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The SBSM Guide to Actigraphy Monitoring: Clinical and Research Applications

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CHAPTER 1

Introduction

Actigraphs are compact, lightweight, computerized accelerometer-based devices that have been used to evaluate sleep and wake in humans for nearly four decades.[1] While polysomnography (PSG) continues to be the gold standard for recording sleep, wrist actigraphy offers the advantages of being easier to use and less expensive and cumbersome. Although actigraphy should not be viewed as a substitute for PSG when an overnight sleep study is indicated (e.g., when EEG parameters are needed or sleep disorders requiring PSG are suspected), actigraphy allows for extended continuous recording of both nocturnal and daytime sleep periods for days or weeks in the patient's home sleep environment. Actigraphy can therefore yield information that is not captured during a single night in the sleep laboratory or via portable ambulatory monitoring. These features are particularly advantageous in select patient groups such as those with suspected circadian rhythm sleep disorders or insomnia complaints, in pediatric patients with sleep difficulties, and in older adults.

Actigraphy can also be useful for objectively assessing the impact of clinical interventions such as cognitive behavioral treatment of insomnia (CBT-I) or changes in schedule, such as adjustment to shift work. In addition, actigraphy can provide information about an individual's sleep patterns and sleep duration prior to quantifying daytime sleepiness with the multiple sleep latency test (MSLT) in order to ensure that the patient's sleep was *typical* (i.e., not unusually restricted or extended) during the week prior to the MSLT. While not indicated for the diagnosis of medically based sleep disorders such as obstructive sleep apnea (OSA) and restless legs syndrome (RLS), actigraphy can also be used to reliably assess other sleep parameters in these patients; for example, one study found that when subjective data were combined with actigraphy data in patients with sleep-disordered breathing, total sleep time and sleep efficiency did not differ from PSG.[2]

When actigraphy first became available, it was used primarily for research purposes, as many of the methodological considerations had not yet been adapted for clinical applications. Since then, there have been numerous studies investigating the use of actigraphy both in research settings and in clinical populations. The review articles written over the last several years have consistently documented that wrist actigraphy can reliably estimate sleep and wake across the lifespan, and is an appropriate and useful addition to the clinical evaluation and assessment of treatment benefits in patients with specific sleep disorders, particularly insomnia, circadian sleep/wake disturbances, and periodic limb movement disorder (PLMD).[1,3–5]

Actigraphs have evolved considerably since they were first introduced in the early 1970s[6–8]; currently available devices have both sophisticated accelerometers to measure movement and sufficient memory to record and store data for multiple weeks. Software programs have also improved over time and now allow for reliable automatic scoring based on established algorithms. They also yield data reports and summaries that provide useful information for clinical and research applications. Many software packages also have scoring programs for circadian rhythm activity analysis, further enhancing the utility of actigraphs for the evaluation of select patients.

The Centers for Medicare Services (CMS) designated a Current Procedural Technology (CPT®) code for actigraphy monitoring (code 95803) defined as "actigraphy testing, recording,

analysis, interpretation, and report (minimum of 72 hours to 14 consecutive days of recording)," enabling providers to apply for reimbursement in clinical settings.[9] As the use of this technology continued to expand, it became increasingly clear that the field was in need of a manual to standardize the use of actigraphy devices, and to define methods for data collection and scoring and interpretation of results. A more systematic manualized approach would further enhance the use of actigraphy in clinical and research settings and allow for comparability across providers, investigators, and settings.

Responding to this unmet need, this scoring and instructional manual was commissioned by the Society of Behavioral Sleep Medicine (SBSM) primarily to assist clinicians, but in addition to inform researchers in the use of actigraphy. The content was developed by experts in the field of actigraphy and sleep, and represents the current "state of the science" in the use of wrist actigraphy for clinical populations. The manual chapters cover a wide variety of core topics, including minimal technical specifications for devices and software, patient instructions, auxiliary clinical information that must be collected to optimize the accuracy of recordings, editing and scoring of actigraphy data, interpretation of results, and report generation. A brief discussion about the future of actigraphy as a clinical and research tool is included. When appropriate, some chapters include a section at the end highlighting any special considerations for research applications that may differ from routine clinical implementation of actigraphy.

CHAPTER 2

Minimal Technical Specifications to Consider When Purchasing an Actigraph

This chapter helps clinicians and researchers understand the key features to evaluate when choosing an actigraph (summarized in Table 1). It should be noted that the devices discussed here are those specifically designed and validated for measuring sleep-wake patterns; devices currently on the market that were developed for direct-to-consumer sale typically do not incorporate an accelerometer or a sleep-scoring algorithm that has been validated for sleep detection, and thus are not included. While these relatively low-cost devices have a number of appealing features, including integration with mobile devices and software, insufficient data exist at the present time to establish the validity and reliability of sleep parameters measured by these devices. In fact, the few available studies suggest they are not sufficiently accurate in either clinical or research settings, and thus their use cannot currently be recommended.[10,11]

The number and types of features available on actigraphy devices vary; and their relative importance and desirability for the intended purpose should be carefully considered when comparing specific models. These may include the sampling rate of the accelerometer, the modes available for calculating activity data, appearance, size and weight, additional functions such as the presence of an event marker button or the recording of ambient light data, battery life, data storage and computer system requirements, safety concerns, and water resistance. It should be emphasized that the authors and editors of this manual do not endorse any specific

TABLE 1
Technical Specifications for Actigraphy Devices

Type	*Definition*
Accelerometers	Omnidirectional or triaxial accelerometers with available validation studies are **required**. The ability to collect data as "time above threshold" or "digital integration" mode is **recommended**.
	The ability to record data in 30-second or 1-minute epochs is **required**. Flexible data collection parameters (e.g., epoch length) are **recommended**.
Appearance	Product dimensions should be **considered**, particularly among infants and young children, as the weight of some devices may be cumbersome or limit adherence.
Event markers	Event markers are a useful addition to an actigraphy log. These are **recommended**.
Light sensors	Light sensors embedded in the device can facilitate identification of bed times and rise times. These are **recommended**.
Battery type	A battery (rechargeable or disposable) that can record data for a minimum of 3 days is **required**. A battery (rechargeable or disposable) that can record data for a minimum of two weeks is **recommended**.
Data storage and memory	Nonvolatile memory that allows information to be stored even if the battery fails is **recommended**. The ability to store data for a minimum of 3 days is **required**.
Customer support	Support for both device and software is **required**.

brand or manufacturer, but rather provide the detailed information below in order to guide the user in selecting the most appropriate device.

MINIMUM REQUIREMENTS

Accelerometers

Different brands of actigraphs use a variety of accelerometer technologies and some accelerometers may be more reliable or accurate than others, especially when considering the population that is to be studied (e.g., children vs. older adults). It is important to confirm that the accelerometer data have been validated for each device being considered, with results published in peer-reviewed journals. Typically, omnidirectional or triaxial accelerometers are used for the measurement of sleep. These devices are different from accelerometers that are used to estimate calorie expenditure or to calculate pedometry variables.

There are also multiple modes of collecting and calculating activity data, with the most common being time above threshold, zero crossing, and integration modes. Different manufactures may use different modes, with different names, and only some will give the user a choice in setting the mode for data acquisition. As described below, each of these modes determines sleep and wake based on a combination of three primary variables:

1. duration and/or frequency of movements
2. amplitude or strength of the movement
3. acceleration or speed of the movement

Each mode has advantages and disadvantages. The *time above threshold* method counts the cumulative amount of time per epoch (a given time period) that the level of the movement is above some threshold (commonly 0.1 to 0.2 g). In some software packages the threshold can be adjusted (e.g., high, medium, or low). The disadvantage of this mode is that the amount the amplitude above threshold is ignored, as is the acceleration of the movements over time.

The *zero-crossing* method counts the number of times per epoch that the activity signal crosses zero. The disadvantages of this method are that, as with the time above threshold, the amplitude of the movement is ignored, as is the acceleration of movements over time. In addition, high-frequency artifacts may be counted as movement.

Digital integration involves calculating the area under the curve for the accelerometry output, which is sampled at a high rate for each epoch to be scored. The advantages are that this procedure involves rectifying the analog signal, doubling the amount of data available for analysis of each epoch; and the output reflects both acceleration and amplitude of movement. In this mode, however, the duration and frequency of movements are not evaluated.

In studies that have compared the three modes, digital integration was found to be better than time above threshold for identifying movement amplitude and both digital integration and time above threshold functioned better than zero crossing mode for accurately detecting sleep and wake.[12] It should also be noted that some actigraphs can record simultaneously in more than one mode, making it possible to determine which method to use after data are collected.

Finally, research has shown that some modes, as well as scoring algorithms, are more accurate in younger populations while others are more accurate in older adults.[13] It is therefore necessary to review published data on the specific patient population to be studied to help determine which method of data gathering is optimal.

Appearance

The product dimensions (size, weight) and appearance vary across manufacturers. Some actigraphs have a digital display, while others do not. The digital display often includes a watch face (which may allow patients to wear the actigraph in place of a wristwatch), and some allow patients to view feedback from the actigraph recording itself (which may be useful in monitoring other behavioral markers along with sleep). The device selected should meet the needs of the specific patient group.

Additional Functions and Features

Some models allow for the collection of adjunctive data. Since each of these parameters and features will impact battery life and memory consumption, the user manual that accompanies the device should be reviewed to identify the maximum recording duration given a particular set of parameters. Many models have an event marker button that can be useful in editing the data (e.g., for bedtime, time out of bed in the morning, times the device was removed). Subjective data such as ratings of fatigue or sleepiness can be collected with some models. Light sensors are often available, and light data (e.g., sunrise, sunset, lights out at night) can be useful in editing the actigraph recordings as well as for determining overall light exposure. If light data recording is desired, consideration should be given to what levels of light exposure

measurement are needed, as different devices can record different wavelengths and some specify minimum and maximum light levels that can be detected.

Some devices include an actual watch face, and thus settings are available for date and time, including time zone and 24-hour clock display. Some units allow patients to have control over changing the visible time/date, or disabling the clock feature altogether. Finally most actigraphs are water-resistant and do not need to be removed for bathing (see chapter 3 for more information regarding water exposure and immersion).

Battery Options

Varieties of battery options are available. Some batteries are rechargeable, while others require routine replacement. Battery life should be considered when selecting a device because the unit should be able to record for the entire length of time during which a patient would generally be required to wear it. Some devices have a long battery life (up to several months), but need to be shipped back to the manufacturer for battery replacement. The appropriateness of each power source should be considered, given the planned use of the device.

DATA STORAGE AND MEMORY

Epoch Length

Data are collected and stored in *epochs*, which can range from 1 second to 5 minutes and vary by device. The epoch length is sometimes modifiable by the user. The longer the epoch length, the less the memory and battery life are used. However, longer epoch lengths decrease sensitivity and specificity to detect sleep and wake after sleep onset. The most validated and commonly used epoch lengths are 30 seconds and 1 minute.

The size and type of memory storage can also vary. The amount of memory should allow for a length of recording time that is sufficient for the patient's needs, at the desired epoch length. Nonvolatile memory allows for data retrieval even if the battery dies during the recording period.

Actigraph Interface With the Computer

Currently, actigraphs need to be connected to a computer to initialize and to download data, and wireless technologies are not widely available. Communication interfaces vary and require different modes of connection to the computer. Some require a docking station device or cable (e.g., USB, infrared) for connection to the computer, sometimes requiring an additional power source or battery for the docking station as well. Several devices now have connections that are Bluetooth® compatible, an attractive alternative likely to become more common over time. Consider where and how a given device needs to be initialized and data downloaded when purchasing an actigraphy system. More information on interfaces can be found in chapter 3.

SAFETY

While actigraphs are generally considered low-risk medical devices, there are some safety considerations that should be kept in mind. For example, the exterior of the actigraph that will be in direct contact with skin may contain substances which can cause irritation or to which some patients are allergic (i.e., latex or nickel). However, since an actigraph measures movement, direct contact with skin is not necessarily required; therefore the device could be worn over clothing or a cloth wristband to reduce the likelihood of skin rashes and allergic reactions. Some devices, however, use an off-wrist detection technology that does require skin exposure. There may also be specific restrictions on use that impact particular patient populations; for example, it should be determined whether the actigraph may be worn in the presence of radiation, magnetic fields, defibrillators, pacemakers, or oxygen actively in use.

SOFTWARE AND SCORING ALGORITHMS

The computer operating system used must be compatible with the actigraph software, and this may limit the use of some software systems in institutional settings. The amount of computer memory and storage space needed for the software and storage of actigraphic recording files should be appropriate for the computer system to be used; however, current computer storage parameters are typically ample for storing the relatively small actigraphy data files (typically <1 megabyte per recording for week-long recording).

The sleep-scoring algorithm employed by the device should have been validated and published in peer-reviewed articles, confirming the accuracy of the sleep/wake assessment method used by the software compared to the gold standard of PSG.

The availability of additional features for scoring or editing the files should be considered, as needed. These include the ability to:

- View a visual actigram for hand scoring
- Switch from single-day display to dual-day or multiple-day display
- Change the start and end time of the display (e.g., midnight to midnight or 9 a.m. to 9 p.m.)
- Merge separate records
- Ability to readjust epoch length, such as from 15 seconds to 1 minute
- Force scoring of wake when it is clear that the device was off-wrist and the patient was not sleeping (for example, removed to play football);
- Replace a known wake time period with a certain level of activity (e.g., daily mean, or a fixed number)
- Export epoch-by-epoch raw data
- Automatically score rest intervals and off-wrist detection algorithms

The sleep measures in the standard report output should be reviewed to insure they are acceptable (see chapter 6). Some software also allows for calculation of circadian activity rhythm parameters, so the user should determine if that feature is needed.

ADDITIONAL CONSIDERATIONS

There are many companies that provide actigraphs for clinical and research applications, and each type of device has both advantages and drawbacks. In addition to the points to consider listed above, as with any diagnostic device, the type of technical support package should be considered. The actigraph manufacturer should have a website or help line that can be contacted for troubleshooting problems with either the device or the software. Each device should have a unique serial number for tracking purposes, that is, linking the specific unit to the specific patient. This becomes especially important if it is anticipated that the patient will be monitored during several successive intervals in order to assess changes in sleep patterns over time, as the same actigraph device should be used throughout the entire monitoring period.

Each device should offer a warranty; the cost and duration of these warranties vary by manufacturer. Some companies may offer the option to return the actigraph for refurbishment or recalibration on an annual basis, which may be desirable if the actigraph will be used for a long time period. As previously stated, a critical consideration is that the device chosen and its related sleep-wake algorithms must have been validated for the specific intended clinical or research purposes (age group, related medical issues, etc.).

CONSIDERATIONS FOR RESEARCH

While there may be situations in which clinical and research needs differ (for example, research may require additional parameters that are not necessarily needed for clinical applications such as recording periods lasting >1 month), the minimum requirements discussed above are essentially the same for both applications.

CHAPTER 3

Basic Patient Instructions for Use and Auxiliary Information

INITIALIZING/PROGRAMMING ACTIGRAPHS

Prior to the start of an actigraphy recording, devices must be set up, initialized, or programmed to initiate data collection. Although every device differs in the actual process, the first step for all devices is to connect the actigraph to the computer through some type of interface (i.e., docking station: USB cable, infrared cable, Bluetooth® connection). Next, the parameters for the collection of data should be set using the software provided by the device manufacturer. Although the names and settings may differ by device, there are typical parameters that must be specified each time a device is set up for data collection.

Data Collection Start and End Times

Options typically include having data collection begin immediately or at some future time (e.g., 1 to 3 days later). The latter option is helpful in conserving battery life or memory capacity if recording will not begin immediately. Some devices also allow for a data collection endpoint to be set. Again, this can be used to conserve battery life in the event that the patient will maintain possession of the device long after the conclusion of the recording (e.g., patient cannot return for follow-up visit until several weeks after a 2-week recording).

Ambient Light

Many devices have light sensors embedded in the actigraph itself, allowing for the collection of ambient light data. As mentioned previously, this can provide useful information for the scoring of actigraphy studies as change in light levels can be used to corroborate sleep diary-documented bedtimes and rise times. However, keep in mind, as mentioned above, that the use of the light sensor will decrease available memory and battery life, which may result in fewer recording days.

Rating Scale Capabilities

Some devices allow patients to provide a numeric rating for a predetermined clinical or research question to be answered in real time (e.g., "How much pain are you having right now?" or, "How sleepy do you feel?").

PATIENT INSTRUCTIONS FOR WEARING AND USING ACTIGRAPH DEVICES

Patient Instructions

It is essential to provide clear written and verbal instructions for the wearing and use of actigraph devices (see sample patient instructions in Appendix A). Individuals should be informed that the actigraph records movement, which is measured by an accelerometer similar to the accelerometer incorporated into many smart phones and personal fitness tracking devices. (Note: As delineated in chapter 2, "Technical Specifications," we only recommend the use of actigraphs that have been established as valid and reliable tools for assessing sleep parameters. Much less is known about the validity of smart phone applications, or apps, that purport to record sleep/wake patterns. At the time of this writing, there is no evidence to support their validity for measuring sleep.) Showing patients an example of an actigram (Figure 1) will help them to understand the data that will (and will not) be collected. This example is also useful to clarify the importance of when to use an event marker and why it is critical to fill out the actigraphy log (both described below) in order to improve the accuracy of the results.

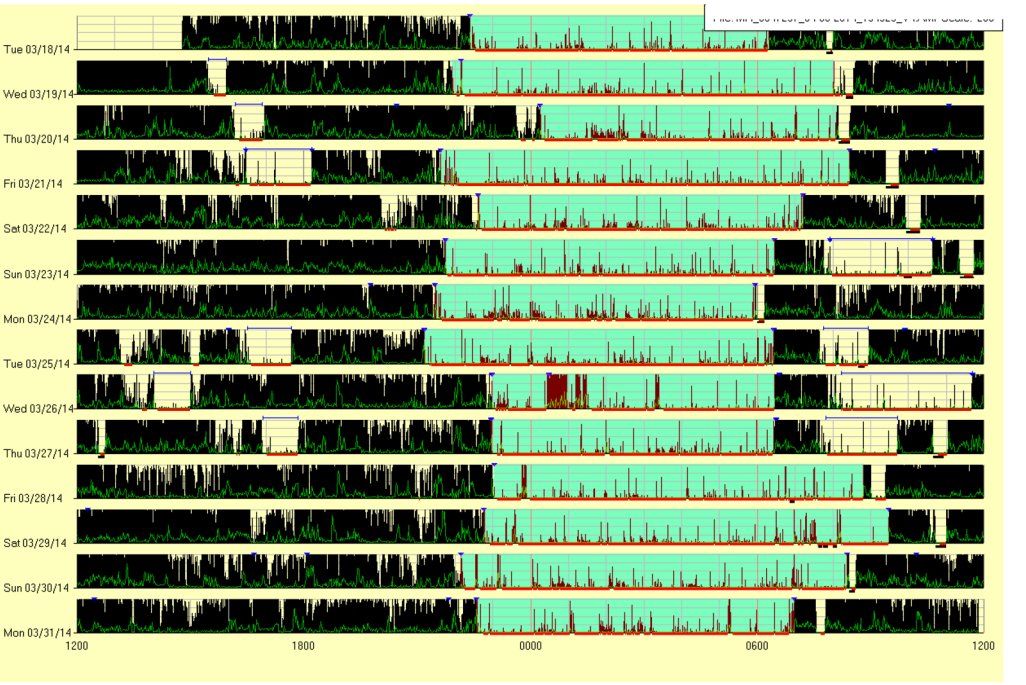

FIGURE 1 This graph represents the patient's sleep during the study. The dates are on the left and the time is across the bottom, starting at noon, with midnight in the middle. The black sections are when the watch thought the patient was awake. The underlined sections are when the watch thought the patient was asleep. Shaded is the sleep period per actigraphy log. The event marker is the triangle at the top of the row. (Color figure available online.)

Device Placement and Bands

Placement of the actigraph is an important consideration. Most devices are designed to be worn on the wrist. While the majority of studies have reported the validity of actigraph devices worn on the nondominant wrist to measure sleep-wake patterns, it has not been clearly determined whether wearing the device on the nondominant wrist yields more valid data than wearing it on the dominant wrist. While a few studies have recently examined the use of trunk or arm placement for wake and sleep in adults, this evidence remains limited. Thus, in adults, the nondominant wrist remains the best-validated placement of the device. In some patient populations with limited mobility (e.g., nursing home residents), however, the device may be placed on the dominant wrist so more movement can be captured.

In contrast, in infants and toddlers the common practice is to attach the actigraph to the ankle rather than the wrist, in order to limit the child's engagement with the device and promote safety. Most algorithms for these younger age groups have been based on ankle placement. There are also actigraph devices that have been designed specifically to be worn on the ankle to measure periodic limb movements in sleep in adults.

The actigraph should fit snugly around the wrist. It should not be so tight as to be uncomfortable, but it should not be so loose that it moves freely around the wrist. For individuals who have concerns about wearing the device against their skin, a lightweight wristband can be placed under the device (after confirming that an off-wrist detection feature will not erroneously indicate that the device is not being worn), or the actigraph can be placed on top of the sleeve. While this may impact readings for an off-wrist sensor, it will increase adherence to wearing the device while minimizing any issues related to skin sensitivities.

Most actigraph devices come with a watchband that allows individuals to remove the device as desired. When a device is returned, these bands (as well as the device) should be thoroughly cleaned and disinfected prior to giving the device to another individual. Single-use disposable bands resembling hospital bracelets can also be used. Since these bands must be cut off, it will be apparent if the device has been removed during the recording; thus these types of bands are particularly useful if there are concerns about the individual removing the device and either forgetting to put it back on or losing it. The disadvantage of these types of bands, however, is that they limit the individual's ability to remove the device for bathing, showering, and swimming, or if the individual will be engaging in an activity or is likely to be in an environment in which the device is likely to get damaged.

If a device does not have a watch feature, and an individual prefers to wear his or her own watch, the participant's wristwatch can either be worn next to the actigraph on the same wrist, or the participant may transfer the wristwatch to the dominant wrist. While ideally the actigraph is applied to the participant's wrist by the clinician or researcher, this is not always possible (e.g., if the device is sent to participants by mail). In that case, detailed written instructions should be provided (supplemented by telephone instructions if possible). A graphic or photograph demonstrating proper placement can also be helpful.

Infants and children less than three years old and special populations. When working with children, there are two additional considerations for actigraph placement. First, as mentioned above, for infants and young children (under the age of 3 years), placement of the actigraph on the ankle has been well-validated and is preferred over wrist placement. Second, children with autism, sensory issues, or other neurodevelopmental disorders often will not tolerate the wrist placement of an actigraph device, and it can be placed on the ankle in these children as well. A pilot study has shown that placing the actigraph in a special pocket on the sleeve of a shirt is also a valid way to estimate sleep-wake patterns in pediatric patients.[14] Although not as accurate as nondominant wrist placement, this alternative placement allows for data collection in individuals that would likely not otherwise tolerate this procedure.

Recording Length and Removing Devices During Study

The number of days and nights that the actigraph will be worn will vary. According to CPT® code 95803, a minimum of 72 hours of recording is necessary to bill for actigraphy testing as a stand-alone service.[9] Clinically however, 7 to 14 days of recording are more likely to provide adequate information about a patient's sleep/wake patterns, as capturing both weekday and weekend sleep can help inform the clinical picture. To assess differences between weekday and weekend sleep patterns (essential for adolescents and others with variable sleep schedules), a 14-day recording that captures two weekends is preferred.[15]

Individuals are typically instructed to wear the actigraph 24 hours per day for the entire assessment period, as continuous activity monitoring can help to place nocturnal movement data in context, and assist with interpretation of the findings. Even if nocturnal sleep is the main variable of interest, information about daytime napping behavior is often very helpful in rounding out the clinical picture and pinpointing problematic sleep patterns. A common situation, for example, involves a patient who dozes frequently during the day while presenting with sleep-onset insomnia. Without the daytime napping information, this type of clinical presentation could be misinterpreted. Furthermore, if actigraphy is being conducted to estimate circadian activity rhythms rather than just sleep, it is all the more important to keep the device on for as much of each 24-hour period as possible.

However, this raises the important question of whether the actigraph should be removed when bathing or swimming, or engaging in other activities that would expose the actigraph to water or could potentially damage the device. Individuals should be informed whether the device they will be wearing is water-resistant, waterproof, or neither (see discussion in chapter 2). Briefly, waterproof devices may be kept on at all times including when swimming. Water-resistant devices need to be removed if submerged under water or exposed to moderate amounts of water. Devices that are neither water-resistant nor waterproof are to be removed in any situation in which water is involved. It must be emphasized to the patient that the actigraph should be replaced on the wrist as soon as the water-related activity is over. In addition, the time the device was removed and replaced on the wrist should be noted in the actigraphy log, along with any comments regarding what the patient was doing during this time (for example, swimming, which would suggest that the patient was awake during that time period and thus this interval should be manually scored as wake if the algorithm inappropriately scored this interval as sleep; see chapter 3).

Another important point that should be conveyed to patients is that if an actigraph is removed, it should be reattached to the same wrist. In other words, an actigraph that was placed on the nondominant wrist should not be transferred or reattached on the dominant wrist and vice versa. Switching wrists during the assessment period may adversely impact data collection and interpretation, as activity levels may differ by wrist.

For children and adolescents, concerns related to actigraph devices being lost or damaged at school, on the playground, and so forth need to be considered. A discussion with families about this possibility is essential in order to determine, for example, whether the child has physical education class or participates in sports during which the device could either be removed and placed in a locker, or might be damaged if not removed (e.g., football). In these cases, it is useful to proactively identify with the family specific behaviors that would be linked with the removal of the actigraph device before school, and the replacement of the actigraph device after school as reminders (e.g., remove device at breakfast and leave it on the kitchen table, and place the device back on the child's wrist when the child is having an after-school snack).

Use of Light Sensors

If the device being used contains a light sensor or photometer that will be activated during programming, it is important to inform individuals of this feature. They should be told that light exposure is an important synchronizer of sleep/wake patterns, that the actigraph will be recording the levels of light in their environment, and that they should be mindful that their

clothing does not cover the actigraph and thus obstruct the light sensor. Sleeves can be rolled up to prevent interference with light measurement, or in some cases, the device can be worn on top of lightweight clothing.

SUPPLEMENTAL DATA REQUIRED FOR SCORING AND INTERPRETATION

An advantage of actigraphs over self-report sleep measures is that these devices provide objective data about an individual's sleep-wake patterns. Actigraphs provide information using automated scoring by software packages on sleep intervals throughout the 24-hour day. Preliminary estimates of sleep onset time (i.e., when the individual fell asleep), sleep offset time (i.e., terminal waking in the morning), and sleep duration (i.e., time from sleep onset to sleep offset) can be analyzed without additional information such as sleep diaries. However, for individuals with atypical sleep habits or patterns, sleep onset and offset times may not be accurately detected by the scoring software. In addition, supplemental information is always required to obtain sleep onset latency and sleep efficiency data (see below), as well as to identify misclassified sleep or wake in the recording (e.g., extended motionless time such as during a movie scored as sleep). This supplemental information can be provided through sleep diaries or logs, use of concurrent ambient light measurements, event markers on the actigraph device, or the use of daily phone calls. Whenever possible, more than one source of information (e.g., actigraphy log plus event marker) is preferable, allowing for better-informed scoring and interpretation of actigraphy results.

In order to be able to calculate sleep onset latency and sleep efficiency, it is important to precisely identify the sleep period (e.g., lights off to lights on, or time person attempted to fall asleep to the time of getting up to start the day). Because "bedtime" can be interpreted in multiple ways, it is useful to have individuals identify both the time they got into bed and the time they *attempted to fall asleep*. For example, some individuals will read or watch television in bed prior to falling asleep. This time would not be counted within the sleep period (see chapter 5 on scoring and chapter 6 on interpretation for more information). Similarly, because some people spend time reading or watching television in bed in the morning, with no intention of sleeping, it can be helpful to assess the time that an individual wakes up and no longer is intending to sleep, as well as the time of getting out of bed. This is also useful for older patients who spend large amounts of time in bed or are bedridden for various reasons.

Actigraphy Log

Unlike a detailed sleep diary, the actigraphy log often includes fewer variables, depending on the clinical or study question. For example, the consensus sleep diary[16] is of great value when conducting CBT-I, but generally includes more information than what is needed for clinical or research applications of actigraphy. For that reason, even if the individual is filling out a sleep diary, an actigraphy log should also be completed if the following variables are not included in the sleep diary. The essential components for an actigraphy log are the following:

- Time the individual got into bed
- Time the individual attempted to fall asleep at night

- Time the individual woke up for the last time in the morning
- Time the individual got out of bed to start the day in the morning (no longer trying to sleep)
- Times of any daytime naps
- Times that the actigraph was removed from or replaced on the wrist
- Any unusual circumstances that might have affected sleep/wake patterns (e.g., illness, travel across time zones, novel sleeping environment, sitting still for prolonged periods of time such as during a movie)

Individuals should be encouraged to keep the actigraphy log in one specific and obvious place that will help them remember to complete the questions about daytime use each night and the questions about the night each morning (e.g., next to the bed).

For children, it is important to consider that the actigraphy log is often completed by parents. However, adolescents should be encouraged to complete their own diaries, as parents are often not involved in their sleep routines and may not be aware, for example, of the time an adolescent goes to bed at night. Similarly, a child who is 8 years or older should be encouraged to help the parent complete the actigraphy log each day, as the child may be old enough to contribute valuable information in this domain. This is particularly important in regard to reporting prolonged sleep onset latency or nighttime awakenings of which the parent may not be aware.

Event Marker

Some actigraphy devices include an event marker button, which the wearer is instructed to press to note a specific event. While the event marker should not be viewed as a substitute for an actigraphy log, it can be used to complement the log or to gather data about events such as device removals. Again, depending on the clinical question, individuals may be encouraged to press the event marker at certain times, including:

- Time attempted to fall asleep at night
- During any nighttime awakenings
- Time awakened in the morning to start the day
- At the start or end of naps
- When the actigraph is removed and replaced

It is important to educate individuals about how to press the event marker (some models have a screen that shows whether the marker was properly pressed) and to explain that the event markers do not start or stop data collection; instead, pressing the event marker provides a time stamp on the recording that assists with the scoring and interpretation of the collected data (Note: Showing the patient a picture of an example actigram with event markers is helpful at this point; see Figure 1). Individuals should also be instructed not to press the event marker at times other than those specified. For example, some individuals may forget to press the event marker when they wake in the morning, and will then press it 3 hours later, believing that it is important for data collection. This can actually make interpretation of the event markers more challenging.

Daily Phone Calls

Although phone contact (or text messaging) may be cumbersome in clinical practice and thus is more often employed for research purposes, asking individuals to leave a voicemail (or text) at a designated number regarding the time they go to bed and wake up in the morning can provide valuable diary information. Not only does this provide regular information regarding the individual's adherence to the study protocol, but it also provides a time-stamped record of bedtime and wake time that can further inform scoring and interpretation.

Electronic Sleep Diaries and Sleep Diary Apps

The number of available sleep diaries that can be completed electronically is rapidly growing. While these are appealing for patients, they are typically not designed for use with actigraphy and thus they often do not capture all of the information needed for scoring and interpretation of actigraphy recordings (see above). As a result, these are not currently recommended unless they are specifically developed to measure the information required by actigraphy and the information can readily be made available to the technician scoring the actigraphy recording (i.e., the information can be gathered or transferred in ways compliant with the Health Insurance Portability and Accountability Act, or HIPAA).

CONSIDERATIONS FOR RESEARCH

Generally, the same guidelines regarding patient instructions and supplementary data apply for clinical and research applications. In research, however, the daily actigraphy log is often combined with a sleep diary completed by participants. Researchers may also wish to document specific activities of interest within the actigraphy log (e.g., meal times) and additional variables can be added as indicated by the research hypotheses to be tested.

CHAPTER 4

Identification of Invalid or Missing Data Periods and Preliminary Editing

To maximize the accuracy and validity of actigraphy recordings, specific steps are required for data cleaning by the individual scoring the record prior to interpretation. Immediately after the device is retrieved from the patient, the recording should be uploaded and reviewed. This process is required whether or not the software includes automatic scoring and rest-period detection. The actigraph log, as well as any other adjunctive data (e.g., event markers) should be used to assist the editing process. The main purpose of the initial review is to ascertain whether there are technical problems with the device or the recorded data.

Once the actigraphy log has been reviewed, the actigraphy file should be opened and data visually examined to get an overview of the record. Generally, there are two common types of issues that arise: device removals, and in pediatrics, artifacts associated with parenting (see Table 2). The following steps are recommended:

1. Omit times at the beginning and end of the recording when the device was not on the patient's wrist:
   a. Edit the start of the file: Any time period in the beginning of an actigraphic recording during which the device was not worn should be deleted (note that data are typically hidden, rather than permanently deleted in most software packages). This will happen if the actigraph is initialized to begin recording before the patient actually puts it onto his or her wrist. If there are data from unwanted day(s) or night(s) before the official start of data collection, these too should be deleted. Most systems preserve and hide deleted data so that in the event that an error is made during this process, the data can be restored. Prior to initiating this step, it is important to note the specific requirements of the software being used.
   b. Edit the end of the file: Any blank time period at the end of an actigraphic recording should similarly be deleted. This will happen at the end of the recording period if the patient continues to wear the actigraph, if the actigraph is recording while in transit to clinic, or if the actigraph is removed some time before the data are downloaded. If there are any data from unwanted days or nights at the end of the data collection period, these should also be deleted.
2. Identify missing data:

   The most common issue encountered in the review of actigraphy data are periods with no activity in which the scorer cannot determine whether the patient was asleep or awake. If the actigraph was removed, the recording would show a flat line with no activity (i.e., activity values are at 0). During these time periods, the data typically need to be "deleted" from the analysis manually so they are not included as time asleep.

TABLE 2
Considerations for the Initial Data Review

Type	*Definition*
Device removal	When the actigraph is removed, the actigraphy log will help determine if the patient was awake during this time period (e.g., if patient reports swimming then it can be assumed he or she was awake and the scorer can manually score recording to reflect wakefulness rather than sleep).
Parenting artifact	For pediatrics, any part of the actigraphic recording with involuntary activity caused by sleeping on a rocking crib, or being held by parents.
Abnormal data patterns/artifacts	1. Continuous activity during nighttime and no sleep could be scored (suspect device malfunction) 2. Unreasonably high levels of activity and/or light (if available), even during nighttime (suspect device malfunction) 3. Unreasonably low levels of activity during daytime, when the wearer is most active (suspect device malfunction)

These periods should be compared to the actigraphy log (or event markers), and when an actigraph removal is noted, the editor should delete the activity data.

3. Note abnormal or unusual movements in the recording:

   If an actigraphic recording shows abnormal patterns of activity for any part of the record, it may indicate that the actigraph has malfunctioned and that part of the recording should not be used. In some instances, parents interacting with sleeping children can lead to the appearance of wakefulness during sleep. This may occur when the parent is rocking the child while the child is asleep or if the child naps in the car. In this case, an actigraphy log or event marker can be used to document this activity so the scorer can accurately identify movement artifacts. Documented times can be used as a guide.

CONSIDERATIONS FOR RESEARCH

A common issue in research is that recording start and end times may need to be synchronized. In such cases, a universal start time can be set for all participants. This may mean that the device start time may be before, during, or after the participant starts wearing the device. The instructions above should be followed to omit any erroneous data.

CHAPTER 5

Scoring Nighttime Sleep/Wake and Considerations for Daytime Naps

Once the actigraphy recording is reviewed and edited, sleep scoring can begin. In some systems, sleep is automatically scored when the file is opened. In other software packages, the user must manually score the data by selecting specific algorithms and settings, and then activating the analysis manually. It is also possible to manually score sleep and wake on an epoch-by-epoch basis in most software programs.

SCORING SLEEP AND WAKE

Algorithm and Parameter Selection

If different sleep-scoring algorithms (modes) are available, the appropriate one should be designated first (see chapter 2 for an explanation of the different acquisition and display modes). In some software packages, the same sleep scoring algorithm can be used for difference modes of activity collection. Some actigraphy software packages also provide a variety of scoring algorithms for adult and pediatric applications. Check the literature and relevant information to make sure that an appropriate algorithm, validated for the specific device and population to be studied, is selected and used.

Sleep analysis parameters then need to be chosen, if applicable. Typically, users will employ the default settings in the scoring software; however, at times, adjustments must be made. These parameters may include activity thresholds for sleep or wake, sleep onset and offset times, the definition of long sleep or wake episodes, and so forth. These settings need to be confirmed each time the software is used, as some packages revert to default settings each time the software is activated.

Major Sleep Period

For most patients, the key variables of interest will be sleep/wake during the major sleep period at night. A key step, then, is to accurately determine when that period of time begins and ends. This period is typically defined as the window of time spent in bed between the bedtime (beginning time) and rising time (end time) as noted on the actigraphy log and with the event marker. In some cases, these will not be available, and the scorer will need to rely instead on information within the activity data itself to estimate.

Many software packages automatically mark the major sleep period as a "rest" or "down" interval. While these may be fairly close approximations to the major sleep period in normal sleepers, in many patient groups with sleep disorders, the accuracy of these time windows is less certain and should not be considered as more accurate than the actigraphy log. In some cases, the beginning and end of the major sleep period will be so ambiguous that the recording for that specific night cannot be used; however, in some cases, the scorer can use the following guidelines to estimate the sleep window:

1. Bedtime is reflected as a sharp decrease in activity. This decrease may not be as pronounced if an individual is inactive for an extended period before getting into bed (e.g., elderly adults with limited mobility). In such instances, there may actually be a spike of activity as the individual transitions into bed (e.g., in older sedentary patients with low activity levels). The bedtime may also appear as a sharp decline in light levels (if the device has an integrated light sensor) when the patient turns off the lights or places the arm wearing the actigraph under the bedcovers.
2. Rise time is reflected as a sharp increase in activity, sometimes accompanied by an increase in light levels if rise time occurred before sunrise.

When determining the beginning time and end time, the following situations should be taken into consideration, if applicable:

1. The documented times may not be accurate, due to wearers' memory bias, or the time differences between the clock used by the wearer and the time that the actigraph reads internally. Efforts to increase the patient's investment in accurately maintaining the actigraphy log will reduce the risk of recall bias.
2. The wearer may go to bed late and rise late on weekends and holidays or may do some shift work. These variations make the sleep periods difficult to ascertain on some nights, particularly if the presleep routine is different.

3. The actigraph devices typically do not adjust to changes in time zones or to Daylight Saving Time transitions. This results in a systematic mismatch between the actigraphy log and the device times. The scorer should adjust accordingly.

Major Sleep Period Interval Placement

The time period between the beginning time and the end time should then be set as the in-bed time interval. This may also be referred to as the "rest" or "down" interval by some actigraph manufacturers.

Major Sleep Period Intervals and Editing

In order to avoid incorrect estimation of sleep/wake parameters, any incomplete in-bed intervals (see below for definition) should be removed from the summary of the data using the following rules, which are based on expert consensus:

1. In some instances, the device may be set to begin recording after the patient has gone to bed for the night. For the first major sleep period interval, if data collection starts 1 hour or less after the habitual or documented bedtime, this can be used as the first in-bed interval; if data collection starts more than 1 hour after the habitual or documented bedtime (i.e., an incomplete in-bed interval), this incomplete in-bed interval should be omitted from the summary analysis.
2. For the last in-bed interval, if the actigraph is removed, or stopped recording for any reason 1 hour or less before the habitual or documented rising time, set it as the last in-bed interval; if the actigraph is removed, or stopped recording for any reason more than 1 hour before the habitual or documented rising time (i.e., an incomplete in-bed interval), this incomplete in-bed interval should be omitted.
3. If the time of an artifact or device removal, or the total time of all artifacts or device removals, lasts 1 hour or longer within 1 in-bed interval, this interval should be omitted.

Sleep/Wake Data Review

After all in-bed intervals are correctly set and all removals are appropriately edited, review the software-generated sleep/wake data to assure that all needed major sleep period intervals are included, and all incomplete major sleep period intervals (as defined above) are excluded.

SCORING NAPS AND DAYTIME SLEEP

Information about sleep outside of the major sleep period can be clinically informative, and some software packages have the capability to examine data on napping and daytime sleeping. It is important to consider, however, that the sleep scoring algorithms validated for nighttime sleep estimation are not as well validated for scoring of daytime sleeping and naps. The following methods are recommended to estimate napping if this is relevant to the clinical presentation.

Recording Naps on the Actigraphy Log

The wearer should be directed to document any naps and any actigraph removals during all out-of-bed times (intervals) by marking them on the actigraphy log and/or event marker, particularly if daytime napping or inadvertent dozing is suspected. This will typically be sufficient to capture intentional naps during the recording period.

Out-of-Bed Interval Placement

A time period that lies between two major sleep period intervals, or before the first or after the last major sleep period, is an out-of-bed interval. This may also be referred to as the "active" or "up" interval by some actigraph manufacturers. In some cases, software will automatically generate statistics for the periods of time outside the major sleep period. In other cases, these periods will need to be demarcated manually, following the same procedures as those used to identify the major sleep period at night. These out-of-bed interval guidelines are particularly relevant for scoring naps.

Out-of-Bed Interval Editing

For the time period before the first in-bed interval, if data collection started within 3 hours after the previous habitual or documented rising time, set that time period as the first out-of-bed interval; if data collection started 3 hours or more after the previous habitual or documented rising time (i.e., an incomplete out-of-bed time period), delete that incomplete time period to increase the likelihood that all possible naps will be counted during a day.

For the time period after the last in-bed interval, if the actigraph is removed, or stopped recording for any reason within about 3 hours (note that there are no hard and fast rules about this time frame as this has not been validated) before the next habitual or documented bedtime, set that time period as the last out-of-bed interval; if the actigraph is removed, or stopped recording for any reason 3 hours or more before the next habitual or documented bedtime (i.e., an incomplete out-of-bed time period), delete that incomplete time period to ensure all possible naps will be counted during a day.

If the time of an artifact or a device removal, or the total time of all artifacts or device removals, lasts 3 hours or longer within 1 out-of-bed interval, this interval should be omitted from the nap analysis.

Nap Scoring

There are several ways to score napping. If the nap scoring function is provided by the software, use the following steps to score napping:

1. Confirm or change parameters for nap analysis, such as nap onset and offset times and the minimum and maximum length limits of a nap, if desired.
2. Activate the nap analysis function.
3. If the out-of-bed intervals are correctly set, the nap data will be automatically calculated.

4. Review the nap data, making sure all needed out-of-bed intervals are included and all incomplete out-of-bed intervals are excluded.

If nap information is available on the actigraphy log, it may also be used to score napping by employing the following steps:

1. Set the reported nap time period(s) based on reported nap start and end times.
2. Make sure only needed nap intervals are set.
3. Activate the software to calculate nap data, like calculating sleep data for in-bed intervals.
4. Sleep/wake analysis parameters may need to be changed to obtain appropriate nap data.
5. Sometimes the documented nap time may not be accurate, due to wearers' memory bias, or the time differences between the clock used by the wearer and the time that the actigraph reads internally. If this is the situation, adjust the nap start and end times by referring to activity levels or event markers, if available.

If a nap analysis function is not available, or no information is available about documented naps (diaries, event markers), the software-scored sleep/wake data during out-of-bed intervals could be used to estimate napping. The sleep/wake scoring parameters may need to be adjusted for nap analysis.

CONSIDERATIONS FOR RESEARCH

Exporting Actigraphy Data

Scored sleep/wake data may also be exported for research purposes or statistical analysis of aggregated data. Variables of interest should be chosen first and then exported into an appropriate data file format. The scored epoch-by-epoch activity, sleep/wake, light (if available) and interval data may also be exported and analyzed by using other statistical tools, such as SAS®, Stata® or SPSS®.

Scored nap data may also be exported for research purposes. In this case, the needed variables should be chosen first, and then exported into an appropriate format. The scored epoch-by-epoch activity, nap, light (if available), and interval data may also be exported and analyzed by using other statistical tools.

CHAPTER 6

Reports and Interpretation

Reports of the results of actigraphy recordings performed for clinical reasons should follow systematic guidelines so information can be compared across time within a patient and so that comparisons can be made among groups of patients and across sites. Sample reports for adults,

children, and teenagers can be found in Appendices B–E. To optimize the integrity of the data gathered, it is recommended that the parameters and settings used for each recording be documented in the report. This chapter outlines the information required and recommended for inclusion in reports as well as information that is optional, based on the reason for conducting the actigraphy recording.

Justification or Reason Recording Was Conducted

Actigraphy reports should open with a statement about the reason the recording was conducted. A statement about the sleep complaint, why actigraphy was needed to help with diagnosis, treatment planning, and monitoring outcomes would also be useful. In many cases, this will inform the duration of the recording. For example, a longer recording time may be required for assessment of circadian rhythm sleep disorders, where it may be critical to capture both weekdays and weekends over several weeks compared to recording for an individual with insomnia for whom treatment outcomes are being assessed that may be reasonably captured with a week of recording. Similarly, older children and adolescents will need a longer recording time to capture weekday-weekend variations due to differences in school days and nonschool days.

Technical Specifications for Device and Settings

Each report should specifically state information about the device used and any proprietary software used in the scoring. In addition, the specific algorithm and settings used for sleep scoring should be noted. Specifically, the following details should be provided in each report:

1. Device manufacturer
2. Device model
3. Name and version of software used for scoring
4. Parameters and settings (including default settings within the software) for activity data collection, including epoch length and sampling rate
5. Algorithm and settings (including default settings within the software) for sleep scoring, including the threshold for sleep, if applicable (e.g., high, medium, or low sensitivity), or the name of the algorithm employed (e.g., Cole-Kripke)

Duration of Recording

The current requirements for actigraphy recordings for clinical purposes require the recording to be at least 72 hours in length. Both the intended length of the recording and the number of usable days should be included in the report. If some days cannot be analyzed, this should be documented in the report.

Settings of Recording

Documentation of the location of the patient during the recording should be included. This will typically be in the individual's home sleep environment; however, if the individual was in a hospital or institution, this should be documented as well.

Actigraphy Log

It should be noted whether the patient was asked to keep a concurrent actigraphy log, that for children and adolescents it is important to note whether the patient or the parent filled out the actigraphy log. If the actigraphy log was not returned or correctly completed, this too should be noted and any limitations associated with interpreting the results in the absence of a valid actigraphy log should be clearly stated. At times, the actigraphy data will not align with the patient's actigraphy logs. In this case, documentation about this discrepancy should be included in the report, and the clinician may wish to document the suspected reason for the discrepancy.

Comment on Technical Quality of Recording

The technical quality of the recording should be indicated. If there are no technical concerns, a statement such as, "There were no apparent technical issues with the recording. All data were used in sleep scoring and analysis" should be included within the report.

If it appears the patient removed the device (or if removals were indicated on the sleep log), this should be documented and the method used to handle device removals should be indicated. That is, if a manual scoring process was used, that process should be noted. If the automatic off-wrist detection was used, that also should be noted.

Standard Variables to Report

All actigraphy reports should include a core set of sleep variables for the duration of the recording. In some cases, it may be preferable to report the nightly (and corresponding daily) data as well. The way in which the variables were derived should be specified carefully, because software varies considerably. It is recommended that the major sleep period be identified using a patient-recorded actigraphy log or other method (e.g., use of an event marker on the device) rather than relying on automated processes available in some software packages for identifying the major sleep period (as described in chapter 5). The reason for this procedure is that, in patient populations with disrupted sleep (e.g., insomnia), individuals often spend excessive amounts of time in bed, but with considerable movement, resulting in potentially invalid automatically detected rest periods.

The following variables should be included in all actigraphy reports:

1. Recorded variables extrapolated from actigraphy log
   a. Bedtime: Clock time attempted to fall asleep based on actigraphy log or event marker
   b. Wake time: Clock time of final awakening in the morning based on actigraphy log or event marker
   c. Time in bed (TIB): Duration between reported bedtime and wake time (reported in hours or minutes). For most individuals, this will take place at night; however, for some (e.g., shift workers) it may not.
2. Actigraphy variables
   a. Sleep onset: Clock time individual fell asleep as determined by the actigraph based on the sleep-scoring algorithm or hand-scoring rules.

b. Sleep offset: Clock time individual woke up as determined by the actigraph based on the sleep-scoring algorithm or hand-scoring rules.
c. Sleep period: Duration between sleep onset and sleep offset (reported in hours or minutes).
d. Total sleep time (TST): Duration of sleep during the major sleep period (reported in hours or minutes).
e. Total wake time (TWT): Duration of wake during the major sleep period (reported in hours or minutes). The sum of TST and TWT should equal the sleep period.
f. Sleep efficiency (SE) or sleep percent: There are a number of ways in which SE is computed, and it differs across devices; however, the variable of interest is the proportion of time the patient is asleep out of the total time in bed. Sleep efficiency should technically only be calculated when reported variables are available (providing the TIB). Sleep percent, on the other hand, provides the percent of time the individual is asleep during the actigraphically scored in-bed period.

The following variables may be included, but are not required:

1. Sleep onset latency (SOL): Duration between reported bedtime and actigraphically scored sleep onset time. While most software packages will provide an estimate of SOL, this variable requires the presence of reported sleep information from the actigraphy log or event marker. In addition, SOL is less reliable than the required variables listed above for some patient populations, particularly, for patients with insomnia disorders. As a result, this variable should be reported and interpreted with caution.
2. Night waking: Devices and software packages vary widely in how awakenings are defined. Also, the correspondence between these variables and PSG is less consistent than for the required variables listed above. These variables should be reported and interpreted with caution. For research, some investigators use a predetermined number of minutes of wake (e.g., 5 minutes) preceded and followed by predetermined number of minutes of sleep (e.g., 15 minutes). The definition used should be included in the final report.
3. Night waking frequency: number of night wakings; Fragmentation Index.
4. Night waking duration: sum or average duration of night wakings.
5. 24-hour sleep duration: amount of sleep per 24-hour period (reported in hours or minutes). This may be useful in studies of younger children where napping is age-appropriate.
6. Naps (frequency and/or duration): Scoring rules similar to night waking are required to define naps (i.e., predetermined number of minutes asleep preceded and followed by predetermined number of minutes of wake). Nap frequency and nap duration can then be defined, based on these rules. One key advantage of wrist actigraphy is that, because the devices can be worn for 24 hours, information is available about activity patterns during the daytime as well as the nighttime. In some cases, it may be relevant to report the total sleep time, percent time asleep, or other parameters separately for the period of time outside of the major sleep period.
7. Variability across days: Indices of the variability of the sleep parameters may be informative, and in some cases, it may be important to separately report types of days such as weekdays and weekends, school days and nonschool days, to inform interpretation of the findings. This may be particularly relevant in establishing the diagnosis of a circadian

rhythm sleep disorder, where a phase shift is not obvious on days when the sleep schedule is imposed on the patient (e.g., school days) compared to days when the patient is free to choose his or her own sleep schedule (e.g., weekends).

8. Circadian variables: Some devices and software packages provide information on the circadian (i.e., 24-hour) patterns of activity, independent of the sleep/wake scoring. These parameters typically include the rhythm acrophase (timing of activity rhythm peak), amplitude (height of the activity rhythm peak), mesor (midpoint of the activity rhythm from peak to trough), and F-statistic (a measure of robustness of the rhythm). Some devices and software packages provide other variables, which can be reported as well. Statistical software packages can be used to implement algorithms to compute these parameters; for example, an SAS© program is available for research data analysis.[17]

Report Summary and Interpretation and Clinical Recommendations

The report summary should include details of the recording that are relevant for the referral question and any additional information that would inform treatment planning. When actigraphy is used to evaluate response to treatment, the outcome of treatment should be included. For example, the change in sleep efficiency with insomnia treatment, or the shift in the sleep schedule after treatment of a circadian rhythm sleep disorder (CRSD), should be reported.

When the actigraphy recording does not provide sufficient detail to clarify or in some cases establish a diagnosis or to evaluate treatment outcomes, the report should include a recommendation for additional diagnostic testing (e.g., extended actigraphy, laboratory PSG).

Limitations of the actigraphy recording should also be noted when appropriate. For example, if the study was ordered due to complaints of daytime sleepiness, it should be stated that actigraphy is not a measure of daytime sleepiness per se. However, the findings from the study suggest that daytime sleepiness may be a result of a certain observed sleep pattern.

Considerations for Research

For research purposes, variables beyond those listed above are often required and the data may be needed in the original (rather than aggregated) form. As a result, a summary clinic report often is not needed. Rather than a per-patient report, it is recommended that each study use a set protocol for generating the variable summary, and this document should be included as part of the standard operating procedures or standard operating procedures (SOPs) for each study.

CHAPTER 7

The Future of Wrist Actigraphy

Actigraphy is an evolving technology, and the clinical application of this technology is still in its infancy. As the digital world moves quickly forward, the types of actigraphs and user interfaces

available, as well as the varied applications for actigraph devices, are also changing. The past decade has seen the emergence of mobile phone applications and activity monitors marketed directly to consumers that emulate actigraphy and allow individuals to monitor their own sleep and activity levels. While these are appealing because of low cost and the user-friendly interfaces, they first need to be validated against gold-standard methods before implementation into clinical or research practice. Unfortunately, the limited available studies suggest poor correspondence between these consumer-ready devices and those that have been validated by rigorous research.

Actigraphy was traditionally used for scoring of sleep and wakefulness alone. It is now also being used more frequently for the measurement of circadian activity rhythms, and some manufacturers have built automated algorithms into their software to make this an option for clinicians working with patients who have circadian rhythm sleep disorders. For researchers, exported raw data from actigraphy can be modeled using other software (see Marler et al.,[17] for example).

In the meantime, the use of actigraphs in clinical practice is growing as more clinicians understand the benefits of long-term recordings of sleep/wake patterns in place of (or in addition to) the one-night snapshot offered by laboratory PSG. For sleep clinicians, actigraphy can provide useful information about the patient's sleep over a series of nights. Actigraphy also supplies information about change in sleep over time—in the patient's home sleep environment—and can inform clinical decision making. In research settings, standardized processes for the use of actigraphy will enhance reliability across studies and lead to easier comparisons across descriptive studies and intervention trials.

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APPENDIX A

Sleep Watch Instructions and Care

As part of your clinic evaluation, you are being asked to wear a special watch. This watch can tell us about when you are asleep and when you are awake. Please wear the watch on the wrist that you don't write with (so if you are right-handed, wear the watch on your left wrist) Here are other some important things for you to know.

THE SLEEP WATCH IS NOT A TOY. PLEASE BE *VERY CAREFUL* WITH IT!

- If you are going someplace where the watch might get lost or damaged, please leave the watch at home.
- Do not try and take the sleep watch apart, as this will ruin it and we won't be able to use it again.

- These watches cost a lot of money to replace (more than if you bought two Apple iPads), so again, please be careful!

The sleep watch is water resistant, but not waterproof.

- This means it is okay if the watch gets wet, but if you are showering, bathing, or swimming, you should take the watch off (but don't forget to put it back on after!).

THERE ARE TWO BUTTONS ON THE SLEEP WATCH

EVENT: You should press the event marker once at the following times:

1. When you first try to fall asleep at bedtime (after you turn the light out)
2. When you wake up during the night (if you wake up during the night)
3. When you wake up in the morning to start your day
4. When you try to nap (if you take a nap)

When you press the Event button, you should briefly see an E on the screen.
MODE: If you press this button, it will display the date (dat) as MMYY (731 for July 31).
Problems?!? Please call XXX-XXX-XXXX right away!!

APPENDIX B

Sample Adult Actigraph Report

Patient Name: Jane Doe **DOB: 06/22/1971**
MR#: 12345678 **DOS: 03/18/2014–04/01/2014**
Report Interpretation: 04/11/14

Jane Doe is a 42-year-old woman with a history of excessive daytime sleepiness. An actigraphy study was ordered to evaluate Ms. Doe's sleep patterns in her home environment, including sleep onset time, sleep onset latency, night waking frequency and duration, sleep offset time, and sleep efficiency. Ms. Doe was asked to wear an Ambulatory-Monitoring Sleepwatch actigraph for two weeks on her nondominant wrist and keep a concurrent sleep diary. The data were collected in 1-minute epochs, and scored with the Action-W 2.7 software using the Cole-Kripke algorithm. There were no apparent technical issues with the recording. All data were used in sleep scoring and analysis. This report contains an overall summary as well as an actigram, which provides a picture of the full actigraphy study.

SUMMARY OF OVERALL SLEEP PATTERNS

Ms. Doe pressed a button on her watch each night when she attempted to fall asleep, and these times matched her reported sleep attempt time on the daily diary. Her average reported bedtime was 10:25 p.m. Actigraphy found a sleep onset time of 10:39 p.m. Ms. Doe reported an average wake time of 7:24 a.m., with actigraphy showing his average wake time to be 7:21 a.m.

Ms. Doe's average sleep onset latency was within normal limits at 14.1 minutes, with a sleep onset latency under 15 minutes on 9 out of 14 nights, suggesting a relatively rapid sleep onset at bedtime most nights.

Overall, Ms. Doe had an average sleep opportunity of 9.0 hours, with her sleeping an average of 8.1 hours. Ms. Doe's sleep efficiency (actigraphy time sleeping divided by reported time in bed) was normal at 90.6%. On only 1 out of 14 nights was her sleep efficiency low (77%), and according to the diary, this was a night where she was up multiple times to care for a sick child.

Ms. Doe averaged 0.4 wakings per night (>10 minutes), with a range of 0 to 3 wakings per night. It is notable that on 10/14 nights Ms. Doe had no prolonged night wakings lasting more than 10 minutes.

Weekday Versus Weekend Sleep

Ms. Doe's bedtime was slightly later on weekends than weekdays by report (27 minutes), with actigraphy showing a slightly later weekend sleep onset time (10:25 p.m. vs. 11:03 p.m.) weekdays and weekends. Notably wake time was 95 minutes later both by report and actigraphy on weekends compared to weekdays. Average total sleep time was 58 minutes longer on weekends.

Daytime Naps

Actigraphy identified 10 naps during this study on 7 individual days (with more than one nap occurring on 3 days). On the sleep diary, Ms. Doe identified that for three of these naps she was sitting quietly with little movement. However, the duration of these three periods and level of activity would suggest that she did indeed fall asleep during these periods. The naps ranged in duration from 20 minutes to 3.4 hours, with an average of 83.8 minutes.

SUMMARY AND RECOMMENDATIONS

Ms. Doe is a 42-year-old woman with a history of excessive daytime sleepiness. Actigraphy per se is not a measure of daytime sleepiness; however, this study confirmed significant daytime sleepiness, with frequent naps occurring despite an adequate sleep opportunity, an appropriate nighttime sleep duration, and a lack of prolonged nighttime awakenings. Further evaluation with polysomnography and multiple sleep latency testing may be indicated to clarify the cause and severity of her daytime sleepiness.

APPENDIX C

Sample Adult Actigraph Report

Patient Name: Sarah Brown **DOB: 03/22/1990**
MR#: 0113355 **DOS: 08/18/2014–08/28/2014**
Report Interpretation: 09/02/2014

Sarah Brown is a 24-year-old woman with an irregular sleep schedule and daytime sleepiness. An actigraphy study was ordered to evaluate Sarah's sleep patterns in her home environment, including sleep onset time, sleep onset latency, night waking frequency and duration, sleep offset time, and sleep efficiency. Sarah was asked to wear an Ambulatory-Monitoring Sleepwatch actigraph for 10 nights on her nondominant wrist and keep a concurrent sleep diary. The data were collected in 1-minute epochs, and scored with the Action-W 2.7 software using the Cole-Kripke algorithm. There were no apparent technical issues with the recording. All data were used in sleep scoring and analysis. This report contains an overall summary as well as an actigram, which provides a picture of the full actigraphy study.

SUMMARY OF OVERALL SLEEP PATTERNS

Sarah pressed a button on her watch each night when she attempted to fall asleep, and these times matched her reported sleep attempt time on the daily diary. Her average reported bedtime was 4:55 a.m. (range 3:10 a.m. to 7:25 a.m.). Actigraphy found a sleep onset time of 5:35 a.m. (range 3:54 a.m. to 7:41 a.m.). Sarah reported an average wake time of 1:19 p.m. (range 8:45 a.m. to 4:27 p.m.), with actigraphy showing her average wake time to be 1:13 p.m. (8:42 a.m. to 4:12 p.m.).

Sarah's average sleep onset latency was within normal limits at 15 minutes, with a sleep onset latency under 30 minutes on 9/10 nights (the other night was 31 minutes), suggesting a relatively rapid sleep onset at bedtime. Notably on her sleep diary, Sarah reported an average sleep onset latency of 36 minutes (range 15 to 75 minutes).

Overall Sarah had an average sleep opportunity of 8.4 hours (range 5.6 to 10.9 hours), with her sleeping an average of 7.2 hours (range 3.6 to 10.4 hours). Sarah's average sleep efficiency (actigraphy time sleeping divided by reported time in bed) was normal at 86% (above 80% on 9/10 nights).

Once asleep, Sarah reported few prolonged nighttime awakenings (>10 minutes). By actigraphy Sarah averaged 0.8 wakings per night (>10 minutes, range 0–2, longest waking 46 minutes), with no prolonged wakings on 6/10 nights.

Consistently across data points, Sarah's shortest sleep duration and poorest sleep quality was a result of the one day where she had to wake early for a class, and thus attempted to fall asleep significantly earlier than usual (3:00 a.m).

Daytime Naps

Actigraphy identified 5 naps during this study on 5 individual days, consistent with the sleep

diary. The naps ranged in duration from 14 minutes to 4.8 hours, with Sarah sleeping an average of 1.6 hours.

Total Sleep Duration

When considering both naps and "nighttime" sleep duration, Sarah averaged 8.1 hours of sleep per 24 hours (range 5.8 to 11.8 hours).

SUMMARY AND RECOMMENDATIONS

Sarah Brown is a 24-year-old woman with an irregular sleep schedule and daytime sleepiness. The results of this actigraphy study are consistent with a diagnosis of delayed sleep/wake phase disorder, as she is unable to fall asleep before the early hours of the morning, but once asleep has nearly adequate sleep duration and good sleep quality. Although actigraphy is not a measure of sleepiness per se, it is likely that Sarah's daytime sleepiness is a result of being required to be awake (e.g., for early morning classes) at a time when her biological clock is wanting to be asleep.

I discussed at length with Sarah what it means to have a diagnosis of delayed sleep/wake phase disorder and different treatment approaches. Due to the need to be awake for classes that begin as early as 8:00 a.m., Sarah agreed to do a trial of chronotherapy, advancing her sleep-wake schedule around the clock. Once she achieves the desired sleep schedule, she will use melatonin (0.5 mg taken 4–5 hours before bedtime) and bright light therapy (30–60 minutes) to maintain this schedule 7 nights a week.

APPENDIX D

Sample Child Report

Patient Name: Peter Jones **DOB: 5/22/06**
MR#: 098765 **DOS: 10/3/13–10/17/13**
Report Interpretation: 10/25/13

Peter Jones is a 7-year-old boy with asthma and concerns related to insufficient sleep duration and daytime sleepiness. Peter was asked to wear an Ambulatory-Monitoring Sleepwatch actigraph on his nondominant wrist for 2 weeks to assess his sleep patterns in his home environment, including sleep onset and offset times, sleep onset latency, and the frequency and duration of night awakenings. In addition, his parents kept a daily sleep diary to identify the time he attempted to fall asleep and when he woke in the morning. The data were collected in 1-minute epochs, and scored with the Action-W 2.7 software using the Sadeh algorithm. There were no apparent technical issues with the recording. This report contains an overall summary

of 12 out of the 14 nights (he did not wear the watch on two nights). Attached is an actigram, giving a picture of the full actigraphy study.

SUMMARY OF OVERALL SLEEP PATTERNS

Peter's average bedtime (time when he attempted to fall asleep) was 8:19 p.m. Actigraphy found a sleep onset time of 8:33 p.m. Peter reported an average wake time of 6:42 a.m., with actigraphy showing his average wake time to be 6:31 a.m. Peter's average sleep onset latency was normal at 14 minutes.

Overall Peter had an average sleep opportunity of 10.4 hours, with his sleeping an average of 8.5 hours. Peter's sleep efficiency (actigraphy time sleeping divided by reported time in bed) was on the lower end of normal at 82% (normal above 80%).

Peter averaged 2.3 wakings per night (>10 minutes), with a range of 1 to 4 wakings per night. However, Peter only had one night with an awakening longer than 25 minutes, and by parent report this was because his siblings woke him early, but he did return to sleep.

Weekday Versus Weekend Sleep

Peter's reported bedtime was later on weekends than weekdays by report (21 minutes), with actigraphy also showing a later sleep onset time on weekends (8:57 p.m.) than weekdays (8:21 p.m.). Wake times by report and actigraphy were similar on weekdays and weekends. Together this resulted in approximately a 30-minute shorter sleep duration on weekends.

Activity During Sleep

Restlessness was estimated by activity level during sleep. Peter averaged 52% of the night with no activity. While only 15% of the night included moderate to high levels of activity, 33% of the night included a low level of restlessness that may contribute to his daytime sleepiness.

CLINICAL CORRELATION AND RECOMMENDATIONS

Peter Jones is a 7-year-old boy with asthma, who presents with concerns of insufficient sleep duration and daytime sleepiness. Actigraphy per se is not a measure of daytime sleepiness; however, it does provide an estimate of his sleep patterns for 2 weeks, identifying potential factors that contribute to his sleepiness. In clinic, Peter and his mother reported prolonged sleep onset latency, which was not found with this actigraphy study. In addition, mom reported concerns that Peter was awake for prolonged periods during the night, but since he did not wake her, the frequency and duration were unclear. Again, this actigraphy study did not identify issues with prolonged night awakenings.

Since Peter has needed to be awakened several times since the start of the school year, he may benefit from a slightly earlier bedtime on weekdays (e.g., 15 minutes) and a weekend bedtime more consistent with his weekday bedtime. This is especially important as Peter does

not compensate for a later bedtime on weekends with a later wake time, resulting in a loss of almost an hour of sleep each weekend.

Finally, because of his restless sleep, Peter may benefit from having his serum ferritin level checked. Ferritin below 50 ng/mL has been associated with restless sleep in children. Following iron therapy treatment, many children have improved sleep quality. Should Peter be treated for low ferritin, a repeat actigraphy study should be done approximately three months after iron therapy begins.

APPENDIX E

Sample Teen Report

Patient Name: John Smith **DOB: 9/17/2000**
MR#: 0224466 **DOS: 12/6/13–12/12/13**
Report Interpretation: 12/19/13

John is a 13-year-old boy with a history of hypersomnolence. An actigraphy study was ordered to evaluate John's sleep patterns in his home environment, including sleep onset time, sleep onset latency, night waking frequency and duration, sleep offset time, and sleep efficiency. John was asked to wear an Ambulatory-Monitoring Sleepwatch actigraph on his nondominant wrist for one week and keep a concurrent sleep diary. The data were collected in 1-minute epochs, and scored with the Action-W 2.7 software using the Sadeh algorithm. There were no apparent technical issues with the recording. All data were used in sleep scoring and analysis. This report contains an overall summary. Attached is the actigram, giving a picture of the full actigraphy study.

SUMMARY OF OVERALL SLEEP PATTERNS

John pressed a button on his watch each night when he attempted to fall asleep, giving him an average bedtime of 10:01 p.m. Actigraphy found a sleep onset time of 11:01 p.m. John reported an average wake time of 8:23 a.m., with actigraphy showing his average wake time to be 8:19 a.m.

John's average sleep onset latency was prolonged at 60 minutes. The last three nights of the study, his sleep onset latency was less than 20 minutes (normal). However, the two nights prior had significantly prolonged sleep onset latencies of 156 and 121 minutes.

John averaged 2.4 wakings per night (>10 minutes), with a range of 0 to 6 wakings per night. All of his night wakings were less than 30 minutes in duration. However, he had a significant number of briefer arousals and restless sleep, with high amplitude activity level noted for over 20% of the night.

Overall, John had an average sleep opportunity of 10.4 hours, with him sleeping an average of only 7.4 hours. John's sleep efficiency (actigraphy time sleeping divided by reported time in bed) was low at 72%.

Weekday Versus Weekend Sleep

John's bedtime was significantly later on weekends than weekdays by report (103 minutes), with actigraphy showing a later sleep onset time on weekends versus weekdays (12:50 a.m. vs. 10:17 p.m.). Wake time was approximately 2.5 hours later both by report and actigraphy on weekends compared to weekdays. Notably total sleep time was only 10 minutes longer on weekdays.

Summary

John is a 13-year-old boy with a history of hypersomnolence. This actigraphy study identified prolonged sleep onset latency, multiple night wakings, and restless sleep, resulting in a low sleep efficiency. In addition, John had significantly shorter sleep duration during the week, which also contributes to daytime somnolence. Notably, the nights with his longest sleep onset latency followed days with a much later bedtime and wake time. This would suggest that John is experiencing "social jetlag" on weekends, resulting in a circadian shift and contributing to his insufficient sleep. Actigraphy per se is not a measure of daytime sleepiness, but it is likely that the shortened total sleep time and poor sleep quality found in this study contribute to John's daytime concerns.

RECOMMENDATIONS

Based on this actigraphy study and clinical correlation, John would benefit from a consistent sleep schedule 7 nights a week, improving his sleep onset latency and sleep duration. In addition, John should have his serum ferritin level checked. Ferritin below 50 ng/mL has been associated with restless sleep in children.