SLEEPJ, 2018, 1–12

doi: 10.1093/sleep/zsy146
Advance Access publication Date: 6 August 2018
Original Article

Original Article

Assessment of infant sleep: how well do multiple methods compare?

Marie Camerota[1,*], Kristin P. Tully[2], Melissa Grimes[1], Noa Gueron-Sela[3] and Cathi B. Propper[4]

[1]Department of Psychology and Neuroscience, University of North Carolina at Chapel Hill, Chapel Hill, NC, [2]Carolina Global Breastfeeding Institute, Department of Maternal and Child Health, Gillings School of Public Health, University of North Carolina at Chapel Hill, Chapel Hill, NC, [3]Department of Psychology, Ben-Gurion University of the Negev, Beer-Sheva, Israel, and [4]Center for Developmental Science, The University of North Carolina at Chapel Hill, Chapel Hill, NC

*Corresponding author. Marie Camerota, UNC-CH, Campus Box 3270, 235 E. Cameron Street, Chapel Hill, NC 27599. Email: marie.camerota@unc.edu.

Abstract

The current study compares sleep variables obtained from videosomnography, actigraphy, and sleep diaries, three of the most common sleep assessment methods used in infant sleep studies. Using a sample of 90 African American 3-month olds, we compare correlations and discrepancies for seven sleep variables across each of the three pairs of assessment methods for one night of a week-long sleep study. These seven variables are indicative of sleep schedule (e.g. sleep onset time, rise time), duration (e.g. sleep period, sleep time, wake time), and fragmentation (e.g. night wakings, longest sleep period). We find that across all sleep assessment methods, correlations are highest for variables indicative of sleep schedule, and lowest for variables indicative of sleep fragmentation. Comparing the magnitude and significance of the discrepancies, we find that actigraphy and sleep diaries significantly overestimate sleep period duration and underestimate the number of night waking episodes, compared with videosomnography. Actigraphy and sleep diaries were more concordant with one another than with videosomnography. Epoch-by-epoch analyses indicated that actigraphy had low sensitivity to detect wakefulness, compared with videosomnography. Contrary to our hypothesis, the discrepancies between sleep assessment methods did not vary widely based on infant sleep location (own room vs. parent's room) or sleep surface (own bed vs. parent's bed). Limitations and implications of these findings for future research are discussed.

Statement of Significance

Scientists across many disciplines are increasingly interested in incorporating measures of infant sleep into their research studies. However, it is currently unclear what the best methods are for measuring infant sleep, or how the available methods compare to one another. The current study quantitatively compares indicators of infant sleep schedule, duration, and fragmentation across three common assessment methods: videosomnography, actigraphy, and sleep diaries. We found significant discrepancies across all pairs of sleep methods. The magnitude of these discrepancies did not vary by infant sleep location or sleep surface. We conclude that these three methods of sleep assessment are not interchangeable. Researchers must take care to choose their assessment methods and interpret their findings in light of these demonstrated differences.

Key Words: videosomnography; actigraphy; sleep diaries; infant; observational methods

Submitted: 25 January, 2018; **Revised:** 4 June, 2018

Sleep is one of the most dramatically developing processes across the first years of life [1] and is implicated in the development of children's cognitive [2, 3] and emotional [4, 5] functioning. As such, researchers are increasingly interested in incorporating sleep measures into larger studies of infant and child development. There are several sleep assessment methods that have been developed for use with pediatric populations [6]. However, it is difficult to compare findings using these various methods due to the substantial variations in what they are measuring and how they are measured. These measurement differences may be responsible for mixed findings in the field. As these measures are typically used independently in studies, thus far there has been a little direct comparison of the output obtained from these diverse methods. The current study compares measures of sleep quantity and quality obtained from three common assessment methods within the same sample, in order to evaluate their convergence or divergence on key constructs. These analyses promise to inform researchers' decisions regarding sleep assessment as well as facilitate comparison of research findings across different studies utilizing different assessment methods.

Sleep assessment methods

Current methods available for measuring sleep in young children include polysomnography, videosomnography (i.e. video observation), actigraphy, and parent-report questionnaires (e.g. sleep diaries). Although polysomnography (a recording of the multiple physiological changes occurring during sleep) is considered the gold standard of sleep assessment, its use in research is limited due to the extensive equipment and laboratory setting it requires. On the other hand, videosomnography, actigraphy, and questionnaires can all be used nonintrusively in the clinical or home environment, and thus are the most popular sleep assessment methods in infant sleep research [6]. These three types of assessments are not interchangeable, as each method contains its own idiosyncrasies that can influence the quality and meaning of the data that are collected. We review these three sleep assessment methods to highlight their unique offerings and to point out potential areas of agreement and disagreement across methods.

Videosomnography

Videosomnography involves overnight, time-lapse recording that captures the infant sleeping in his/her natural environment, such as hospital [7, 8] and home settings [9–12]. Videos can later be coded for infant state (e.g. asleep vs. awake) using a combination of cues, such as body movement, eye opening, and vocalization. Videosomnography also makes it possible to observe child behavior [9, 13] and parent–child interaction [12, 14–16] at bedtime and throughout the night.

The benefit of videosomnography is that it relies on objective indicators, and therefore is capable of capturing sleep and wake periods throughout the night that parents may not know about, or may forget by the morning. Video observation with high-definition cameras permits a wide-angle capture of the infant sleep environment with the ability to zoom-in on the infant during analyses. Because multiple cues (e.g. any distressed vocalizations, gross body movement) are used to determine infant state, videosomnography shows high concordance with polysomnography for measures of wakefulness in infants [17]. However, there are several challenges to collecting videosomnography data which have prevented it from becoming ubiquitous in infant sleep research. For one, the portable systems that capture time-lapse video recording are expensive and require experimenter training for home installation and video download. Additionally, data may be lost in cases of equipment failure or when the child is not in view of the camera, either due to his/her own motion, blockage by people or objects, or because he/she is moved to another room. Finally, parental concerns over privacy may influence their willingness to participate or their compliance with study protocols [6]. Therefore, although videosomnography demonstrates excellent accuracy when compared with polysomnography, the cost and effort required may sway researchers to consider other alternatives.

Actigraphy

Actigraphy is a sleep assessment method which measures movement using a watch-sized monitor positioned on the infant's wrist or ankle for the duration of the observation period. These devices contain accelerometers which measure limb movement in set epochs, which are later scored as sleep or wake using the commercially available software. Algorithms and hand-editing can then be applied to raw data to produce summary statistics indicative of sleep quantity and quality. In infants, actigraphy has been shown to demonstrate adequate agreement when compared with polysomnography [18] and direct observation [19, 20]. Longitudinal studies have demonstrated that actigraphy captures expected age-related changes in sleep patterns across the first year of life [21].

Actigraphy is a popular sleep assessment method due to its relatively low cost, ease of data collection, and automated scoring via programmed algorithms. At least 5 days of monitoring have been recommended for maximum reliability in children and adolescents [22], and this data collection period has been shown to be feasible in multiple studies of infants and children [23, 24]. However, as with videosomnography, this methodology is not without its limitations. First, there are multiple different actigraphy devices on the market, each with its own software and algorithm for scoring sleep/wake state, which calls into question the issue of inter-device reliability. One study comparing two different devices with the same pediatric population found inter-device reliability to be low [25], implying that it may not be possible to compare findings from studies using different devices. Next, an artifact caused by external motion (e.g. car rides, rocking) or participant error (e.g. device falls off) further threaten the validity of collected actigraphy data [6]. The prevalence of artifacts necessitates the concurrent use of sleep diaries during the sleep assessment period, where participants can note periods of external motion or device removal, followed by subsequent hand-editing of actograms to exclude these periods of time before applying automated algorithms. Additionally, because actigraphy relies solely on motion to score sleep/wake states, it has been found to have a high false positive rate for scoring wakefulness in infants, as compared with polysomnography [26, 27]. Therefore, although cost-effective and relatively easy to collect over multiple days, actigraphy data may not be comparable across different devices, requires time investment in the form of actogram editing before analysis, and may provide inflated estimates of infant wake time.

Sleep diaries

Like actigraphy, parent questionnaires regarding their infant's sleep are prevalent in the literature, perhaps due to their cost-effective and minimally labor-intensive nature [2, 3, 28–30]. One of the most common types of sleep diaries asks parents to report, in 30-min increments, whether their child was asleep or awake [28]. This method results in a mapping of the child's sleep and wake states across the day and night. Another type of sleep diary asks explicitly about the timing and duration of children's daytime naps, as well as their sleep onset time, rise time, number of night wakings, and types of interventions used in response to night wakings [30]. At least 3 days of data collection are recommended for these types of measure [31]. Like actigraphy, sleep diaries provide information on 24-hr sleep patterns and can be used to obtain measures of both sleep quantity and quality.

No study of which we are aware has compared sleep diary data to polysomnography. However, sleep diary data have been shown to correlate with actigraphy data in infants [32, 33]. The magnitude of these correlations is highest for indicators of sleep schedule (i.e. sleep onset time and rise time) and lowest for indicators of wakefulness (i.e. number and duration of night wakings). Specifically, sleep diaries have been found to underestimate infant night wakings and overestimate nighttime sleep duration [32, 34].

The reason for these discrepancies may be that, unlike actigraphy, sleep diaries capture parental perceptions of their child's sleep, rather than the child's sleep per se. It is widely acknowledged that parents' ratings of their children are influenced by parents' own characteristics, including symptoms of psychopathology and parenting stress [35]. Further, parents' own fatigue may lead to memory lapse, and social desirability may influence parents' willingness to report challenging infant sleep behaviors, such as night wakings. Additionally, given how common it is for infants to attend childcare during the day, and sleep in solitary arrangements at night, parents may not know the full details of their infants' sleep behavior. For example, naps that occur while the infant is in daycare, or wakings that occur while the infant sleeps in his/her own room may not always be known or reported by parents. Despite these limitations, the sleep diary remains a widely used tool for studying infant sleep because of its low cost and ease of administration.

Predictors of discrepancies across sleep assessment methods

One additional question regards the extent to which the accuracy of different sleep assessment methods varies as a function of the infant's sleep environment. We are aware of only a handful of studies that compare sleep assessment methods by infant sleep location or surface [33, 36]. One of these studies compared sleep diary and actigraphy data for 52 infants and did not find that the correlation among sleep variables derived from these two sleep methods differed by whether room-sharing infants slept in their parents' bed or their own bed/crib [33]. Because only two participants in their study slept in a separate room, meaningful comparisons by infant sleep location (i.e. own room vs. parents' room) were not conducted.

A second study examined differences in infant sleep quality based on sleep location in 3- and 6-month olds [36]. The authors found that, although mothers of infants who room-shared reported more night wakings at 3 months than mothers of infants who slept in a separate room, there were no group differences in the number of night wakings as determined by actigraphy. A comparison of the mean number of night wakings as a function of assessment method and sleep location show that the difference between reported and actigraph-determined night wakings was smaller for infants who room-shared (2.37 vs. 2.80 wakings) than for infants who slept in their own room (2.39 vs. 1.63 wakings). These findings support the notion that subjective sleep measures may be more concordant with objective sleep measures for dyads who sleep in the same room, compared with dyads who sleep in separate rooms. However, no study to date has included videosomnography as another objective assessment method. Therefore, the difference in concordance between videosomnography, actigraphy, and sleep diaries by sleep location and surface remains to be determined.

The current study

To date, no study has analytically compared sleep variables derived from videosomnography, actigraphy, and sleep diaries within the same sample of infants. The current study addressed these gaps in the literature using a community sample of African American infants and caregivers. We compared discrepancies in sleep schedule (e.g. sleep onset time, rise time), duration (e.g. sleep period, sleep time, wake time), and fragmentation (e.g. number of night wakings, longest sleep period) across the three most common sleep assessment methods, using videosomnography as our gold standard, due to its demonstrated high level of agreement with polysomnography [17]. We also considered agreement between actigraphy and sleep diaries, to enable comparison with previous studies. Given the reliance in previous studies on correlational analyses, which has been criticized as an inadequate technique for comparing methods [37], we additionally conducted epoch-by-epoch comparisons of actigraphy and videosomnography to assess the sensitivity and specificity of actigraphy to detect infant wakefulness. Finally, we tested whether the magnitude of discrepancies between methods varies based on infant sleep location (i.e. own room vs. parent's room) and sleep surface (i.e. own bed vs. parent's bed).

We hypothesized that there would be smaller discrepancies between videosomnography and actigraphy than between videosomnography and sleep diaries. Whereas parents' reports of infant sleep may be biased by parental characteristics [35], or by infant sleep location and signaling behavior [32, 34], actigraphy captures sleep/wake behavior based on infant movement, a completely objective measure. Therefore, we expected higher agreement between the two objective measures. However, we predicted that there would be some discrepancy between actigraphy and videosomnography, particularly for sleep fragmentation variables, since videosomnography uses infant vocalization and eye opening as additional cues to infant state. Periods of infant wakefulness determined by vocalizations and/or eye opening in the absence of gross body movement may have be missed by actigraphy. We expected these differences to also be reflected in our epoch-by-epoch analyses such that actigraphy would have low sensitivity to detect wake, as compared with videosomnography.

Further, we predicted that the discrepancies between videosomnography, actigraphy, and sleep diaries might vary based on infant sleep location and surface. Specifically, we predicted that sleep diaries would be less accurate, as compared with videosomnography and actigraphy, for infants who slept in their own room as opposed to infants who slept in their parent's room. While videosomnography and actigraphy capture infant state regardless of location (as long as the infant is on camera and/or wearing the actigraphy monitor), parents can only report on infant sleep behavior that they are aware of, and this awareness of infant state may be diminished when infants sleep in another room.

We did not pose specific hypotheses about discrepancies between sleep diaries and videosomnography in bedsharing versus nonbedsharing infants. However, due to artifact resulting from external movement, we did expect that actigraphy may be more inaccurate in cases where the infant shares a sleep surface with parents.

Methods

Participants for this study were drawn from the Neonatal and Pediatric Sleep (NAPS) Study, an investigation of African American infants and their caregivers (N = 103). Using public birth records, we recruited women who lived within a 50-mile radius of a large public university in North Carolina and had an infant less than 3 months of age. A subsample of these families (N = 61) was recruited during pregnancy via electronic medical records and community advertisements to answer additional research questions related to prenatal experiences. Potential participants were excluded if mothers were younger than age 18, did not identify as African American, did not speak fluent English, or if infants had experienced serious medical complications at birth (e.g. NICU stay > 7 days) or were part of a twin pair. Eight infants (7.8%) were born prematurely (e.g. gestational age < 37 weeks) and thus their visit dates were delayed until they reached the appropriate adjusted age ($M_{adjustment}$ = 11.9 days).

These analyses include only the dyads (N = 90; 57% male) for which videosomnography, actigraphy, and/or sleep diary data were available at 3 months of age (M = 3.61 months, range = 2.67–5.17). On average, primary caregivers in this sample were 29 years of age (standard deviation [SD] = 5.9 years) and had 14.7 years of education (SD = 2.22 years). A majority (63%) of infants in the sample resided in the same household as their biological father, and a minority (36%) of infants in the sample were firstborns.

Procedure

Infants and caregivers were visited in their home for a data collection visit when infants were 3 months of age. During this daytime home visit, dyads participated in various parent–child interaction tasks and caregivers completed questionnaires. Starting on the evening of the 3-month home visit, families completed a 1-week sleep assessment, consisting of one night of videosomnography, 7 days and nights of actigraphy monitoring, and 7 days of caregiver-reported sleep diaries. Infants were provided with a small toy at the end of each home visit, and mothers received compensation of up to $130 in the form of a gift card. All procedures were approved by an institutional review board, and participants gave written consent before data collection.

Sleep measures

Videosomnography

After the completion of home visit activities, research assistants (RAs) set up four infrared, high-definition, color Hikvision (DS-2CD2432F-IW) cameras with internal microphones. RAs probed caregivers about the infant's sleep locations, as well as any other areas of the home where the infant and caregiver might spend time together before bedtime or during the night. These locations guided the choice of camera placement. In addition, at least one camera was set up directly above the infant's intended primary sleep location. Cameras were connected to an Exacq (IPS04-1000-LC) video surveillance recorder via Power over Ethernet (PoE) ports of a NETGEAR ProSafe Plus (GS108PE) switch. Ethernet cables were secured to the floor and furniture for safety. Caregivers were instructed to turn on the video equipment at 6:30 pm. RAs returned to the home the following morning to terminate the video recording and collect the video equipment. Data were downloaded from the video recorder using ExacqVision Client software (version 8.4) and stored on external hard drives for later video coding.

Behavioral sleep data were coded from videosomnography by trained RAs, starting when the infant first fell asleep, and ending when the infant woke up in the morning [12]. Infant *sleep onset time* was determined by examining the sleep diary for caregiver-reported bed time. One RA would begin watching the overnight video at the parent-reported infant bedtime, and mark the first 5-min period of continuous infant sleep [14]. Infant sleep was denoted when the infant's eyes were closed, and he/she was not exhibiting gross motor movement or vocalization. If the infant was already asleep at the parent-reported bedtime, the video was watched in reverse to determine the first interval in which the infant was asleep. In cases where there was no sleep diary for the night of video observation, the RA began watching the video at the beginning of the nighttime recording and noted the first 5-min period of continuous infant sleep.

Infant *rise time* was determined in a similar manner. An RA watched the overnight video starting at the parent-reported rise time and marked the first 5-min period of continuous infant wakefulness. Infant wakefulness was denoted when the infant's eyes were open, he/she was vocalizing, or he/she was exhibiting gross motor movement for more than 15 s. If the infant was already awake at the parent-reported rise time, the video was watched in reverse to determine the first interval in which the infant was awake. In cases where there was no sleep diary for the video observation, the RA watched the video in reverse from the last interval of the nighttime recording. Using sleep onset time and rise time, we subsequently calculated the duration of the infant's *sleep period*.

Infant state was coded during the sleep period in 30-s intervals [12]. That is, for every 30-s period, the RA noted whether the infant was asleep or awake. The infant was coded as asleep whenever the infants' eyes were closed, and there was no gross body movement. Infant state was coded as awake whenever the infants' eyes were wide open, the infant was vocalizing, or when the infant was engaged in gross body movement for 15 s or more. Four hours of the nighttime period were double coded for 24% of videos in order to establish and maintain inter-rater reliability for all infant state measures (kappa > .85).

From this coding of infant state, we derived four additional variables. Infant *sleep time* in minutes was calculated by dividing the total number of sleep intervals by 2. Infant *wake time* in minutes was calculated by dividing the total number of wake intervals by 2. Infant *night wakings* were defined as the number of periods of wakefulness longer than 10 intervals (i.e. 5 min). Importantly, five consecutive minutes of sleep had to pass before coding a new night waking. These criteria were adopted based on existing actigraphy literature [32, 38]. Finally, the *longest sleep period* was defined as the longest consecutive interval of sleep during the nighttime period.

Actigraphy

At the beginning of each home visit, a lightweight actogram (Actiwatch-2) was placed on the infant's left ankle. Caregivers were instructed to keep the device on the infant for the entire sleep assessment week, except during baths lasting longer than 20 min. These monitors contain an accelerometer which measures limb movement in 15-s epochs. At the end of the sleep assessment week, actigraphy data were downloaded to a PC computer and edited using Phillips Actiware software (version 6.0). Actogram algorithm settings were selected as follows: immobile minutes for sleep onset were set to 5 min; minimum rest interval size was set to 20 min; multiple rest intervals per day were allowed; automatically set minor rest intervals were allowed. The activity threshold for scoring the infant as awake was set to the Automatic setting (.888 × average activity count) at 3 months. Both the algorithm and threshold for scoring sleep/wake state have been previously validated [18].

Even with the appropriate algorithm settings, the Actiware program can miss intervals of sleep or wake, necessitating the manual entry of additional intervals. Guidelines for manually inserting intervals were created at the start of the project by comparing three example cases of actigraphy data at 3 and 6 months to behavioral coding of infant state from the same overnight observation. The following rules for inserting missed wake and sleep intervals were determined: (1) sleep intervals were manually added when periods greater than 20 min showed low or no activity for the infant, (2) wake intervals were added when periods greater than 5 min in length showed average activity levels greater than 40 counts, and (3) excluded intervals were added when no activity was recorded for extended (>6 hr) periods of time, indicating that the infant was not wearing the actogram. Subsequently, one RA edited all 3-month actigraphy data.

Output from the Actiware program includes a listing of all sleep and wake intervals (both automatically and manually determined). Using this output from night 1 of data collection, we created seven variables that correspond to the data obtained from videosomnography. Infant *sleep onset time* was determined as the start time of the sleep interval that was closest to the caregiver-reported bed time. Because infants are frequently cycling through sleep and wake states at 3 months of age, we used caregiver-reported bed time as a way to more accurately pinpoint when the infant was going to sleep for the night, rather than taking a late afternoon or early evening nap. Similarly, infant *rise time* was determined as the end time of the sleep interval that was closest to the caregiver-reported rise time. Using sleep onset time and rise time, we subsequently calculated the duration of the infant's *sleep period*. Infant *sleep time* in minutes was determined by summing infant sleep time in each sleep interval between sleep onset time and rise time. Infant *wake time* in minutes was determined by summing infant wake time in each sleep interval during the sleep period. Infant *night wakings* were determined by subtracting 1 from the number of sleep intervals during the nighttime sleep period (i.e. if the infant slept in three sleep intervals, there were two night wakings). Finally, the *longest sleep period* was equal to the duration of the longest sleep interval during the nighttime sleep period.

Sleep diary

Every day during the sleep assessment week, RAs called mothers to obtain information about the previous day's naps and nighttime sleep, including number, location, and duration of naps, infant bedtime, number of night wakings, types of interventions used during night wakings, and infant rise time [30]. Mothers were also asked to report any unusual occurrences that may have influenced the previous night's sleep, such as child illness.

From the first night of the sleep diary, we retained four variables that correspond to data obtained from videosomnography. Infant *sleep onset time* and *rise time* were equal to the caregiver reported bedtime and rise time, respectively. Infant *sleep period* in minutes was calculated using reported sleep onset time and rise time. The number of infant *night wakings* was equal to the number of night wakings caregivers reported. Because caregivers were not asked to report the length of each night waking, we were unable to obtain measures of sleep time, wake time, or longest sleep period from sleep diary data.

Infant sleep environment

Infant sleep location and sleep surface were determined from videosomnography. Infant sleep location could include own room or parent's room, whereas sleep surface could include own bed/crib or parent's bed. In cases where infants slept in multiple locations or on multiple surfaces (e.g. fell asleep in crib but was brought to parent's bed after a night waking), the location and surface where the infant spend the majority of time sleeping were coded.

Missing data

Of the 103 families recruited into the study, 12 did not complete the 3-month home visit. Of the 91 families who completed 3-month home visits, 82 had videosomnography data, 82 had actigraphy data, and 87 had sleep diary data. A majority (79%) of families had data from all three sleep assessment methods. Families may have been missing whole methods due to noncompliance with study protocols (e.g. actigraphy monitor fell off and was not replaced) or in rare cases, because of equipment failure (e.g. video kit hard drive crashed).

Of the 82 families with videosomnography data, 2 infants were asleep when the recording began and 11 infants were still asleep when the recording ended. Because accurate sleep measures could not be determined in these cases, there are 2 cases of missing sleep onset time data, 11 cases of missing rise time data, and 13 cases of missing sleep period, night wakings, sleep time, wake time, and longest sleep period data. Of the 87 families with sleep diary data, two caregivers failed to provide an estimate of their infant's rise time. Therefore, there are two cases of missing rise time and sleep period data. One additional infant was excluded from the sleep diary data because of an extreme discrepancy (>4 hr) in reported sleep onset time as compared with videosomnography.

Analytic plan

First, we examined concordance between sleep variables derived from videosomnography, actigraphy, and sleep diaries using correlations and discrepancy scores. These analyses were done for each sleep variable that was the same across actigraphy and videosomnography (sleep onset time, rise time, sleep period, sleep time, wake time, number of night wakings, longest sleep period) sleep diaries and videosomnography (sleep onset time, rise time, sleep period, number of night wakings), and sleep diaries and actigraphy (sleep onset time, rise time, sleep period, number of night wakings). For consistency of comparison, only the first night of data were compared for all methods. We used paired *t* tests to determine the significance of any discrepancies. Because of the small sample size, effect sizes are also presented and interpreted.

We next created Bland–Altman plots [37] as a visual representation of the disagreement between methods. The Bland–Altman procedure entails obtaining the amount of inter-method disagreement for each individual, calculating the mean and *SD* of this disagreement, and plotting the individual values of disagreement against the mean level of disagreement, with a 95% limit-of-agreement interval (i.e. ±1.96 *SD*s of the mean difference). For brevity, we present these plots for select measures that are the most commonly used indicators of infant sleep quality (i.e. wake time, number of night wakings, longest sleep period).

Next, we conducted epoch-by-epoch analyses to compare agreement in the scoring of sleep and wake states between videosomnography and actigraphy. Because this study was not prospectively designed for these specific analyses, data first needed to be restructured. First, we split each 30-s videosomnography epoch into two equally coded 15-s epochs. We then time-synchronized actigraphy data to correspond to the observed videosomnography period. Using this time-synchronized data, we calculated Cohen's (1960) kappa values for each individual as a measure of inter-method agreement. We also determined the sensitivity and specificity of actigraphy to detect infant wakefulness when compared with videosomnography. Sensitivity was defined as the number of intervals that actigraphy correctly determined as wake divided by the total number of intervals that videosomnography determined as wake. Specificity was defined as the proportion of intervals that actigraphy correctly determined as sleep divided by the total number of intervals that videosomnography determined as sleep.

Finally, we tested whether the concordance between videosomnography, actigraphy, and sleep diaries varied as a function of infant sleep location and sleep surface, using independent sample *t* tests. We estimated and compared discrepancy scores for children who slept in their own room versus their parent's room, and in their own crib versus their parent's bed for each of the three pairs of sleep assessment methods described above. Additionally, we compared kappa, sensitivity, and specificity values based on infant sleep location and sleep surface. All analyses were conducted using SAS version 9.3.

Results

Descriptive statistics

First, we examined means and *SD*s of our seven sleep variables (Table 1). As determined using videosomnography, the average sleep onset time in our sample at 3 months of age was 21:58:48 (9:58:48 pm) and the average rise time was 7:12:52 am, resulting in an average sleep period of 563.20 min (9.39 hr). On average, infants woke up 3.52 times in the night. During the sleep period, infants slept an average of 467.10 min (7.79 hr) and were awake for an average of 72.67 min (1.21 hr). The longest continuous sleep period was, on average, 232.30 min (3.87 hr).

As seen in Table 1, variables indicative of sleep schedule (i.e. sleep onset time, rise time, sleep period) were highly correlated among all three sleep methods (r = .70–.90, p < .01). Number of night wakings were moderately correlated across methods (r = .37–.51, p < .01). Sleep time, wake time, and longest sleep period were also moderately correlated (r = .45–.56, p < .01) when comparing actigraphy to videosomnography.

Comparison of sleep methods

Next, we conducted paired *t* tests to quantify the average discrepancy in sleep variables. As discussed earlier, we considered videosomnography to be the gold standard of sleep assessment in our study, and thus use this method as a frame of reference from which to compare actigraphy and sleep diaries. For consistency with previous research [30, 33, 36], we also present comparisons of actigraphy and sleep diaries. These results are presented in Table 2.

Actigraphy versus videosomnography

On average, actigraphy estimated infant sleep onset time to be 29 min earlier than determined by videosomnography, $t(71) = -3.64$, $p < .001$, though there was not a significant discrepancy in infant rise time, $t(65) = -.31$, $p > .05$. Overall, actigraphy tended to overestimate the length of the infant sleep period by 23 min, $t(63) = 2.24$, $p = .03$. Actigraphy underestimated the number of infant night wakings by 1.06, $t(72) = -4.02$, $p < .001$, yet overestimated the amount of time the infant spent awake at night by 64 min, $t(73) = 6.54$, $p = .03$. The amount of time the infant spent asleep was not significantly different between actigraphy and videosomnography. Finally, actigraphy overestimated the duration of the longest continuous sleep period by 35 min, $t(72) = 2.27$, $p = .03$.

Sleep diary versus videosomnography

Like actigraphy, sleep diary data also estimated infant sleep onset time to be 23 min earlier than determined by videosomnography, $t(76) = -3.57$, $p < .001$. Sleep diary data also estimated infant rise time to be 13 min later than determined by videosomnography, $t(68) = 2.26$, $p = .03$, leading to an overestimation of the infant sleep period by 32 min, $t(66) = 3.72$, $p = .002$. Similar

Table 1. Descriptive statistics and correlations among sleep variables from videosomnography, actigraphy, and sleep diaries

	Video, *M (SD)*	Actigraphy, *M (SD)*	Sleep diary, *M (SD)*	Video vs. actigraphy (*r*)	Video vs. sleep diary (*r*)	Actigraphy vs. sleep diary (*r*)
Sleep onset time	21:58:48 (1:46:30)	21:24:56 (1:41:09)	21:35:49 (1:33:00)	.79	.84	.91
Rise time	7:12:52 (1:07:34)	7:15:13 (1:19:52)	7:31:29 (1:11:54)	.76	.74	.84
Sleep period	563.20 (116.11)	590.28 (131.14)	597.26 (107.40)	.78	.81	.90
Night wakings	3.52 (2.08)	2.50 (1.52)	2.18 (1.30)	.47	.37	.51
Sleep time	467.10 (106.85)	453.82 (91.95)		.54		
Wake time	72.67 (48.90)	136.46 (100.47)		.59		
Longest sleep period	232.30 (112.76)	268.20 (110.03)		.38		

M, mean, *SD*, standard deviation, *r*, correlation coefficient. All correlations are significant at $p < .05$.

Table 2. Results from paired *t* tests comparing sleep variables from videosomnography, actigraphy, and sleep diaries

	Actigraphy—video				Sleep diary—video				Sleep diary—actigraphy			
	Mean discrepancy	*t*	*df*	*d*	Mean discrepancy	*t*	*df*	*d*	Mean discrepancy	*t*	*df*	*d*
Sleep onset time	−0:29:23	−3.64***	71	.43	−0:23:51	−3.57***	76	.41	0:06:17	1.30	77	.15
Rise time	−0:01:59	−.31	65	.04	0:13:19	2.26*	68	.27	0:15:08	3.18**	76	.36
Sleep period	23.64	2.24*	63	.28	31.99	3.72**	66	.45	8.41	1.28	76	.15
Night wakings	−1.06	−4.32***	63	.54	−1.38	−5.52***	65	.68	−.26	−1.60	76	.18
Sleep time	−10.67	−.87	63	.11								
Wake time	58.43	5.78***	63	.72								
Longest sleep period	35.52	2.27*	63	.28								

df, degrees of freedom; *d*, Cohen's *d*. Cohen's *d* interpretation guidelines: 0.2 = small effect; 0.5 = medium effect; 0.8 = large effect.
*$p < .05$, **$p < .01$, ***$p < .001$.

to actigraphy, sleep diary data also underestimated the number of infant night wakings by 1.38, $t(65) = -5.52$, $p < .001$.

Sleep diary versus actigraphy

Maternal report of infant sleep onset time did not differ significantly from actigraphy, $t(77) = 1.30$, $p > .05$. However, sleep diary data estimated infant rise time to be 15 min later than what was determined by actigraphy, $t(76) = 3.18$, $p = .002$. There were no significant differences in the length of the infant sleep period or the number of night wakings between sleep diary and actigraphy.

Bland–Altman plots

Bland–Altman plots (Figure 1) were created to visually represent case-by-case and average levels of inter-method agreement for three variables (i.e. number of night wakings, wake time, longest continuous sleep period). In these figures, the solid black line represents the mean difference between measures, whereas the dashed lines represent the 95% limit-of-agreement interval. From these plots, it is possible to detect trends in inter-method discrepancy based on the mean value of the variable being considered. For example, when comparing the number of night wakings determined by actigraphy and videosomnography, there is a clear trend where actigraphy underestimates the number of night wakings more for infants who wake up more times during the night ($r = -.36$, $p < .01$). Compared with videosomnography, sleep diaries also underestimated the number of night wakings more for infants who woke up more times during the night ($r = -.47$, $p < .001$). There were no significant linear trends for night wakings (sleep diaries vs. actigraphy) or longest sleep period (actigraphy vs. observation). However, actigraphy overestimated infant wake time more for infants who spent more time awake during the night ($r = .73$, $p < .001$).

Epoch-by-epoch analyses

Time-synchronized data ($N = 160\,234$ epochs) were used to assess the reliability of actigraphy to score infant sleep/wake state, as compared with videosomnography. Across individual cases, the average kappa value was .47 (range = −.14 to .86), which can be interpreted as evidence for moderate agreement in scoring infant state. Sensitivity and specificity values for infant wakefulness revealed that, on average, actigraphy had 52% sensitivity (range = 1%–97%) and 95% specificity (range = 68% to 100%) to detect wakefulness, compared with videosomnography. In other words, actigraphy correctly detected infant wakefulness 52% of the time (with a 48% false negative rate), and had only a 5% false positive rate, on average.

Comparison of sleep methods by infant sleep location and surface

Finally, we tested whether the discrepancies found between sleep variables across methodologies differed as a function of infant sleep location (own room vs. parent's room) and sleep surface (own bed vs. parent's bed). These findings are presented for each pair of sleep methods in Table 3.

From Table 3, several points are apparent. Comparing actigraphy to videosomnography, we found that actigraphy tended to underestimate infant sleep onset time more for infants who slept in their parent's room, as opposed to infants who slept in their own room, $t(72) = 2.04$, $p = .046$. Concerning the discrepancy between sleep diary and videosomnography, sleep diary data estimated infant rise time to be later than that determined by videosomnography, but only for infants who slept in their own bed, $t(67) = 2.03$, $p = .05$. There were no differences in the discrepancy between sleep diary and actigraphy based on infant sleep location or sleep surface.

For our epoch-by-epoch reliability analyses, we found that on average, kappa values were lower for infants who slept in their own room ($M = .35$, $SD = .25$), as opposed to a parent's room ($M = .50$, $SD = .27$), $t(74) = 1.99$, $p = .05$. There were no differences in kappa based on infant sleep surface. The sensitivity and specificity with which actigraphy detected infant wakefulness, compared with videosomnography, did not vary based on infant sleep location or sleep surface (all $p > .05$).

Post hoc analyses

Because maternal report of infant sleep onset time was important for determining the beginning of the overnight period for both videosomnography and actigraphy measures, we reran the above analyses excluding infants who were missing sleep diary data ($n = 4$). Overall, our substantive conclusions remained the same. One exception was that there was a significant, rather than a marginally significant difference, in the discrepancy in LSP derived from actigraphy versus videosomnography based on infant sleep surface. That is, actigraphy overestimated LSP more so for infants who shared a parent's bed ($M = 74.09$ min,

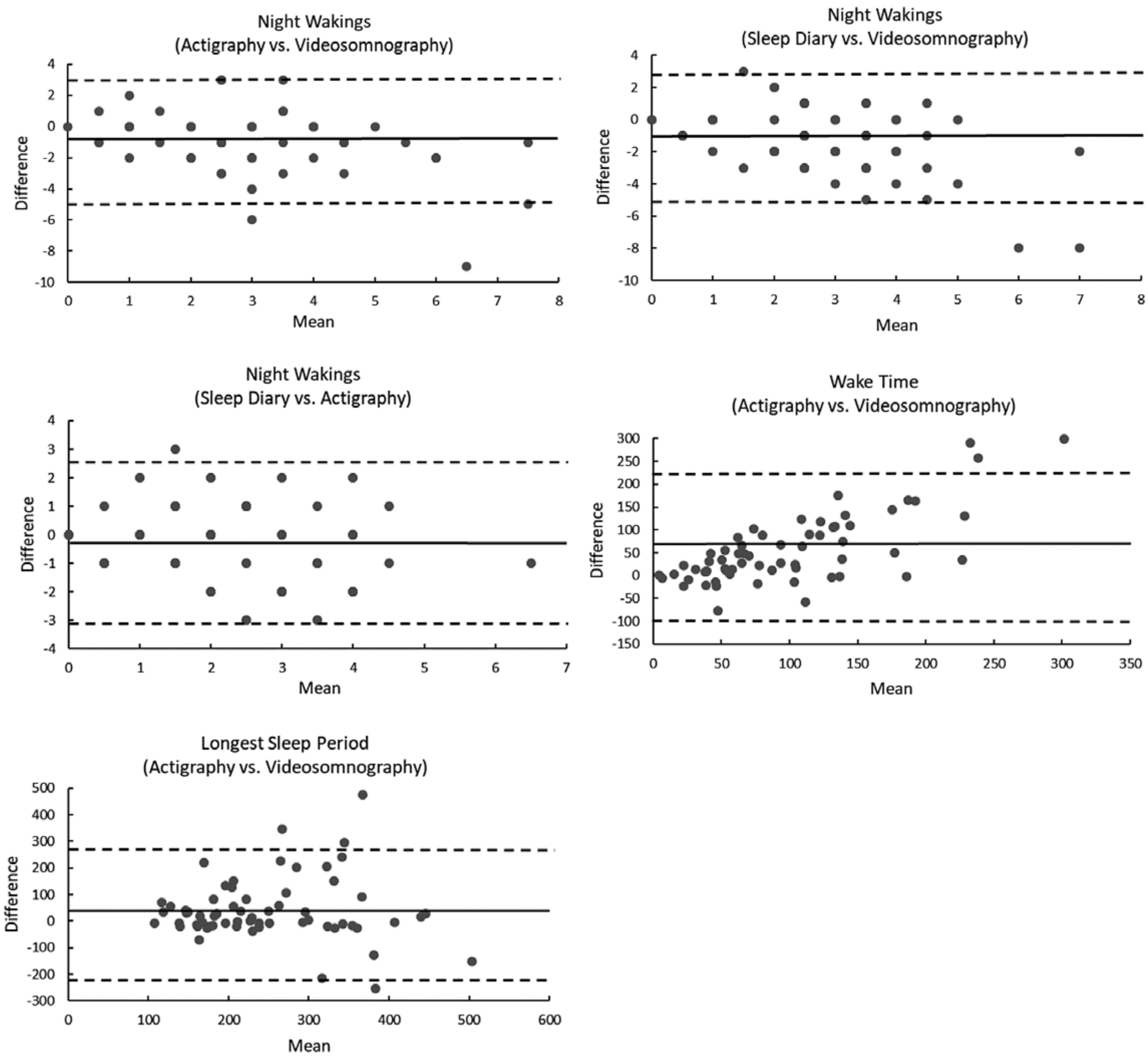

Figure 1. Bland–Altman plots of night wakings, wake time, and longest sleep period across different sleep assessment methods. The solid black lines indicate the mean level of inter-method differences while the dashed lines indicate the 95% limits of agreement.

SD = 132.5 min) as opposed to infants who slept in their own bed (M = 10.53 min, SD = 118.2 min), $t(60) = 1.98$, $p = .05$.

Discussion

The current analyses compared indicators of infant sleep schedule, duration, and fragmentation across videosomnography, actigraphy, and sleep diaries, three of the most commonly used sleep assessment methods. When considering correlations across pairs of sleep methods, there was a high level of agreement for variables indicative of sleep schedule, while there was moderate agreement for indices of sleep duration and fragmentation. When we quantified the actual magnitude of these discrepancies, we found significant differences between all pairs of sleep methods. Additionally, time-synchronized analyses revealed that actigraphy demonstrated low sensitivity to detect infant wakefulness. There was limited evidence that these discrepancies varied as a function of infant sleep location and surface. This study was the first to compare three sleep assessment methods within the same sample of infants, and our findings promise to aid future researchers in the selection of sleep assessment method and interpretation of subsequent findings.

More specifically, although indicators of sleep schedule were highly correlated across all three pairs of methods (i.e. actigraphy vs. videosomnography, sleep diary vs. videosomnography, sleep diary vs. actigraphy), there were only moderate correlations for number of night wakings; videosomnography estimated the most night wakings on average, and sleep diaries estimated the fewest. Moderate correlations were also observed for sleep time, wake time, and longest sleep period, although only videosomnography and actigraphy could be compared. These findings are consistent with previous work showing that measures of sleep schedule tend to be the most highly correlated across sleep assessment methods, whereas indicators of wakefulness tend to be the lowest [32, 33]. Whereas previous work has only examined these correlations among actigraphy

Table 3. Discrepancy between actigraphy and videosomnography data by infant sleep location and surface

	Own room	Parent's room	t	df	d	Own bed	Parent's bed	t	df	d
Actigraphy vs. videosomnography										
Sleep onset time	0:02:02	−0:37:39	2.04*	70	.51	−0:21:04	−0:39:13	1.12	70	.27
Rise time	−0:06:46	0:00:35	−.40	64	.12	0:01:45	−0:07:03	.68	64	.17
Sleep period	−8.80	33.58	−1.72+	62	.47	23.24	24.19	−.04	62	.01
Night wakings	−.87	−1.12	.44	62	.12	−.78	−1.44	1.34	62	.33
Sleep time	−42.62	−.89	−1.46	62	.41	−22.51	5.56	−1.14	62	.28
Wake time	75.22	53.30	.92	62	.26	71.95	39.92	1.58	62	.40
Longest sleep period	−6.300	48.32	−1.49	62	.43	10.53	69.76	−1.91+	62	.48
Sleep diary vs. videosomnography										
Sleep onset time	0:00:18	−0:29:42	1.80+	75	.49	−0:16:29	−0:32:15	1.18	75	.27
Rise time	0:18:20	0:11:55	.45	67	.13	0:23:35	−0:00:02	2.03*	67	.50
Sleep period	18.03	36.01	−.87	65	.24	34.43	28.78	.32	65	.08
Night wakings	−1.43	−1.37	−.10	64	.02	−1.11	−1.72	1.23	64	.30
Sleep diary vs. actigraphy										
Sleep onset time	−0:01:44	0:06:33	−.65	69	.19	0:01:13	0:09:10	−.76	69	.18
Rise time	0:25:06	0:12:45	.99	68	.31	0:19:57	0:09:39	1.00	68	.25
Sleep period	26.83	5.56	1.24	68	.38	18.73	−.71	1.38	68	.33
Night wakings	−.50	−.32	−.42	68	.13	−.32	−.41	.26	68	.06

df, degrees of freedom; *d*, Cohen's *d*. Cohen's d interpretation guidelines: 0.2 = small effect; 0.5 = medium effect; 0.8 = large effect.
+$p < .10$, *$p < .05$, **$p < .01$, ***$p < .001$.

and sleep diaries, our findings are the first to report a similar pattern of correlations among actigraphy, sleep diaries, and videosomnography. However, relying on correlations to compare sleep assessment methods is insufficient, as two measures with large discrepancies can be highly correlated, as long as both measures increase in a proportional manner with one another [26, 37]. Therefore, we also used paired samples *t* tests to compare our methods and we measured the magnitude of mean differences by calculating effect sizes (Cohen's *d*; Table 2). For actigraphy and videosomnography, we additionally considered epoch-by-epoch comparisons and calculated reliability measures (i.e. kappa, sensitivity, specificity).

When comparing actigraphy and sleep diaries to our gold standard of videosomnography, we found that both methods significantly underestimated infant sleep onset time (d = .41–.43), while overestimating the length of the nighttime sleep period (d = .28–.45). These two methods also significantly underestimated the number of infant night wakings (d =.54–.68), and actigraphy overestimated the length of the longest sleep period (d = .28). Taken together, these findings suggest that actigraphy and sleep diaries provide inflated estimates of infant sleep duration and underestimate the number of episodes of wakefulness, as has been suggested by others [27]. As a result of fewer identified night wakings, actigraphy and sleep diaries may portray infant sleep as occurring in longer uninterrupted stretches. Measures of effect size suggest that these discrepancies are not trivial. For example, actigraphy and sleep diaries both underestimated the number of night wakings as compared with videosomnography by more than half a *SD*. These differences could have major implications for how we describe typical infant sleep patterns, as well as how we define and diagnose infant sleep problems.

It is not surprising that videosomnography detected significantly more long night wakings (>5 min) than either actigraphy (d = .54) or sleep diaries (d = .68). These differences, which had moderate effect sizes, may be due to the different ways in which these three assessment methods determine infant wakefulness. Videosomnography makes use of multiple cues to determine infant state, including gross motor movement, eye opening, and vocalizations. As actigraphy only uses movement to determine infant state, wakings that are characterized by periods of eye opening and/or vocalizations, in the absence of gross motor movement, would not be captured. Similarly, sleep diaries rely on maternal report of infant night wakings and therefore only capture night wakings of which the mother is aware. Mothers may have been unaware of wakings that were not signaled via vocalizations or, if bedsharing, wakings that did not involve gross motor movement. Therefore, videosomnography remains the most comprehensive way to capture the full range of infant night waking episodes.

Although actigraphy underestimated the number of infant night wakings compared with videosomnography, it overestimated the amount of time the infant spent awake (d = 72). However, in time-synchronized analyses, we found that actigraphy had low sensitivity to detect true wakefulness, although it had high specificity. In other words, actigraphy often missed true periods of infant wakefulness, but was not likely to falsely detect wakefulness when the infant was sleeping. Thus, our findings from the two types of analyses are seemingly contradictory.

To better make sense of this set of findings, it is important to note that in analyses comparing the total amount of wake time, actigraphy, and videosomnography were not time-synchronized. Additionally, actigraphy tended to overestimate the length of the sleep period by significantly underestimating infant sleep onset time. Therefore, it may be that actigraphy was falsely detecting sleep onset at a time where the infant was becoming less mobile, but was not necessarily asleep (e.g. eyes may have been open). During this transition period, because the infant was not yet truly asleep, there may have been increased wakefulness that would have been picked up by actigraphy and included in the total wake time. Videosomnography, on the other hand, would not have included this transition period as part of the coded nighttime interval, and therefore it may have picked up less total wake time than actigraphy. Afterwards, during the overlapping nighttime period which was coded by both actigraphy and videosomnography (and was thus included in epoch-by-epoch analyses), actigraphy seemed to have low sensitivity to detect infant wakefulness, which is consistent with previous studies [18]. Again, this may be due to the fact that videosomnography makes use of multiple cues to infer wakefulness, whereas actigraphy relies solely on movement. These intriguing findings raise the possibility that actigraphy may have differential sensitivity and specificity to detect wakefulness during different periods (e.g. before and after sleep onset). For a more nuanced understanding of the differences between actigraphy and videosomnography, future studies should compare coding of infant state during the transition to sleep, as well as during the nighttime period.

Finally, comparing sleep diaries to actigraphy, we found no significant discrepancy in sleep onset time, sleep period duration, or number of wakings. These findings contradict previous studies with older infants (i.e. 7 months and above), which have found that sleep diaries tend to underestimate the number of night wakings, while overestimating nighttime sleep duration, as compared with actigraphy [32, 34]. These discrepancies are often attributed to differential detection of signaled versus nonsignaled night wakings between the two methods. While actigraphy can detect night wakings that are signaled or nonsignaled, parents usually only report signaled wakings, as these are the only wakings they may know about. Therefore, sleep diaries may underestimate the total number of night wakings by failing to account for nonsignaled wakings. As the ability to self-soothe is immature at birth and increases linearly across the first year of life [13], we might expect that the 3-month-old infants in our sample were primarily signaling their wakings. Therefore, it is reasonable that the discrepancy between parent-reported and actigraphy-determined wakings would be low, as we observed. In his pair of studies, Sadeh [32, 34] also observed that parent-report measures became more inaccurate as compared with actigraphy over the course of the study week, due to increased study fatigue. Because our sleep diary and actigraphy data were compared for the first night of the study week, agreement may have been higher than if we compared them on the last night of the study week.

While sleep diaries and actigraphy tended to be in agreement on most variables, there was a significant discrepancy when comparing infant rise time, such that sleep diaries estimated rise time to be significantly later than determined by actigraphy (d = .36). This difference, which was small in effect size, may have resulted from infants waking up in their cribs before parents realize or engage with them, or before the parent being awake him/herself for the day. Additionally, the process of the infant waking up may have involved increasing amount of motion, such that it reached the actigraphy threshold for wakefulness before the infant being consciously awake and vocalizing.

We were surprised by the overall lack of findings regarding discrepancies across sleep assessment methods based on infant sleep location and sleep surface. Contrary to previous research [36], parents were not less accurate regarding infant night wakings when infants slept in a separate room. This result may indicate that infants in our sample were primarily signaling their wakings, and thus parents were aware that their infant was awake regardless of sleep location. Another possible explanation is that parents were more observant of their infant's sleep patterns on the first night of the sleep study week, regardless of where the infant was sleeping. This possibility is consistent with the studies described previously showing decreasing parental accuracy over the course of a sleep study week [32, 34].

Also contrary to our hypotheses, we did not find actigraphy to be more inaccurate for infants who slept in a parent's bed versus their own bed. This finding is consistent with a previous study which did not find that the correlation between sleep variables derived from actigraphy and sleep diaries varied as a function of infant bedsharing [33]. Although external motion may contribute to artifact when using actigraphy [6], bedsharing may not constitute a significant source of external motion, as compared with cases where baby sleeps in a car or a swing. Although these results stand to be replicated, this preliminary evidence suggests that actigraphy compares similarly to videosomnography and sleep diaries for bedsharing and nonbedsharing infants.

Additional studies are needed to confirm these findings, as the current study may have been underpowered to detect small to medium effect sizes. As an example, actigraphy tended to overestimate the length of the longest sleep period, as compared with videosomnography, but only for infants who slept in their parents' room (mean discrepancy = 48.32 min) For infants who slept in their own room, actigraphy slightly underestimated the length of the longest sleep period (mean discrepancy = −6.30 min, Cohen's d = .43). Despite a moderate effect size, this comparison was not statistically significant in our sample. Given our small sample size, we were mainly concerned with the risk of type II error in these analyses. However, it is also worth noting that we did not correct for multiple comparisons, which may have increased our risk of type I error. Both issues should be addressed in future large-scale studies.

Our study was further limited by our reliance on a sample of exclusively African American 3-month olds. Although this was a strategic choice in our larger study, to better understand the sleep patterns and processes within this understudied population [39], it is also a limitation in regards to the generalizability of the current analyses. While we do not have reason to believe that the agreement between sleep assessment methods would vary by infant race, it is important that these findings are replicated with other samples. In addition, previous studies have documented differential agreement between methods for infants of different ages, particularly across the first year of life [19]. As the circadian rhythm matures, sleep becomes more consolidated into the nighttime period [40], while the frequency of nighttime wakings decreases [13], meaning it may be easier to differentiate distinct sleep and wake states regardless of methodology. Inter-method agreement might therefore be expected to increase across the first year of life, although this remains to be tested.

Other methodological choices may also have constituted study limitations. For example, although our study made use of 15-s actigraphy epochs, which is the highest-resolution setting provided by Actiware equipment, one study found that this epoch length may not be ideal for use with infants [27]. Given the marked differences in epoch length reported in the pediatric literature [26], additional research is required to determine the most appropriate epoch length for use with children of different ages. Additionally, the sleep diary used in the current study was conducted as a daily phone interview, administered each morning to assess the infant's previous night's sleep patterns. On the one hand, conducting a daily interview may be preferable to leaving a week's worth of sleep diaries in the home, which mothers may forget to fill out each night. However, this method may not have been as accurate as mother's real-time reporting of her infant's sleep. Further technological advances (e.g. digital sleep diary; scheduled text reminders) may improve the accuracy of maternal sleep diaries in future research.

Further, we were only able to compare our three sleep methodologies for night 1 of our sleep study week. Future research should attempt to replicate these findings comparing multiple days of sleep assessment. By doing so, we can test whether day-to-day differences between methods "wash out" when multiple days of sleep assessment are averaged together. We can also attempt to understand better how the concordance between methods changes as the study week progresses, given evidence that parents experience study fatigue and thus become more inaccurate reporters of infant sleep as the study week progresses [32, 34]. Finally, it would be important for future research to compare the predictive validity of these various methods for infant and parent outcomes. To the extent that parental perceptions of infant sleep contribute to their own sleep quality and stress [41, 42], parent report measures of infant sleep may be especially predictive of parent outcomes. However, when examining the relationship between infant sleep and infant outcomes, such as cognitive or emotional functioning, objective measures of sleep may be more predictive.

In sum, we find significant discrepancies between videosomnography, actigraphy, and sleep diaries, the three most popular sleep assessment methods for young children. These discrepancies did not vary markedly based on infant sleep location or sleep surface. We conclude that these methods should not be used interchangeably, and researchers should take care to interpret their findings based on these known discrepancies. We find that actigraphy and sleep diaries are especially problematic in their underestimation of the number of infant night wakings, as well as their overestimation of the length of the infant sleep period, compared with videosomnography. These methods may thus overestimate infant sleep quantity and quality. Actigraphy and sleep diaries tend to be more concordant with one another, although actigraphy is capable of measuring more sleep variables than sleep diaries (e.g. sleep time, wake time, longest sleep period).

Based on our findings, we suggest the following recommendations for future studies utilizing infant sleep measures. First, videosomnography may be the best method for studies that are primarily focused on infant night waking behavior. Not only do sleep diaries and actigraphy show poor concordance with videosomnography for number of night wakings and total wake time, but videosomnography is the only method that captures infant (e.g. signaling) and parent (e.g. intervention) behavior during night waking episodes, which provides additional information about self-soothed versus nonself-soothed wakings [9]. Second, actigraphy may be particularly useful for studies examining sleep duration, as it did not differ significantly from videosomnography for measures of total sleep time. This information is beneficial for researchers to know, as actigraphy is less invasive, lower in cost, and requires less data coding time, compared with videosomnography. Further, actigraphy provides information about 24-hr sleep patterns, and can provide data for extended study periods (e.g. 1 week), both of which would be impractical using videosomnography. Finally, although sleep diaries differed significantly from videosomnography for all variables considered, they may be appropriate to use in studies where parental perceptions of infant sleep are the main focus. All of this information, as well as practical issues pertaining to data collection, coding, and cost, should be weighed to determine the most appropriate sleep assessment method for a given research study.

Conflict of interest statement. None declared.

Funding

Support for this research was provided by the Eunice Kennedy Shriver National Institute of Child Health and Human Development, Grant #R21HD077146.

References

1. Iglowstein I, *et al*. Sleep duration from infancy to adolescence: reference values and generational trends. *Pediatrics*. 2003;**111**(2):302–307.
2. Bernier A, *et al*. Relations between physiological and cognitive regulatory systems: infant sleep regulation and subsequent executive functioning. *Child Dev*. 2010;**81**(6):1739–1752.
3. Bernier A, *et al*. Sleep and cognition in preschool years: specific links to executive functioning. *Child Dev*. 2013;**84**(5):1542–1553.
4. Mindell JA, *et al*. Sleep and social-emotional development in infants and toddlers. *J Clin Child Adolesc Psychol*. 2017;**46**(2):236–246.
5. Minde K, *et al*. Sleep problems in toddlers: effects of treatment on their daytime behavior. *J Am Acad Child Adolesc Psychiatry*. 1994;**33**(8):1114–1121.
6. Sadeh A. Iii. Sleep assessment methods. *Monogr Soc Res Child Dev*. 2015;**80**(1):33–48.
7. Holditch-Davis D, *et al*. Sleeping and waking state development in preterm infants. *Early Hum Dev*. 2004;**80**(1):43–64.
8. Tully KP, *et al*. Postnatal unit bassinet types when rooming-in after cesarean birth: implications for breastfeeding and infant safety. *J Hum Lact*. 2012;**28**(4):495–505.
9. Goodlin-Jones BL, *et al*. Night waking, sleep-wake organization, and self-soothing in the first year of life. *J Dev Behav Pediatr*. 2001;**22**(4):226–233.
10. Anders TF, *et al*. Sleeping through the night: a developmental perspective. *Pediatrics*. 1992;**90**(4):554–560.
11. Batra EK, *et al*. Nocturnal video assessment of infant sleep environments. *Pediatrics*. 2016;**138**(3):e20161533.
12. Philbrook LE, *et al*. Bidirectional associations between bedtime parenting and infant sleep: parenting quality, parenting practices, and their interaction. *J Fam Psychol*. 2016;**30**(4):431–441.
13. Burnham MM, *et al*. Nighttime sleep-wake patterns and self-soothing from birth to one year of age: a longitudinal intervention study. *J Child Psychol Psychiatry*. 2002;**43**(6):713–725.
14. Teti DM, *et al*. Maternal emotional availability at bedtime predicts infant sleep quality. *J Fam Psychol*. 2010;**24**(3):307–315.
15. Jian N, *et al*. Emotional availability at bedtime, infant temperament, and infant sleep development from one to six months. *Sleep Med*. 2016;**23**:49–58.
16. Philbrook LE, *et al*. Maternal emotional availability at bedtime and infant cortisol at 1 and 3 months. *Early Hum Dev*. 2014;**90**(10):595–605.
17. Anders TF, *et al*. The use of time lapse video recording of sleep-wake behavior in human infants. *Psychophysiology*. 1976;**13**(2):155–158.
18. So K, *et al*. Actigraphy correctly predicts sleep behavior in infants who are younger than six months, when compared with polysomnography. *Pediatr Res*. 2005;**58**(4):761–765.
19. Sadeh A, *et al*. Activity-based assessment of sleep-wake patterns during the 1st year of life. *Infant Behav Dev*. 1995;**18**(3):329–337.
20. Gnidovec B, *et al*. Actigraphic assessment of sleep-wake rhythm during the first 6 months of life. *Clin Neurophysiol*. 2002;**113**(11):1815–1821.
21. So K, *et al*. The use of actigraphy for assessment of the development of sleep/wake patterns in infants during the first 12 months of life. *J Sleep Res*. 2007;**16**(2):181–187.

22. Acebo C, *et al*. Estimating sleep patterns with activity monitoring in children and adolescents: how many nights are necessary for reliable measures? *Sleep*. 1999;**22**(1):95–103.
23. Sadeh A, *et al*. Infant sleep and parental sleep-related cognitions. *J Fam Psychol*. 2007;**21**(1):74–87.
24. Staples AD, *et al*. Bedtime routines in early childhood: prevalence, consistency, and associations with nighttime sleep. *Monogr Soc Res Child Dev*. 2015;**80**(1):141–159.
25. Meltzer LJ, *et al*. Direct comparison of two new actigraphs and polysomnography in children and adolescents. *Sleep*. 2012;**35**(1):159–166.
26. Meltzer LJ, *et al*. Use of actigraphy for assessment in pediatric sleep research. *Sleep Med Rev*. 2012;**16**(5):463–475.
27. Insana SP, *et al*. Invalidity of one actigraphy brand for identifying sleep and wake among infants. *Sleep Med*. 2010;**11**(2):191–196.
28. Acebo C, *et al*. Sleep/wake patterns derived from activity monitoring and maternal report for healthy 1- to 5-year-old children. *Sleep*. 2005;**28**(12):1568–1577.
29. DeLeon CW, *et al*. Intrinsic and extrinsic factors associated with night waking in 9-month-old infants. *Infant Behav Dev*. 2007;**30**(4):596–605.
30. Hall WA, *et al*. A comparison of actigraphy and sleep diaries for infants' sleep behavior. *Front Psychiatry*. 2015;**6**:19.
31. St James-Roberts I, *et al*. Individual differences, daily fluctuations, and developmental changes in amounts of infant waking, fussing, crying, feeding, and sleeping. *Child Dev*. 1996;**67**(5):2527–2540.
32. Sadeh A. Assessment of intervention for infant night waking: parental reports and activity-based home monitoring. *J Consult Clin Psychol*. 1994;**62**(1):63–68.
33. Asaka Y, *et al*. Comparing sleep measures of infants derived from parental reports in sleep diaries and acceleration sensors. *Acta Paediatr*. 2011;**100**(8):1158–1163.
34. Sadeh A. Evaluating night wakings in sleep-disturbed infants: a methodological study of parental reports and actigraphy. *Sleep*. 1996;**19**(10):757–762.
35. De Los Reyes A, *et al*. Informant discrepancies in the assessment of childhood psychopathology: a critical review, theoretical framework, and recommendations for further study. *Psychol Bull*. 2005;**131**(4):483–509.
36. Volkovich E, *et al*. Sleep patterns of co-sleeping and solitary sleeping infants and mothers: a longitudinal study. *Sleep Med*. 2015;**16**(11):1305–1312.
37. Bland JM, *et al*. Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet*. 1986;**1**(8476):307–310.
38. Tikotzky L, *et al*. Infant sleep and early parental sleep-related cognitions predict sleep in pre-school children. *Sleep Med*. 2012;**13**(2):185–192.
39. Crosby B, *et al*. Racial differences in reported napping and nocturnal sleep in 2- to 8-year-old children. *Pediatrics*. 2005;**115** (1 Suppl.):225–232.
40. de Roquefeuil G, *et al*. New data on the ontogeny of the child's sleep-wake rhythm. *Chronobiol Int*. 1993;**10**(1):43–53.
41. Wake M, *et al*. Prevalence, stability, and outcomes of cry-fuss and sleep problems in the first 2 years of life: prospective community-based study. *Pediatrics*. 2006;**117**(3):836–842.
42. Meltzer LJ, *et al*. Relationship between child sleep disturbances and maternal sleep, mood, and parenting stress: a pilot study. *J Fam Psychol*. 2007;**21**(1):67–73.