Actigraphy

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to leave the laboratory between testing periods. The patient should also refrain from using nicotine 30 minutes before each nap and to avoid using caffeine, napping between test periods, sitting in a dark room, and an excessive amount of bright light or physical activity [1]. If the laboratory provides breakfast and lunch during the day of the study, food allergies or any other special dietary restrictions must be determined.

When scoring the MWT, mark "lights out," "lights on," and "sleep onset." As with the MSLT, arousals need not be scored. Remember that the emphasis is on sleep onset, not on how well the patient sleeps. If no sleep occurs, the sleep latency for that particular nap opportunity is 40 minutes.

A urine drug screen may be done the day of the procedure to verify that no substance has influenced sleepiness or wakefulness. If the sleep clinician wants a urine drug screen to be performed, the patient should fill out a release form and list any medications he or she has taken within the last 14 days. If the screening is positive, obtain another fresh sample and retest for accuracy. Notify the physician if the urine drug screen is positive. It would be best to run the screening early in the day, so that if it does comes back positive there is time to run another drug screen.

Although these tests are helpful, they should not be the sole rationale for making or discarding a diagnosis of a sleep disorder. A patient's entire clinical history should be taken into consideration when making a diagnosis. Most patients do not have all four symptoms of the narcoleptic tetrad. The absence of a mean sleep latency of less than 8 minutes and two or more SOREMs does not exclude a diagnosis of narcolepsy [3]. Test values can be influenced by physiologic, psychologic, and test protocol variables [1]. It is, therefore, important for the sleep technologist to follow the clinically accepted guidelines for both the MSLT and the MWT to rule out any false negatives.

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Actigraphy

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Actigraphy is a term used to describe methods for measuring activity (movement) through small, computerized wristwatch-like devices. During the past few decades, technological advances have resulted in a variety of miniature actigraph systems that can record and store activity data collected continuously for several weeks. Most activity-monitoring systems are similar in that they provide devices, guidelines, and software for collecting, downloading, and analyzing data and scoring algorithms that produce estimates of sleep and wake for aggregated epochs of continuously sampled movement data. Differences between actigraphy systems are notable, however, and have important consequences.

The three most common ways of digitizing analogue signals transduced from motion by actigraphs include time above threshold, zero-crossing, and digital integration, methods yielding very different activity counts for the same underlying motion. In addition, some actigraph systems allow users to vary recording parameters, such as sensitivity or epoch length, which also affect the activity data. These differences in activity count output make difficult direct comparisons of activity data between actigraph systems and between studies using different systems. More important, however, is the impact on results from sleep-wake scoring algorithms. A number of algorithms have been developed for estimating sleep and wake from activity data, each based on data from a unique combination of recording mode and epoch length and validated against another sleep estimation method, usually polysomnography (PSG). Reasonable validity for several algorithms from different systems has been shown. An algorithm used to estimate sleep and wake from one device and recording mode, however, will produce different results when applied to data collected from another device or recording mode, and validity will be affected. It is important for the new user to

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understand that varying any part of an actigraph system (device, settings, recording mode, and algorithm) probably will change the final results. Such consequences underscore the need for professionals to understand the strengths and weaknesses of different actigraphic systems and the issues surrounding the use of actigraphy in clinical and research settings.

This article provides a brief overview of actigraphy with regard to validity and reliability issues, practical concerns and procedures, diagnosis of clinical sleep disorders, and use in research settings. Recommendations for using actigraphy effectively are also be made. Additional information about actigraphy and comprehensive reference lists of studies that have used this technology may be found in several recent review articles. A 1995 paper [1], written under the auspices of the American Sleep Disorders Association (now renamed the American Academy of Sleep Medicine), reviewed technical information, validity and reliability studies, and studies using actigraphy for clinical evaluation and research before 1995. This review highlighted problematic methodological issues, many of which have yet to be resolved. In 2003, Ancoli-Israel and colleagues [2], again writing for the American Academy of Sleep Medicine, provided an updated review of actigraph technologies, evaluated newer validity and reliability studies, and assessed actigraphy studies of individuals who had sleep or circadian rhythm disorders and studies using actigraphy as treatment-outcome measures. Sadeh and Acebo [3] also published an actigraphy review that highlighted important practical and methodological issues. Finally, Littner and colleagues [4] published the most recent practice parameters for the role of actigraphy in the study of sleep and circadian rhythms, basing recommendations on the review paper by Ancoli-Israel and colleagues [2].

Is actigraphy a reliable and valid measure of sleep?

During the past decades, actigraphy companies have developed a multitude of new devices, operating procedures, and algorithms for use with clinical populations. Against this background of growth in available actigraphy systems is the issue of the psychometric adequacy of actigraphy for the assessment of sleep. Data on the reliability and validity of sleep-wake measures have not been presented for all devices or for all available modes for specific devices. The issue of the psychometric adequacy of actigraphy is important and complicated, and the current comprehensive reviews summarize laboratory assessments of actigraphy from some systems [1–3]. Other systems have no published peer-reviewed psychometric studies, however.

In general, studies indicate that epoch-by-epoch agreement for sleep estimated by actigraph algorithms and sleep scored from PSG recordings is more than adequate (≥ 0.85) for normal individuals across a variety of ages. Published reports have also shown sufficiently high epoch-by-epoch correspondence between actigraphically estimated and PSG sleep measures in some clinical populations (eg, patients who have insomnia) with some algorithms. Assessment of wake during periods of sleep, however, generally results in lower epoch-by-epoch agreement. Overall, reports have also shown that correlations between whole-night PSG and actigraphic sleep parameters (eg, total sleep minutes, sleep efficiency) are relatively high (>0.80) for normal individuals and some patient samples. Correlations between all-night measures, however, may be relatively high even when epoch-by-epoch agreement is relatively low. The level (epoch-by-epoch or whole-night correlations) at which correspondence has been assessed has implications for the usefulness of specific measures. If the interest is in comparing groups of individuals on whole-night parameters, measures that have adequate correlational validity may be appropriate. On the other hand, high epoch-by-epoch correspondence is important if the interest is in assessing parameters that tap transitions between wake and sleep within a night (eg, number of wake bouts, sleep latency) or in assessing individuals for clinical purposes.

When actigraphy is used in populations who have disordered or disturbed sleep, the accuracy of estimated sleep-wake parameters is generally decreased [5,6]. For example, the primary features of insomnia (ie, sleep-onset delay, prolonged nighttime awakenings) lead to more than usual amounts of quiet wakefulness in patients, and these epochs are likely to be classified as sleep rather than wake by actigraphy algorithms [7,8]. Because the largest discrepancies between actigraph and PSG measures involve transitions from wake-to-sleep and sleep-to-wake, accuracy is also poorer among patients who have sleep-related movement disorders [8] and disturbed sleep related to shift work [9]. Further, differences in the accuracy of algorithms across the lifespan result from age-related changes in the amount of activity during sleep [10–13]. Algorithms have been developed for use with some specific groups, such as very young infants [10], insomnia patients [5], and depressed patients [14]. On the other hand, validity has not been established for many other clinical samples, such as patients who have narcolepsy or psychiatric disorders (eg, anxiety) or those regularly taking medications known to influence sleep and wakefulness.

In conclusion, published psychometric studies largely show the value of using actigraphy to estimate sleep from some actigraph systems across a variety of normal and clinical samples. Reports also highlight the inherent limitations of actigraphy with regard to measuring sleep timing and amount precisely. Much additional work is needed to determine the validity and reliability of actigraph measures in a larger variety of settings and samples. Standardized methods of data acquisition, recording procedures, and variables do not exist, and new users often find no published validity studies for the system or measures they wish to use. In this sense, actigraphy is still a new technique.

Also, little-to-no evidence exists for the validity of many of the variables routinely computed for the output of actigraph analysis software (eg, sleep-onset latency, sleep bouts, wake bouts, motionless sleep, movement indices, circadian parameters). A great deal of additional work is needed in assessing the psychometric adequacy of these parameters, particularly circadian rhythm parameters and measures that describe waking activity.

How can actigraphy measures be used even if they do not have adequate validity?

Measures of behavior that do not show high validity may still prove useful for description and prediction in clinical and research settings. First, studying a large number of individuals, averaging measures across groups of individuals, collecting repeated measures of data over extended periods of time or across multiple treatment conditions, or replicating a study in a new sample can mitigate error variance associated with these measures. Second, measures with moderate validity may provide convergent evidence in studies using multiple methods. Third, a growing body of published reports shows that actigraphic measures adequately document predicted differences in sleep-wake patterns between groups of individuals. For example, age-related changes in sleep measured with PSG, sleep diaries, and questionnaires are consistent with actigraphic assessments [15,16]. Sleep or activity differences associated with behavioral, drug, light exposure, and other experimental interventions have been documented successfully with actigraph measures [17–20]. Finally, actigraphy may be used to document compliance with fixed sleep schedules imposed during at-home periods before in-laboratory experimental studies when knowledge of a participant's sleep history is important for understanding the results of studies investigating the effects of sleep restriction or circadian and homeostatic processes [21].

Careful consideration should be given to the issue of the duration of recordings. Based upon recommendations from the Standards of Practice Committee of the American Academy of Sleep Medicine [4], at least three consecutive 24-hour periods of actigraph recording time are needed, although this recording time may not be long enough for some applications. Assessments of longer periods are optimal for obtaining measures that reliably characterize individuals, especially when sleep-wake patterns are highly variable or when sleep parameters with lower validity are being used [22]. For example, infants and young children may vary widely night to night at some developmental stages as sleep is consolidated and shifted to nighttime hours. Adolescents and young adults may have large discrepancies in their weekday/weekend sleep schedules. Thus, recording periods of less than 7 days may lead to incomplete or inaccurate descriptions. Shift-worker patterns also may be remarkably variable across a week, and that variability may itself be an important indicator of dysfunction. Aggregating actigraph data across 5 to 7 nights can substantially increase the reliability of measures [22], thereby increasing their predictive validity. Scheduling appointments a week apart for setting up, returning, and checking the actigraph record against the sleep log may be efficient and practical. Further, when data loss occurs because of poor compliance, illness, or other unexpected events, 7 nights of recording may allow the recovery of enough data for analysis.

How can actigraphy be used in the diagnosis of clinical sleep disorders?

Current reviews and the most recent paper on practice parameters [2–4] suggest that actigraphy can be used to complement other clinical assessments in the diagnosis of some sleep disorders. Actigraphy is not appropriate as the sole diagnostic tool for disorders such as sleep-disordered breathing or periodic limb movements; however, actigraphy may be useful in the routine evaluation of insomnia, circadian-rhythm disorders, excessive daytime sleepiness, and restless legs/periodic limb movement disorders. Actigraph patterns indicating excessive activity during the night or decreased activity during the day may signal a need for further screening. Because actigraphy provides continuous recordings in the natural environment, assessments in special groups (eg, children, patients who have dementia) are possible. Further, the ability to monitor sleep and sleep scheduling for long periods makes actigraphy especially useful as an outcome measure in some treatment protocols.

What are the most common sources of artifact?

Artifact in actigraphy records is best controlled when research volunteers or patients are evaluated in the laboratory. Thus, most validity studies comparing actigraph measures against PSG measures in the laboratory compare data collected under ideal conditions. On the other hand, actigraphy assessments made in the natural environment commonly include artifacts that must be identified and discarded from analysis. Sources of artifact may include taking the actigraph off while bathing, swimming, or during athletic activities; forgetting to reattach the actigraph before the nighttime sleep period; participating in quiet at-home activities (eg, watching television, reading); drinking alcohol or consuming caffeinated drinks before bedtime; using medications that affect movement or sleep; and sleeping with a bed partner. Periods when the actigraph is not worn or of quiet wakefulness are likely to be scored as sleep by most algorithms, and periods of excessive movement by the individual or by a bed partner during sleep periods may or may not be scored accurately. Further, sickness or medication/substance use during the recording period may result in a sleep-wake actigraphy pattern that is not characteristic of the individual's normal sleep.

Practical issues and procedures: how can artifact and data loss be controlled?

The most practical and efficient ways to document daily events that lead to actigraph artifact are the use of sleep-wake logs or diaries or daily telephone calls during the entire assessment period. Logs or diaries have the advantage of allowing participants to record important information as the need arises but carry the risk that information may not be recorded in a timely fashion; noncompliant patients or research volunteers may complete the log in the parking lot before the visit. Daily telephone calls from participants to answering machines allow collection of time-stamped information and facilitate intervention if problems arise. Daily telephone calls may also be made to research participants or patients at scheduled times. These forms of documentation support the development of scoring procedures that restrict algorithm scoring to specific sleep periods. The log or call should query information about bedtimes and rise times; times when the actigraph is off; alcohol, caffeine, or medication use; illnesses; naps; times sleeping in moving vehicles; and nights when bed sharing occurred. After actigraph data are downloaded, the record should be printed and carefully compared with the information in the log. Individuals should be questioned as soon as possible about discrepancies between the actigraph record and the sleep log, as well as about ambiguous periods on the record. Some actigraph devices have an event marker feature, which allows individuals to press a button on the actigraph to denote an important occurrence during the recording period (eg, times when the actigraph is taken off and reattached, bedtime, rise time). In addition, some actigraphs can record the level of light in the environment and transpose it on the actigraph record.

Actigraphs are sensitive pieces of hardware that are subject to breakage and malfunction that lead to data loss. Some devices have external buttons that allow individuals to perform a "sound check" to ensure that the actigraph is working. Developing procedures for testing actigraphs that produce suspect recordings (eg, extremely high or low activity amplitude) and for replacing a broken actigraph as soon as possible during a recording period is essential. Good working relationships with actigraph venders should be maintained so that broken devices are repaired promptly.

How should actigraphic data be scored?

A common complaint of new users of actigraphy is that they have difficulty determining the point at which sleep periods begin and end simply by looking at the actigraph recording. For example, showers (with the actigraph off) just before bedtime or soon after waking in the morning can be remarkably difficult to separate from the sleep period. In addition, many individuals commonly spend time in quiet waking activities (eg, watching television on weekends and evenings) just before and just after the nighttime sleep period. These periods of low activity are likely to resemble and to be scored by algorithms as multiple or excessively long sleep periods. Actigraph data may be completely unscorable without procedures for identifying such artifacts. The importance of developing rigorous procedures is highlighted by anecdotal reports from investigators who have spent months or years collecting actigraphy recordings from large numbers of individuals only to realize later that they are not able to distinguish artifact from actual sleep-wake patterns.

Standard procedures for scoring actigraph records do not currently exist, although manuals from individual companies provide some guidelines for setting scoring intervals. Scoring rules described in the methods sections of published reports are also useful. Of primary importance, however, is scoring actigraph records based upon rule-driven procedures with consensus decisions by primary investigators or clinicians for ambiguous nights. Procedures will probably be a result of compromise between software constraints and the needs of the researcher or clinician. The rapid and ongoing development of new actigraphs and software make it unlikely that scoring procedures will be standardized in the future.

Summary

Actigraphy is a methodology for recording and analyzing activity (movement) from small, computerized devices worn on the body. Published reports on the reliability and validity of actigraph measures, although not comprehensive, generally indicate that sleep estimated by scoring algorithms is relatively consistent with PSG-scored sleep for normal individuals across the lifespan and for some patient groups. Accuracy is often greatly decreased when sleep is disordered or disrupted. Although actigraphy may be suitable for documenting and evaluating some sleep disorders, its role in clinical diagnosis is limited. Actigraphy is a useful methodology for investigating group differences, sleep-pattern variations over time, and the effects of behavioral or treatment interventions. Controlling artifacts is extremely important, and using some form of daily log is essential for documenting events. The recording period should be long enough to provide reliable measures and to capture important variations across time.

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Overview of Sleep Disorders

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Sleep disorders are common and can affect anyone, from every social class and every ethnic background [1]. It is estimated that more than 70 million Americans are afflicted by chronic sleep disorders [2]. About one third to one half of the entire adult population has insomnia caused by difficulty initiating or maintaining sleep is [3–6]. The Sleep Commission Report to Congress in 1993 indicated that about 20 million Americans have significant sleep apnea [6]. Many sleep specialists believe that the true prevalence of sleep apnea may be higher than the initial estimate, particularly because recent data suggest that the prevalence of obstructive sleep apnea syndrome (OSAS) in patients who have essential hypertension is greater than 25% [7–10]. In addition, about 25% of patients who have chronic obstructive pulmonary disease have OSAS, and about 50% of CHF patients have sleep apnea [11].

Sleep disorders are probably the most common medical conditions in the United States that often remain undiagnosed and untreated for a significant period of time before appropriate evaluation and treatment are instituted. This delay results partly from a relative lack of awareness by the public of the nonspecific signs and symptoms of sleep disorders [2] and partly from inadequate training and experience in sleep-related disorders among health care professionals [12].

Often, patients may be totally unaware that they may have an underlying sleep disorder, because they are unaware of what happens during sleep. A typical example is someone who snores and may have sleep apnea for years before the condition is brought to the physician's attention by the patient's spouse or bed partner. Various persistent daytime symptoms may not be perceived as sleep related by the patients, their physicians, nurses, or respiratory therapists. These signs and symptoms are typically nonspecific. Patients may complain of daytime tiredness, easy fatigability, frequent

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