.2% of the total epoch number) were not included in developing the algorithm. Otherwise, activity data were matched on a minute-by-minute basis with the observers' scoring (wake, active sleep, quiet sleep).

In Phase I, discriminant function analysis was used to develop an algorithm for sleep–wake state determination (see Sadeh et al., 1989, and Sadeh, Sharkey, & Carskadon, 1994, for more details on the statistical methods) based on actigraph and observation data of the first six 3-month-old infants (calibration sample). The algorithm uses data from an 11-min window (the epoch in question plus the five epochs before and five epochs after the scored epoch). Several activity measures representing each window were subjected to stepwise discriminant analysis (SAS Institute Inc., 1985) to determine the most predictive variables for sleep–wake states (wake, active sleep, and quiet sleep). These measures included the raw activity count of each scored minute, as well as the following parameters derived for each window around the scored epoch: standard deviations, number of minutes with zero activity, number of minutes with activity counts ranging between 1 and 100, number of minutes with activity above 100 counts, mean value, and minimum value. Stepwise discriminant analysis identified five activity measures with a significant contribution to state identification. These five measures were then subjected to a second discriminant function analysis to obtain the final functions to be used in the scoring algorithm (see below).

In Phase II, the resulting algorithm was validated with the remaining five 3-month-old infants (validation sample) and the other age-group samples.

Data Reduction for Nighttime Period. In addition to minute-by-minute observation/actigraph validation, the reliability (stability) of several actigraphically derived summary measures was assessed. For all subjects with at least 3 consecutive days of continuous actigraphic data (11 at age 3 months, 10 at age 6 months, and 8 at age 12 month), sleep–wake measures were derived by applying the algorithm to the actigraphic data during the episodes reported by the mothers as the infants' nocturnal sleep period.

The nighttime period was chosen to minimize artifacts that might have resulted from infant swings, car rides, and other externally induced motion data. The following sleep–wake measures are included in the analysis: (a) *sleep onset time* (first minute detected as sleep during nocturnal bedtime period); (b) *sleep duration* (from sleep onset time to first detection of morning awakening longer than 1 hour); (c) *percent of quiet sleep* (percentage of sleep duration time spent in quiet sleep); (d) *percent of active sleep* (percentage of sleep duration time spent in active sleep); (e) *percent of wakefulness* (percentage of sleep duration time spent in wakefulness); (f) *longest sleep interval* (length of the longest continuous episode of sleep); (g) *mean activity level*; (h) *percent of motionless time* (percentage of sleep duration time the child was motionless as measured by the actigraph); and (i) *state transitions* (number of sleep–wake transitions).

Each measure was assessed in an analysis of variance for repeated measures, and measure reliability (r_{tt}) was calculated according to the procedures of Winer (1971).

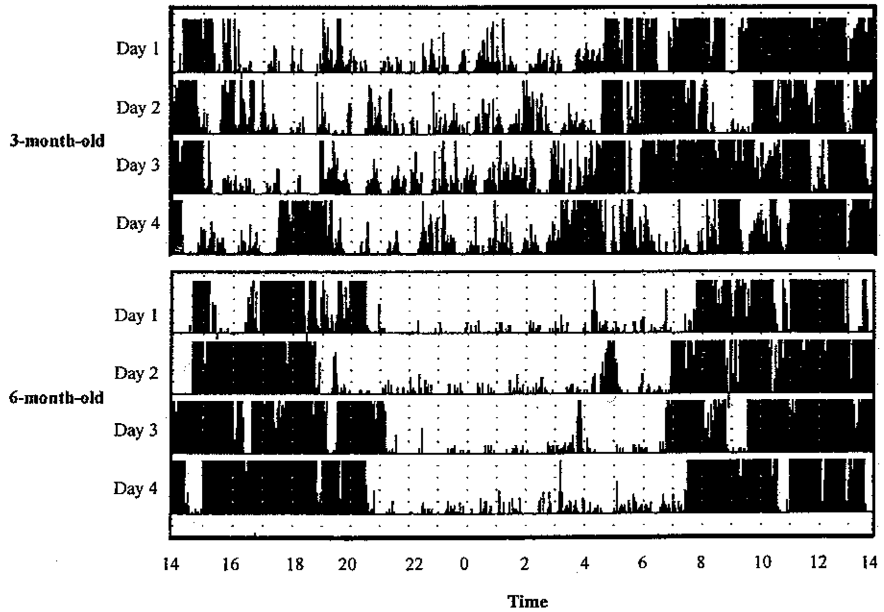

Figure 1. Raw activity data of four consecutive 24-hour periods of 3- and 6-month-old infants. Each black line represents the infant's activity level in a given epoch. Areas with condensed tall black lines represent wake periods, areas with less activity represent active or quiet sleep.

RESULTS

Sleep-Wake Scoring Algorithm

The algorithm for scoring wake, active sleep, and quiet sleep within an observed sleep period included the following parameters:

- nzw = number of minutes with zero activity in the global window (the scored minute plus the 5 min that precede it and follow it);
- ntl = number of minutes with low activity (nonzero but lower than 100 counts) in the global window;
- nth = number of minutes with high activity (equal or greater than 100 counts) in the global window;
- s5 = standard deviation of the window of the scored minutes plus the 5 min preceding it;
- ml = mean activity level of the scored minute and the preceding minute;
- lw4 = the lowest activity count during the window that includes the scored minute plus the following 4 min.

The probability for classification in each of the three states is given in the following indexes:

$$PQS = 15.94 + 3.223*nzw + 2.138*ntl + 1.1036*nth + .0466*s5 + .00292*ml + .0106*lw4,$$

$$PAS = 5.134 + 1.696*nzw + 2.062*ntl + .9568*nth + .0585*s5 + .00556*ml + .0105*lw4,$$

$$PAW = -25.638 + 1.714*nzw + 3.0168*ntl + 4.064*nth + .1066*s5 + .0386*ml - .016*lw4$$

where PQS is the probability of being a quiet sleep epoch, PAS is the probability of being an active sleep epoch, and PAW is the probabiity of being a waking epoch. The actual classification is made according to the highest index for each epoch. This algorithm was used to determine state measures for the following analyses.

Validity Based on Observer/Actigraph Comparison

Minute-by-minute agreement rates between actigraphic and observer scoring were calculated separately for each age group (see Figure 2 and Table 1).

Agreement rates were calculated as percentages based on the direct observation scoring. For example, agreement for wake minutes was calculated by wake minutes mutually scored by the two methods as a percentage of the total number of wake minutes scored by the observer. Agreement rates for combined states (e.g., three states) were calculated by minutes mutually scored by the two methods (as active sleep, quiet sleep, or wake) as a percentage of the total number of minutes scored (matches + mismatches). Across the entire sample, the observer/actigraph agreement rate for the aggregated minutes of wakefulness was 93.5%. The two methods reached an agreement rate of 74.9% for active sleep and 78.0% for quiet sleep (excluding the 12-month-old children, whose observations were not scored for active/quiet sleep state distinction). Agreement for sleep–wake states was 95.6%; whereas agreement across three states (wake, active sleep, and quiet sleep) was 83.5%.

Analysis of the sleep–wake transition epochs revealed that these minutes were scored by the algorithm as either active sleep (68.6%) or wake (31.4%). Uncertain minutes were typically classified as wake (58.8%) or active sleep (32.6%), with quiet sleep (8.6%) accounting for few of these epochs.

To assess the issue of age-specificity of the algorithm, we developed three separate sets of algorithms based on data from the other age groups (instead of the 3-month-old infants' data which was originally used). Analyses using these algorithms resulted in no significant improvement in the validity of the scoring in these age groups. Therefore, the algorithm described was selected for scoring throughout the 1st year of life, thus providing continuity of the derived sleep–wake measures.

In addition to the epoch-by-epoch agreement, we examined the correlation between summary measures (for the entire observation period) derived from the two methods. Global measures of observation time spent in each state were calculated for each child based on the actigraphic and observer's minute-by-minute scoring. These measures were then correlated and provided additional information regarding the validity of actigraphic scoring in estimating the percent of each state in each observation (Table 2). High correlations, ranging between .85 and .99, were found for the percent of time spent in wakefulness for all age groups. Lower correlations, ranging between .36 and .98, were found for active and quiet sleep percents, with the lowest correlations in the newborn group.

Additional analysis compared the means of the state percent calculated by the two methods using t test for paired comparisons and Wilcoxon signed rank test (Table 3). Again, strong agreement was found for the global measures of wake percent, with mean differences ranging between 0.2 and 3.5%. Mean differences for

TABLE 1
Agreement Between Actigraphic and Observer's Scoring: Minutes of Agreement and Percentages (Agreed/Observed) Calculated for Each State and Across States

		State					
Sample	N	Wake	AS	QS	Three States Correct	S–W Correct	Total N
Calibration							
3-Month	6	545 97.7%	317 88.1%	413 77.3%	1,275 87.8%	1,423 98.0%	1,452
Validation							
Newborns	10	240 82.8%	677 74.4%	50 54.9%	967 74.9%	1,148 88.9%	1,291
3-Month	5	622 92.5%	300 78.3%	327 87.2%	1,249 87.3%	1,341 93.8%	1,430
6-Month	10	1,107 97.8%	436 66.4%	636 76.7%	2,179 83.2%	2,563 97.9%	2,618
12-Month	10	754 99.34%	— —	— —	— —	1,325 97.2%	1,363

Note. AS = active sleep; QS = quiet sleep; Wake = minutes of wakefulness; Three States Correct = agreement rate considering the distinction between active and quiet sleep states; S–W Correct = agreement rate on sleep–wake scoring only.

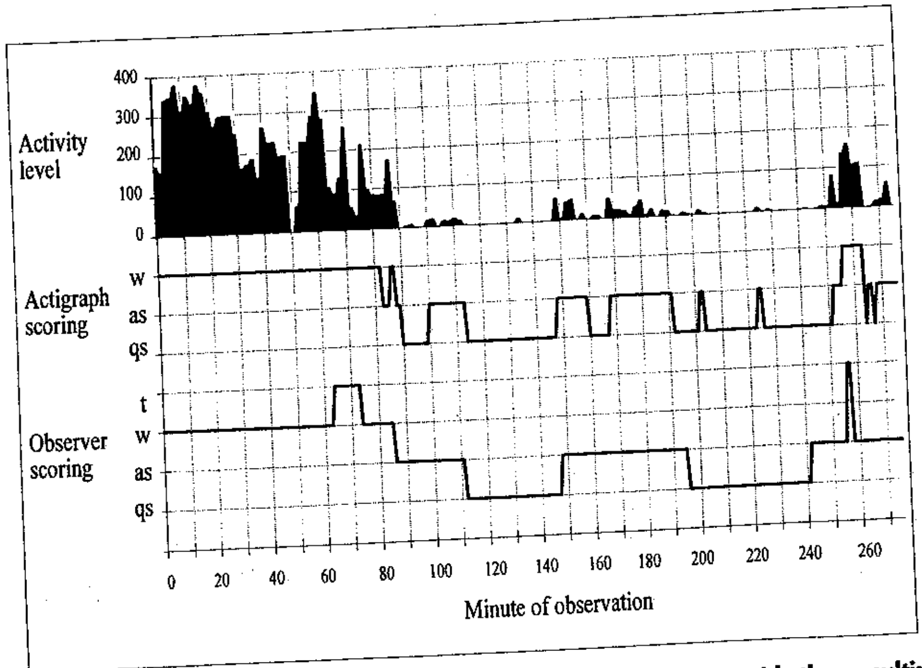

Figure 2. Minute-by-minute correspondence of the raw activity data with the resulting actigraphic scoring and the observer's state scoring in a 3-month-old infant. QS = quite sleep; AS = active sleep; W = wake; T = transition or uncertain period.

the sleep-state percent derived from the two methods ranged between 0.4 and 11.3%. None of the these differences was statistically significant.

Night-to-Night Variability and Stability of Actigraphic Measures

Table 4 summarizes the r_{tt} values calculated for each of the actigraphically derived sleep–wake measures for nocturnal sleep periods over the first three consecutive nights of each subject.

Three measures reached significant levels of r_{tt} in each age group: sleep onset time (.58, .75, and .77 for the 3-month-olds, 6-month-olds, and 1-year-olds, respectively), percent of motionless time (.81, .74, and .96, respectively), and the longest sleep interval (.79, .58, and .78, respectively). The r_{tt} value for the percent of wakefulness did not reach significance in any group.

DISCUSSION

This study examined the validity of actigraphic monitoring for assessing sleep–wake patterns during the 1st year of life. Previous validation studies with older children and adults have used polysomnography as the gold standard. The use of an observation-based method in this study enabled extending the examination to newborns and very young infants for whom polysomnography is less well established. In addition, this study examined for the first time a new miniature actigraph, which may be particularly suitable for young infants.

Before addressing the findings of this study, it is important to reemphasize that actigraphy is based solely on motility patterns; therefore, it is subject to artifacts that may result from externally induced motion (e.g., child sleeping in a moving car or stroller, sharing a bed), from periods in which the actigraph is removed from the child (e.g., while bathing), and from other possible sources (Alster & Sadeh, 1990; Sadeh et al., 1994). This study was conducted in a more controlled setting which minimized the potential for these artifacts (during the observation periods). In more natural circumstances, lack of control for possible artifacts may result in poorer validity, although careful documentation of such artifacts and editing of data sets may be useful. Applying automatic algorithms indiscriminately to unedited actigraphy data is not appropriate.

The results support the validity of actigraphy for distinguishing minutes of sleep from minutes of wakefulness for these defined episodes. Minute-by-minute agreement rates ranging between 88% and 98% are considered highly satisfactory and concur with previous findings comparing actigraphy with polysomnography in older children and adults (Cole et al., 1992; Hauri & Wisbey, 1992; Sadeh et al., 1989; Sadeh et al., 1991; Sadeh et al., 1994). For instance, Sadeh and colleagues found 85.3% minute-by-minute agreement in a group of 11 children ranging in age from 12 to 48 months (Sadeh et al., 1991). The validity of actigraphy for sleep–wake determination is also supported by the high correlation of the overall measures of percentages of wakefulness (ranging between .85 and .99) and by the low and insignificant mean differences of these measures derived by the two monitoring methods.

The validity of the distinction between active and quiet sleep on the basis of activity data alone was not as high as the sleep versus wake distinction. Although the measures of active and quiet sleep may fall within an acceptable range for the 3- and 6-month-old infants, that was definitely not so for newborns. Newborns whose sleep is characterized by overall high levels of activity may be precluded in a more valid distinction of sleep states based solely on motility patterns. Active and quiet sleep measures as obtained by actigraphy are, therefore, of limited validity in newborns.

The issue of day-to-day variations and stability of the measures deserves further investigation. Our exploration of this issue was limited by the small number of infants in each age group and by the cross-sectional nature of our study. Although several measures were stable on a day-to-day basis, others failed to reach a reasonable level of stability. These results may represent the age-specific instability of infant sleep–wake states, lack of reliability of some of these measures, or both. Because the validity of the sleep–wake distinction was highly supported when compared on a minute-by-minute basis to direct observation, the low r_{tt} values found for percentage of wakefulness are more likely due to the instability of sleep–wake patterns rather than lack of reliability of the method.

Surprisingly, only limited research has been done on this issue of day-to-day variations and stability of infant sleep–wake patterns. Thoman and Whitney (1989) reported r_{tt} values ranging between .70 and .87 on a week-to-week basis (1st–5th weeks) in healthy full-term infants for measures of state obtained from pressure-sensitive mattress recordings. Hoppenbrouwers, Hodgman, Arakawa, Giedel, and Sterman (1988) reported substantial variability of EEG-determined sleep–wake measures during the first 6 months of life. Freudigman and Thoman (1993) reported correlations ranging between .06 and .42 for sleep–wake measures of Day 1 and Day 2 in newborns. Our findings suggest that a considerable daily variability exists in sleep–wake patterns during infancy. This variability is an important factor which may adversely affect the predictive value of measures obtained during limited periods of monitoring (e.g., 1 day or a few hours).

Despite our inability to demonstrate high stability for all parameters of sleep and wake measured by actigraphy, we nonetheless

TABLE 2
Correlations Between State Percentages Based on Actigraphic and Observer's Scoring

		State		
Sample	***N***	**Wake**	**Active Sleep**	**Quiet Sleep**
Calibration				
3-Month	6	.99	.79	.78
Validation				
Newborns	10	.85	.78	.36
3-Month	5	.99	.98	.85
6-Month	10	.97	.80	.76
12-Month	10	.99	—	—
Subtotal[a]	31	.94	.85	.77
Total	41	.95	—	—

[a]Subtotal for infants with active/quiet sleep observation scoring.

TABLE 3
Actigraphic (Act) and Observer's (Obs) State Percentages During Observation Time: Means and Standard Deviations*

Sample	Method	Wake	Active Sleep	Quiet Sleep
Calibration				
3-Month	Obs	37.9 (29)	32.5 (18)	29.7 (13)
	Act	37.7 (30)	25.8 (14)	36.5 (20)
Validation				
Newborns	Obs	26.9 (33)	59.4 (27)	13.7 (11)
	Act	23.4 (21)	70.7 (17)	6.0 (8)
3-Month	Obs	48.2 (28)	25.5 (20)	26.3 (11)
	Act	49.1 (27)	26.1 (16)	24.8 (13)
6-Month	Obs	42.8 (29)	27.1 (17)	30.0 (20)
	Act	41.4 (31)	26.7 (20)	31.9 (20)
12-Month	Obs	43.3 (25)	—	—
	Act	41.4 (23)	—	—

Note. Standard deviations are in parentheses.
*None of the paired *t* tests and Wilcoxon signed rank tests for differences between actigraphy and observer's mean state percentages was statistically significant.

TABLE 4
Reliability and Stability of Actigraphic Sleep–Wake Measures: r_{tt} Values Based on Three Consecutive Nights From Sleep Onset to Morning Awakening

Measure	3-Month-Olds	6-Month-Olds	1-Year-Olds
Sleep Onset Time	.58*	.75**	.77**
Sleep Duration	.00	−.01	.81**
M Activity Level	.54	−.33	.62
State Transitions	.55	−.14	.72*
Longest Sleep Interval	.79**	.58*	.78**
% of Motionless time	.81**	.74**	.96**
% of Quiet Sleep	.84**	.40	n/a
% of Active Sleep	.86**	.53	n/a
% of Wakefulness	.44	−.33	−.79

*$p < .05$. **$p < .01$.

emphasize that the overall picture of stability of these measures was very impressive in an age period noted for unstable behavior and state organization (Emde, Gaensbauer, & Harmon, 1976). Low day-to-day stability has also been demonstrated in other behavioral domains. For example, behavioral state (ranging from deep sleep to crying) as measured with the Neonatal Behavior Assessment Scale (Brazelton, 1973) shows day-to-day stability of approximately .20 to .40 (Horowitz, Sullivan, & Linn, 1978). Stability across days of emotional state organization ratings (positive vs. negative mood states) used to characterize temperament in older infants is also low, ranging from .19 to .36 (Seifer, Sameroff, Barrett, & Krafchuk, 1994). Thus, the degree of stability in sleep organization is relatively high when compared with other measures of state and behavior organization characteristic of this age group.

Considering the advantages of actigraphy in terms of cost-effectiveness for long-term, continuous monitoring of infant sleep–wake patterns in naturalistic settings, more research is needed to establish its value for documenting maturational and clinical processes during the 1st year of life. For example, actigraphy may be particularly useful for longitudinal studies assessing maturational trends in normal, premature, sick, or developmentally delayed infants. Similarly, actigraphy may serve as a valuable tool for evaluating clinical interventions with young infants suffering from various medical or developmental disorders affecting the sleep–wake system (e.g., sleep problems, allergies, breathing difficulties, maturation delays). A number of normative and clinical studies in progress in our laboratories will evaluate these issues.

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