MONOGRAPHS OF THE SOCIETY FOR RESEARCH IN CHILD DEVELOPMENT

III. SLEEP ASSESSMENT METHODS

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ABSTRACT Sleep is a complex phenomenon that could be understood and assessed at many levels. Sleep could be described at the behavioral level (relative lack of movements and awareness and responsiveness) and at the brain level (based on EEG activity). Sleep could be characterized by its duration, by its distribution during the 24-hr day period, and by its quality (e.g., consolidated versus fragmented). Different methods have been developed to assess various aspects of sleep. This chapter covers the most established and common methods used to assess sleep in infants and children. These methods include polysomnography, videosomnography, actigraphy, direct observations, sleep diaries, and questionnaires. The advantages and disadvantages of each method are highlighted.

With growing awareness of the role of sleep in child development, the issue of the appropriate way to assess sleep has gained considerable attention. However, sleep is hard to define and covers multiple levels of behavioral, physiological, and neural phenomena. The answer to the question of what is the best way to assess sleep is dependent on what aspect of sleep is relevant to the developmental issue of interest. For instance, a question like "How much time a school-age child needs to sleep for optimal school performance?" is substantially different from a question like "What is the role of REM sleep in brain maturation during early development?" and requires different sleep assessment methods. Sleep can be characterized by multiple dimensions, which can be roughly divided into: (a) duration, (b) quality, (c) brain activity patterns—or sleep architecture, and (d) schedule or circadian aspects (see Table 1); these sleep dimensions are presented in Chapter I.

In this monograph, the prominent sleep assessment methods, particularly actigraphy and sleep diaries, are described and their implementation is demonstrated in the following chapters. Being aware of the advantages and limitations of each method is crucial to understanding sleep. Assessing sleep in infants and children is a challenging task, and there are different methods

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TABLE 1

DIMENSIONS OF SLEEP ASSESSMENT AND A SAMPLE OF REPRESENTATIVE MEASURES[a]

Sleep Quantity	Sleep Quality	Sleep Architecture	Sleep Schedule
• Sleep duration	• Wakings during sleep	• Amount or proportion of slow-wave sleep stages	• Sleep onset time
• Daytime sleep duration	• Sleep efficiency	• Amount or proportion of REM sleep stages	• Morning rise time
• Nighttime sleep duration	• Events of disordered breathing during sleep (e.g., snoring, apnea)	• Spectral distribution of EEG during sleep	• Distribution of naps
• True sleep time (excluding wakefulness during the sleep period)	• Unique expressions during sleep (parasomnias)		• Estimates for circadian (~24 hr) rhythmicity.

[a]There is potential overlap between these dimensions as, for instance, sleep architecture is highly related to sleep quality and vice versa.

to accomplish this task. Each method has its advantages and limitations, and the choice of methodology depends on: (a) specific assessment goals or questions, (b) age of the child, and (c) availability of the equipment and knowledge required. In this chapter the main sleep assessment methods are presented with special emphasis on those that are used mostly in the studies included in this monograph (actigraphy and sleep diaries), and on methodological considerations related to each method. Assessment methods that require equipment are discussed with no reference to specific brand names or companies.

The methods discussed in this chapter include polysomnography, videosomnography, actigraphy, direct behavioral observations, sleep diaries, and questionnaires. A summary of these methods and their main advantages and limitations is presented in Table 2.

POLYSOMNOGRAPHY

Polysomnography is considered the gold standard of sleep assessment. Polysomnography is based on laboratory or ambulatory monitoring that usually includes electrical brain activity (EEG), muscle activation (EMG), eye movements (EOG), breathing efforts and flow, oxygen saturation sensors (oximetry), video recording, and additional channels according to study requirements. Studies with infants and young children are usually conducted

TABLE 2

BEST PRACTICES IN SLEEP ASSESSMENT

	Advantages	*Disadvantages*
Polysomnography	• Provides the most detailed information on sleep architecture and clinical diagnoses • Useful for objective assessment of daytime sleepiness (e.g., multiple sleep latency test, maintenance of wakefulness test) • Ambulatory polysomnography may increase the advantages in normative samples	• In the lab, expensive and usually only one or two nights can be afforded • Usually intrusive unnatural sleep environment • Labor intensive scoring • More difficult to perform in young children • Less informative for daytime sleep, regular night wakings, behavioral insomnia, and schedule disorders • Insufficient reliability and validity of some data parameters and safety issues
Videosomnography[a]	• Enables relatively non-intrusive monitoring at home and screening for clinical disorders • Documents specific child behaviors (e.g., parasomnias) and caregivers' interventions and involvement	• Requires home installation and later visual inspection and scoring • Time consuming and privacy concerns • Limited by sleeping positions and locations and difficult for sleep scoring in older children
Actigraphy	• Enables cost-effective, non-intrusive 24-hr monitoring at home for extended periods • Requires no installation and sleep–wake scoring is relatively easy, but requires elimination of artifacts from data • Provides good data for extended periods and therefore recommended for intervention follow-ups and assessment of schedule disorders	• It only measures activity • It does not provide data on sleep staging, breathing, or specific behaviors • Artifacts related to induced external motion, device removal, and motionless wakefulness are threats to validity
Subjective Reports	• Questionnaires and diaries are easy, cost-effective, and can measure a wide range of sleep parameters in various contexts	• Information is influenced by response biases, compliance, and subject burden

(*Continued*)

TABLE 2. (*Continued*)

	Advantages	*Disadvantages*
	• Sleep diary data may be more accurate for the assessment of some sleep parameters (e.g., duration) than questionnaires • While the correspondence between subjective and objective measures of quality is modest, subjective report provides important, unique information	• Parent reports are limited to the extent of their awareness of children's sleep behaviors • For most questionnaires, there is a lack of standardization and norms stratified by age, gender, ethnicity, etc., for comparative purposes

[a]Many of the advantages and disadvantages listed for videosomnography also apply to direct observations of sleep behavior.

in sleep laboratories (because of a variety of technical and safety issues). The electrodes and sensors are attached to the child prior to bedtime and the child is required to tolerate these attachments throughout the study. These studies are usually conducted for one or two nights.

Polysomnography provides detailed information including electrical tracings of brain activity, sleep architecture, sleep stages, sleep quality, arousals, breathing patterns, oxygen saturation, eye movements and leg movements during sleep. This information is very rich and enables clinical research and diagnosis of a variety of sleep disorders including sleep apnea, periodic movements in sleep, parasomnia (e.g., sleepwalking, night terrors), seizures, narcolepsy, REM sleep disorders, and insomnia. For more information on clinical indications for polysomnography and related sleep stages in infants and children see Beck and Marcus (2009) and Kotagal et al. (2012).

Standard methods have been developed for scoring polysomnography data of infants, children and adults (Anders, Emde, & Parmelee, 1971; Iber, Ancoli-Israel, Chesson, & Quan, 2007; Rechtschaffen & Kales, 1968). Additional rules and guidelines have been developed for scoring specific phenomena such as arousals (ASDA, 1992) or leg movements (Force, 1993). Standardized guidelines also include indications for the use of polysomnography in clinical practice of sleep medicine (Kushida et al., 2005; Littner, Hirshkowitz et al., 2003).

In the last two decades, studies in normal pediatric populations provided reference values (or norms) for sleep and sleep-related breathing measures (Acebo, Millman, Rosenberg, Cavallo, & Carskadon, 1996; Coble, Kupfer, Taska, & Kane, 1984; Montgomery-Downs, O'Brien, Gulliver, & Gozal, 2006; Moss et al., 2005; Quan et al., 2003; Tapia et al., 2008; Traeger et al., 2005;

Uliel, Tauman, Greenfeld, & Sivan, 2004; Verhulst et al., 2007). These reference values are very important for clinical and developmental research as they reflect developmental changes that are very crucial in assessing sleep in infants and young children.

Another important use of polysomnography is for determination of daytime sleepiness. The multiple sleep latency test has been developed for this purpose (Carskadon & Dement, 1982, 1992; Carskadon et al., 1986; Littner et al., 2005; Richardson et al., 1978). The multiple sleep latency test is based on giving individuals a few opportunities to fall asleep at different times of the day and measuring the latency to sleep onset using polysomnography. The underlying rationale is that given the opportunity to sleep, sleepy individuals fall asleep faster than nonsleepy individuals. This test is used with children and adolescents to assess daytime sleepiness for research and clinical purposes.

With modern technology, polysomnography recordings are fully stored allowing more complex computations to be performed on EEG data as well as on other information channels. One such use that has gained popularity is the spectral analysis of density and localization of EEG frequencies (e.g., Feinberg & Campbell, 2010; Jenni & Carskadon, 2004; Kurth et al., 2010; Tarokh, Van Reen, LeBourgeois, Seifer, & Carskadon, 2011). Another informative approach is the analysis of cyclic alternating pattern, which has been documented as a good marker for sleep instability in children and adults (Parrino, Ferri, Bruni, & Terzano, 2012).

Polysomnography provides the most detailed set of data on the sleep process including information that is very crucial for brain research and sleep medicine. Diagnosis of a variety of sleep disorders cannot be accomplished without specific information derived from polysomnography. Furthermore, polysomnography in a laboratory setting provides full control and supervision on the tested individual under standardized conditions. Finally, polysomnography can be used to objectively assess daytime sleepiness with procedures such as the multiple sleep latency test. However, polysomnography requires infants and children to sleep under unique conditions that require tolerance to an unnatural sleep environment (laboratory) and attached electrodes and sensors, which is a challenge to normal sleep patterns and a major limitation. It requires some adjustment in adults (first night effect), and it is certainly more challenging for infants and young children. Therefore, derived measures can be unrepresentative of natural sleep of specific children. Because polysomnography is a costly procedure, it is often done only for one or two nights, which further compromises the representativeness of the data. Finally, infants and young children often spend a significant amount of time sleeping during daytime hours, sometimes with an unexpected schedule. Under such circumstances, capturing all natural sleep episodes with polysomnography is practically impossible.

VIDEOSOMNOGRAPHY

Video recordings are commonly used in child development research. Videosomnography is based on video recordings of sleep that can be done in the natural sleep environment (Anders, 1979; Anders, Halpern, & Hua, 1992; Anders & Sostek, 1976; Burnham, Goodlin-Jones, Gaylor, & Anders, 2002a; Sostek, Anders, & Sostek, 1976). With one or more video cameras in the child's room, it is possible to record and later to identify sleep patterns (that includes active and quiet sleep periods in infants) as well as to document parental interventions and the child's behavior during nighttime waking episodes. Video-based studies have documented the development of self-soothing skills in young children and the differences between infants waking up with or without signaling to their parents by fussing or crying (Anders et al., 1992; Anders & Keener, 1985; Burnham et al., 2002a; Burnham, Goodlin-Jones, Gaylor, & Anders, 2002b; Goodlin-Jones, Burnham, Gaylor, & Anders, 2001).

In addition to the standard videosomnography as developed by Anders and colleagues, home videos can be used to document different episodes reported by parents for clinical evaluation. For instance, it has been shown that video recordings can be used to screen sleep apnea in children (Sivan, Kornecki, & Schonfeld, 1996). It can also be used to obtain direct impression of events such as night terrors, rhythmic behaviors, REM behavior disorders, suspected nocturnal seizures, and other parasomnias.

The main advantage of videosomnography is the ability to directly assess infant sleep in the child's natural sleep environment. The derived information can include the child's nighttime behaviors and parental interventions. However, there are significant limitations that include the need for home installation of the equipment and related safety issues as well as data interferences resulting from the position of the camera and the child's positions and movements in bed. Furthermore, some parents may feel that their privacy is compromised with nocturnal video recordings.

DIRECT BEHAVIORAL OBSERVATION

The initial discovery of REM sleep was made while scientists who were interested in eye movement directly observed infants and noticed the periodicity and unique characteristics of REM sleep. They examined this phenomenon in adults and published their seminal paper on the discovery of REM that is considered the cornerstone of modern sleep research (Aserinsky & Kleitman, 1953). Direct behavioral observation has mostly been used to assess sleep in young infants. The method requires trained observers who complete real time scoring of sleep and wakefulness states over a designated period of time at home or in nursery settings. The method is very labor intensive, is limited by available human resources, and is usually not done overnight (Thoman, 1975, 1990; Thoman & Acebo, 1995). Simultaneous recording of respiration (with a pressure sensitive sensor pad placed under the infant) is a recommended complementary tool. Derived states include: (a) alert; (b) non-alert waking; (c) fuss or cry; (d) drowse, daze, or sleep–wake transition; (e) active sleep; (f) quiet sleep; and (g) active-quiet transition sleep. Good inter-rater reliability has been reported for sleep–wake state scoring in infants and young children. Measures derived from direct observations have demonstrated scientific validity in predicting developmental outcomes including developmental disabilities and neurobehavioral functioning (Thoman, 1975, 1990; Thoman, Denenberg, Sievel, Zeidner, & Becker, 1981).

The main advantages of direct observations are that they can be done at home or in other normal sleep settings of the infant. Direct observations provide rich information on sleep and wakefulness states and related behaviors that correspond with neurobehavioral organization and predict later development. However, this method is highly labor intensive and usually limited to a few hours during daytime hours. It is only applicable for assessing sleep in infants and very young children. Furthermore, having an observer at home may interfere with family routines and sense of privacy.

ACTIGRAPHY

Actigraphy is based on a wristwatch-like device that continuously monitors body movements and provides information on sleep–wake patterns for extended periods in the natural environment of the child. In the early 1950s, crib movements were recorded and used for infant sleep assessment (Kleitman & Engelmann, 1953). Modern technology has led to standalone miniature units that can be easily attached to the ankle in infants and toddlers, or to the wrist in older children and adults (see various studies in this monograph), and collect activity data for extended periods. These data can be translated to validated sleep measures (Ancoli-Israel et al., 2003; Meltzer, Montgomery-Downs, Insana, & Walsh, 2012; Sadeh & Acebo, 2002; Sadeh, Hauri, Kripke, & Lavie, 1995). Active and quiet sleep can also be identified with reasonable validity during the first year of life (Sadeh, Acebo, Seifer, Aytur, & Carskadon, 1995).

The clinical value of actigraphy has been demonstrated in studies showing that: (a) actigraphy can distinguish between sleep-disturbed and control infants (Sadeh, Lavie, Scher, Tirosh, & Epstein, 1991); (b) significant discrepancies exist between parental reports and actigraphy on sleep quality measures in pediatric populations (Sadeh, 1996; Sadeh, Flint-Ofir, Tirosh, &

Tikotzky, 2007; Tikotzky & Sadeh, 2001); and (c) actigraphy can be used to assess the efficacy of behavioral interventions for infant sleep problems (Sadeh, 1994).

Standard of practice guidelines have been developed for the use of actigraphy in sleep medicine (American Sleep Disorders Association, 1995; Littner, Kushida et al., 2003; Morgenthaler et al., 2007). Actigraphy is particularly suitable for the assessment of sleep schedule disorders because it enables continuous monitoring for extended periods. It has been recommended as a complementary method in the assessment of insomnia and treatment response. The guidelines also recommended actigraphy for obtaining sleep data in individuals when subjective or parental reports are not available or are unreliable.

The most prominent threat to the validity of actigraphy is the artifacts resulting from externally induced movements (e.g., a child sleeping in a moving vehicle or in a rocking crib or stroller; Sadeh, Sharkey, & Carskadon, 1994). Therefore, automatic sleep–wake scoring should not be performed prior to careful monitoring and removal of such potential artifacts. Sleep diaries are instrumental in artifact removal as they help in identifying periods when the unit is removed from the child, or periods of externally induced motions (e.g., car rides). At least 5 days of monitoring are recommended for obtaining optimal reliable and representative measures (Acebo et al., 1999). However, fewer days have been reported in many studies with reasonable reliability as well. For instance, in 36-month-old children, the reliability index only drops from .89 to .77 when 2 days were used instead of 5 days (Acebo et al., 1999). A related issue is potential movement artifacts that may be problematic in children with movement or other neurologic disorders. It is also important to mention that there are different types and models of actigraphs that are sold by different companies, and are used in different reported studies in this monograph. When choosing an actigraph for research purposes, it is always very important to verify that it was indeed validated for the age groups or unique characteristics of the sample and that the algorithm used for analyzing the data is based on the relevant validation studies. The actigraphs and algorithms used in the various studies presented in this volume meet these criteria. Further, studies in typically developing infants, children, and adolescents have yielded reference values for actigraphy-based sleep measures (Acebo et al., 2005; Meltzer et al., 2012; Sadeh, Raviv, & Gruber, 2000; Tikotzky & Sadeh, 2001, 2009; Wolfson et al., 2003).

Another potential application of actigraphy is monitoring sleep during naturalistic studies of sleep restriction and other imposed demands on children (Beebe et al., 2008; Fallone, Seifer, Acebo, & Carskadon, 2002; Sadeh, Gruber, & Raviv, 2003). For instance, it has been shown that actigraphy can validate compliance of children during a sleep restriction/extension home study (Sadeh et al., 2003). This capacity opens new opportunities for scientists interested in studies involving sleep manipulation in natural settings. For a thorough review on actigraphy in infants and children see Meltzer et al. (2012).

All the studies in this monograph have used actigraphy for the assessment of sleep measures (with the exception of the chapter on infant sleep arrangement that did not assess actual sleep). A few studies (Chapters VI, VII, and VIII) have used it to assess both sleep duration (sleep minutes or true sleep time) and sleep quality measures (sleep efficiency, number of long wake episodes or percent of motionless sleep). Other studies have used actigraphy to assess only sleep quality measures (Chapters IV and V) and one study used it only to assess sleep duration (Chapter IX). Furthermore, actigraphy enables 24-hr monitoring of sleep (see Chapters VIII and IX); however, other reported studies in this monograph have used actigraphy to assess nocturnal sleep only. The assessment of multiple sleep parameters is optimal as this area of inquiry develops, and there is no one parameter that is considered idyllic. This is reflected in the various sleep variables assessed across the studies presented in this volume.

SLEEP DIARIES

The use of sleep diaries is very common in sleep research in infants and children. Depending on age, diaries can be completed by the child or by a caregiver. Diaries can provide information on sleep schedule, night wakings, and related topics. Parental reports on their child's sleep schedule (e.g., sleep onset, morning rise time) using diaries have been shown to be quite reliable. However, when it comes to sleep quality measures (e.g., night wakings), their validity drops (Sadeh, 1996; 2004; Tikotzky & Sadeh, 2001). Self-reports have been found to be reliable in high school children (Gaina, Sekine, Chen, Hamanishi, & Kagamimori, 2004).

In clinical research, sleep diaries have often been used to document intervention effects. However, having parents document every night-waking for extended periods (sometimes a few weeks) could lead to compliance issues that may compromise the validity of the results (Sadeh, 1994).

In most studies reported in this monograph, sleep diaries were used to control the quality of the actigraphy data (e.g., artifact removal). In some of the studies, sleep variables derived from the diaries were also used in data analyses.

SLEEP QUESTIONNAIRES

Sleep questionnaires offer a very cost-effective way to obtain extensive information on sleep patterns, sleep problems, sleep context, and sleep-related behaviors. Many studies have developed tailored questionnaires that preclude comparisons between studies and populations. However, some questionnaires have been validated and established in the field (Spruyt & Gozal, 2011a, 2011b).

For instance, the Sleep Disturbance Scale for Children (SDSC) is a validated and established questionnaire for assessing sleep problems in children (Bruni et al., 1996, 2006; Ferreira et al., 2009). It provides six factors: difficulty in initiating and maintaining sleep, sleep breathing disorders, arousal disorders, sleep–wake transition disorders, disorders of excessive somnolence, and sleep hyperhydrosis (sweating). The SDSC demonstrated good psychometric properties and discriminative validity between clinical and control samples.

Another popular questionnaire is the Children's Sleep Habit Questionnaire (CSHQ—Owens, Spirito, & McGuinn, 2000), which provides a total score as well as scores on eight specific domains: (1) bedtime resistance; (2) sleep onset delay; (3) sleep duration; (4) sleep anxiety; (5) night wakings; (6) parasomnia; (7) sleep disordered breathing; and (8) daytime sleepiness. The CSHQ demonstrated good psychometrics and discriminative validity between clinical and control samples. A version for younger children (toddlers and preschool age) has been developed and validated (Goodlin-Jones, Sitnick, Tang, Liu, & Anders, 2008).

The Brief Infant Sleep Questionnaire (BISQ) has been developed and validated as a screening tool for younger children (0–3 years) and for online (Internet) administration (Sadeh, 2004). Good psychometric properties have been demonstrated as well as discriminant validity between clinical and control samples (Sadeh, 2004). The questionnaire has been expanded and translated to other languages and cross-cultural studies provided reference data from many countries (Mindell, Sadeh, Wiegand, How, & Goh, 2010; Sadeh, Mindell, Luedtke, & Wiegand, 2009).

Sleep questionnaires for the infancy–toddlerhood period usually address the issue of bedtime routines and parent-child interactions around bedtime. The application of such information is demonstrated in the chapter on infant sleep arrangement (see Teti et al., Chapter X, in this volume).

CHOOSING AN APPROPRIATE ASSESSMENT METHOD

Many researchers in child development use some form of questionnaires and/or daily logs because these are the most readily available instruments that do not require special equipment or technological knowledge. This choice is reasonable for studies interested in sleep duration and schedule and sleep-related behaviors and interactions. However, when the focus is on sleep quality or sleep architecture, the need for more sophisticated methods increases because of the serious limitations of self- or parental reports. Videosomnography is a good choice for those interested in objective sleep assessment and bedtime interaction in infancy. Actigraphy is generally a good choice for those interested in objectively documenting sleep for extended periods in the child's natural environment. It is the method that has been used in most of the studies reported in this monograph. Scientists interested in deeper understanding of underlying processes in sleep are more likely to choose polysomnography-based methods that can document sleep stages or EEG spectral densities. Modern brain imaging methods have generated fascinating knowledge on brain mechanisms associated with sleep manipulations. For instance, in an fMRI study with adults, it was found that sleep deprived individuals exhibited significantly increased amygdala activation in response to emotional stimuli in comparison to rested individuals (Yoo, Gujar, Hu, Jolesz, & Walker, 2007). Furthermore, decreased connectivity between the amygdala and the medial prefrontal cortex (which exerts inhibitory control on the amygdala) was found following sleep deprivation. These types of studies facilitate the understanding of underlying brain mechanisms associated with the cognitive and emotional consequences of sleep deprivation. The ability to combine EEG and fMRI (or PET) in sleep research holds promise for greater understanding of brain processes during sleep (Picchioni, Duyn, & Horovitz, 2013).

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