Chapter 3
Screening Instruments of Sleep Disorders: Actigraphy

Peng-Chih Wang

Abstract Wrist actigraphy is based on the premise that little movement occurs during sleep, but that activity increases when awake. Wrist actigraphy has the advantages of being cost efficient and allowing the recording of sleep in the natural environment. In addition, it can record continuous behavior for 24 h a day, 7 days a week. Although actigraphy is not a replacement for electroencephalography or polysomnography, there are times when it provides clear advantages for data collection.

Actigraphy is particularly useful for studying individuals who cannot tolerate sleeping in a laboratory, for example small children and older adults. It may provide a more accurate estimate of typical sleep duration by providing an opportunity for patients to adhere more closely to their habitual sleep environments. Actigraphy is also becoming an important tool in follow-up studies, and for examining efficacy in clinical outcomes. It has some value in the assessment of sleep disorders, although it may not help in distinguishing between different sleep disorders.

Newer scoring algorithms have great accuracy in determining the variables that are most important in insomnia – that is, they have improved ability to detect wake versus sleep, sleep latency, awakenings during the night, and total sleep time. Actigraphy is superior to a subject's self-reported sleep logs, particularly in detecting brief arousals during the night. It can also be used for the evaluation and clinical diagnosis of circadian rhythm disorders. The ability to detect movement holds promise for the identification of sleep disorders characterized by frequent movements, such as periodic limb movements during sleep, sleep apnea, or rapid eye movement sleep behavior disorders.

Traditionally, the actigraphs are placed on the non-dominant hand, and the data collected is displayed on a computer and examined for activity/inactivity and analyzed for wake/sleep cycles. This chapter will review the development of

---

P.-C. Wang, Ph.D. (✉)
Department of Clinical Psychology, Fu Jen Catholic University, New Taipei City, Taiwan, R. O. C.
e-mail: drwangpc@gmail.com

R.P.-Y. Chiang and S.-C.J. Kang (eds.), *Introduction to Modern Sleep Technology*, Intelligent Systems, Control and Automation: Science and Engineering 64,
DOI 10.1007/978-94-007-5470-6_3,

actigraphy, the major areas where it can be used, tips for its successful use, and its limitations.

Keywords Actigraphy • Actiwatch • Ambulatory activity monitors

3.1 Introduction

Actigraphy, a method for estimating sleep-wake schedules by measuring activity, has been used by researchers to study sleep disturbances in a variety of populations, most frequently for the evaluation of insomnia, circadian sleep/wake disturbance and periodic limb movement disorders [7, 47]. The actigraph can collect data continuously for a prolonged period before it is downloaded onto a computer where an algorithm calculates specified sleep parameters.

The device is electrode-free and can be worn continuously 24 h a day, and for longer than 1 week. It is more sensitive than sleep diaries for documenting sleep fragmentation, and can also be used for people who cannot fill out sleep logs, such as infants and adults who cannot read or write. The actigraph is less expensive, noninvasive, and more conducive to repeated measurements in comparison to polysomnography (PSG). Moreover, studies using actigraphy avoid the "first-night effect" on the quality of sleep [40].

There are variables used in actigraphy data analysis included the following: (1) total sleep time (TST); (2) sleep efficiency (the percentage of time in bed spent sleeping, SE); (3) wake time after sleep onset (minutes awake after in-bed sleep onset where sleep onset is defined as completion of 10 continuous minutes of sleep after getting into bed, WASO); and (4) and number of nocturnal awakenings.

There is no consistency in scoring and a wide variability in the information published in studies involving actigraphy. Procedures used for sampling, data processing and analysis are not consistently reported in the literature. The most recent study of this issue is in sleep and circadian rhythms [28]. However, the scope of these parameters is limited, leaving researchers to independently make many decisions regarding procedures. Advancing the quality of information in published results will enable comparison across studies that use actigraphy, and will enhance the testing of interventions to improve activity and sleep rhythms. Therefore, one purpose of this paper is to review the literature on actigraphy in studies using adult patients, to illustrate methodological challenges related to procedures and reporting, and to make recommendations regarding instrumentation, selection of pertinent variables, sampling, and data processing and analysis.

In terms of validity issues, it is important to note that actigraphy is not a unitary methodology. Multiple vendors offer a range of actigraphs with different operating characteristics. The present variability in actigraph hardware probably exceeds the variability of contemporary polygraphs. Actigraphy vendors provide a variety of sleep-scoring software; some score sleep in a single pass, whereas others use rescoring rules. It is important to note that current data constitutes lower-bound estimates to the degree that these differences augment error variance. This variability may be reduced through standardization, thereby reducing the discrepancies between actigraphy and PSG below current levels. Some sleep-scoring software is better validated against PSG than others.

This chapter reviews three major areas in which actigraphy is used for the measurement of sleep or sleep rhythms. The first area covers the more recent papers on the technology and validity of actigraphy in insomnia. Sadeh et al. concluded that validation studies for normal subjects showed greater than 90% agreement and were very promising [38]. Actigraphy combined with analysis software using different algorithms to process data has been commercially available since the 1990s. Actigraphs differ in how they detect and record movements (e.g. two dimensions vs. three dimensions), and use different methodologies to calculate activity levels.

The second area of review looks at methodological suggestions for using actigraphy in research. From reviewing the current literature, we have found some inconsistencies in the use of the actiwatch in research. Berger and colleagues have tried to address this issue by providing standard formations for future research [5].

The third area of review is examining actigraphy studies in populations with sleep disorders. Actigraphy is being used more often in sleep disorder studies, either as an alternative to PSG, in addition to monitoring, or as a follow-up device.

3.2 History and Background

Actigraphy uses an accelerometer to quantify body movement. Over the last three decades, ambulatory activity monitors (actigraphs) have been improved so that they are precisely calibrated and can store thousands of activity measurements acquired at predetermined times, by use of software-selected amplifier and filter settings (one such monitor is the Motionlogger actigraph, made by Ambulatory Monitoring, Ardsley, New York). The size of these actigraphs has been reduced so that the smallest unit (Mini-Motionlogger) is only slightly larger than a man's wristwatch. A device called the Actillume (also distributed by Ambulatory Monitoring) has also been developed, that uses a linear accelerometer to measure the vigor of movement and provides a second channel for assessing light exposure or temperature.

Advances in computer and video-processing technology have also led to the development of motion-analysis systems that can precisely track and record the two- or three-dimensional position of an object several times per second. For example, the Research Tri-axial accelerometer (R3T; Stayhealthy Inc., Monrovia, CA) is a three dimensional accelerometer. This device was built using the original TriTrac-R3D technology. It is small ($71 \times 56 \times 28$ mm), lightweight (62.5 g), and can store data for up to 21 days [34]. It uses piezoelectric accelerometers that measures motion in three orthogonal dimensions and provides triaxial vector data in activity units [8]. One study compared the equivalence (equivalence test) and agreement (Bland and Altman method) of physical activity output data during walking and running on a treadmill and on land [50]. The equivalence test showed that output data from the treadmill versus on land were equivalent.

3.3 Advantages and Disadvantages

Although the technology for actigraphy has certainly advanced for many applications, there remains a number of advantages and disadvantages which can be listed as follows:

Advantages	Disadvantages
Recordings done in patient's natural environment.	Behavior during recordings not documented.
Easy to record for long durations.	Home recording conditions difficult to control.
Little or no adaptation effect.	Fewer channels of information available.
Less technician time required per study.	Motion artifacts mistakenly identified as wakefulness.
Fewer recording rooms needed.	Lack of standard procedure.
Lower cost.	

The procedure measures sleep in the normal home environment, which overcomes a significant clinical issue. Parasomnias that decrease in frequency when studied in the laboratory will require fewer studies to record an episode for diagnosis. From a technical perspective, the advantages can also be considerable, since this method requires fewer sleep technicians and recording room facilities.

The disadvantages are mainly technical. The number of channels is very restricted, so that a smaller number of variables can be recorded at one time. Another issue that has been repeatedly raised is the lack of standard equipment, procedures and analytic methods in the application of actigraphy which preclude comparisons and conclusions across studies [37].

3.4 Methodological Issues When Using Actigraphy in Research

Actigraphy has become a valuable research and clinical instrument to evaluate sleep, daytime activity and circadian activity rhythms in healthy individuals as well as persons with primary and comorbid insomnia. However, the procedures used for sampling, data processing and analysis are not consistently reported in the literature. The wide variability in how actigraphy is reported makes it difficult to compare findings across studies. Berger and colleagues reviewed 21 studies that used actigraphs to assess sleep and wakefulness in adult patients with cancer to highlight the differences in reporting strategies [5]. They suggested the following to overcome challenges when using actigraphy:

3.4.1 Instrumentation

A. Resources for purchasing actigraphs and interface units: all actigraphs used in a study, particularly in repeated measure designs, should be the same type, and ideally the same model.
B. Model of actigraphy (to increase validity for estimating total sleep time, consider use of event markers and /or light sensor): reports should provide the registered trademark name of the device and model and the name and location of the manufacturer.
C. Placement of the actigraph: actigraph was placed on the dominant or non-dominant arm or leg.
D. Standardized instructions should be given to participants for wearing the actigraph and completing the daily diary.

3.4.2 Selection of Pertinent Variables

A. Include the following five key sleep variables: time in bed (in minutes), total sleep time after sleep onset (in minutes), number of awakenings, minutes awake (WASO-M), and percent awake after sleep onset (WASO-P)
B. Provide clear definitions of selected variables.

3.4.3 Sampling

A. Data collection environment: Record the location, number of days, with/without sleep partner etc.
B. Duration of data collection period: at least 72 h of data collection and one-minute sampling epochs in adults are recommended [28].
C. Selection of days of the week for monitoring needs to be considered. Since weekdays and weekend activities are different, keeping the days of the week consistent or randomized at each time interval is recommended whenever feasible [5, 6].
D. Keep sleep diary for identifying analysis periods or times when the actigraph has been taken off. Habitual sleep-wake scheduling, substance exposure, daytime napping and other demographic data are collected along with sleep diary since these factors might influence the validity of actigraphic sleep measures.
E. The epoch length is important when studying sleep patterns over time: epoch lengths of up to 1 min provide sufficient data for analysis of sleep with activity counts over three to five nights [28].
F. The mode of data collection for each type of monitoring device should be considered. Examples include zero-crossing mode (ZCM; a way of counting

movements, and the primary mode of data collection for sleep estimation), time above threshold (TAT; an estimate of movement duration that is more indicative of the vigor of activity and used primarily in daytime monitoring of activity), proportional integrating measure (PIM; an estimate of movement intensity most useful for daytime activity levels and patterns), or TRI mode (ZCM/TAT/PIM).

3.4.4 Data Processing and Analysis

A. Plan for and report the name and version of the software used to analyze the data, and the algorithm used for scoring.
B. Automated scoring should not be used.
C. Make data editing rules and decisions.
D. Plan for staff training.
E. Set a minimum level of inter-rater reliability and confirm it periodically.

Many challenging issues related to procedures and reports using actigraphy have been described. Reporting salient sleep, activity, and circadian rhythm variables, whenever appropriate, will allow for comparisons among reports. Details about software programs used to generate results can lead to guidelines that will assist in comparing results from different devices.

The body of knowledge regarding objective measurement of sleep, activity, and circadian rhythms will grow when researchers plan studies that address the methodological challenges related to procedures and reporting results. Understanding relationships between subjective sleep measures and objective actigraphy measures of sleep, activity, and circadian rhythms is essential to enhance our understanding of the physical and mental health outcomes in various populations of children and adults with sleep disturbances.

3.5 Validation and Assessment of Insomnia

In the last three decades, actigraphy and PSG measures of sleep have been strongly correlated in regular sleepers and in sleepers with apnea, with the correlation coefficients ranging from .89 to .98 [9, 11, 19, 26, 30, 36]. Actigraphy can identify sleep patterns characteristic of sleep apnea and periodic leg movements, and has been used in many intervention studies in the past. However, recent publications have raised new concerns about the validity of sleep-wake scoring algorithms in certain populations or specific devices [43]. One of the most important arguments is that most of the studies listed above relied on inappropriate statistical methods, specifically correlations and comparison of means [18]. Insana and colleagues suggest using the Bland-Altman Concordance technique to measure these outcomes.

Insomnia, on the other hand, has been predominantly neglected in validation studies of actigraphy. Individual differences in movement patterns, especially among patients with insomnia, blocks the use of actigraphy. The biggest critique has been that actigraphy scores subjects who are simply still as asleep. Until 2006, only five studies had tested the ability of actigraphy to accurately score the sleep of adult populations with insomnia. The first two studies compared actigraphy and PSG on total sleep time (TST). Hauri and Wisbey stated that the mean error when comparing wrist actigraphy with PSG in insomnia was 49 min; in addition, in two of their participants (6% of cases), the error was larger than 2 h [16]. This margin of error is clearly not acceptable for most clinical research studies. Jean-Louis et al. re-analyzed these finding using the same data, but using different software. The result reduced the average difference to 25 min [21].

There have been two other studies conducted on the accuracy of actigraphy in terms of TST. Kushida et al. [25] found that TST and sleep efficiency (SE) were overestimated by actigraphy in the order of 1.0–1.8 h for TST, and 12.1–29.1%, for SE. This discrepancy was larger than the discordance of subjective estimation (TST: 0.3 h; SE: 2.5%). Vallieres and Morin [51] stated that actigraphy was more accurate than sleep diaries, and recommended its use as a complement to the latter. However, there are some limitations to the above four validation studies of actigraphy with insomnia: all had small a sample size of insomnia patients, only one of them evaluated actigraphic measures of WASO, and only one evaluated actigraphy measures of sleep-onset latency (SOL). Furthermore, none of these studies evaluated sex or age as possible confounding factors. One important study in this area was conducted by Lichstein [27]. Results of this study demonstrated successful validation of actigraphy on four measures of sleep pattern: number of awakenings, WASO, TST, and SE percentage. Validation was based on non-significant mean differences and significant correlation between actigraphy and PSG. SOL with actigraphy was not significantly different from PSG, but was weakly correlated with PSG.

Another recent study reassessed the validity of actigraphy in assessing insomnia by comparing 31 insomnia patients to 31 controls using actigraphy and PSG monitoring in their homes [39]. The authors concluded that actigraphy is a valid tool for assessing sleep in insomnia patients and normal controls studied in their home environment. They also reported that actigraphy was sensitive to variations in subjective perception of sleep quality.

Natale and colleagues stated that the lack of quantitative criteria for identifying insomnia using actigraphy represents an unresolved limit for the use of actigraphy in a clinical setting. Therefore, they conducted a study to evaluate the most efficient actigraphic parameter in the assessment of insomnia and to suggest preliminary quantitative actigraphic criteria (QAC; [31]). The results showed that all sleep parameters recorded by actigraphy significantly differentiated between the insomnia group and the normal sleeper group, except time in bed. Natale et al. also developed criteria called linear discriminate function (LDF), whose function was to identify and combine the most useful actigraphy sleep parameters to separate insomnia patients from normal sleepers. From this research, an LDF analysis showed that the most useful combination of actigraphic sleep parameters to assess insomnia was TST, SOL, and number of awakenings longer than 5 min (NA > 5), which obtained the best receiver operator characteristic (ROC) and the best balance between positive and negative predictive values compared to any single actigraphy parameter [31]. Further work on this topic is needed to examine results from different types of insomnia using larger clinical samples, such as those per formed in multicenter studies. We also suggest using a larger cohort to evaluate age effect on QAC, and identify which QAC are stable over a lifetime [32]. Additional studies should also compare QAC among different actigraphy models.

From the studies described above, it can be concluded that actigraphy provides sleep assessment with acceptable sensitivity to detect differences between sleep-disturbed and control groups. These findings suggest that actigraphy can provide useful data in the assessment of insomnia. However, we should note that the large discrepancies between the subjective data of insomnia patients and the objective data from researchers or clinicians should not automatically be attributed to inaccurate self-reporting in patients.

3.6 Clinical Research in Different Populations

3.6.1 Actigraphy Studies of Healthy Adults

Several studies involving normal individuals have used actigraphy as a measure of sleep/wake or circadian rhythms. For example, Tworoger et al. studied factors associated with actigraphic and subjective sleep quality in young women [49]. Their results showed that going to bed late, medication use, employment, increased daylight hours, longer menstrual cycle length, and higher body mass index (BMI) were associated with poorer actigraphic sleep measures. Employment, age, and perceived stress were associated with subjective sleep quality. In a study of the effects on sleep from caffeinated beverages in healthy subjects, Hindmarch [17] stated a dose-dependent negative effect (of tea/or caffeine) on TST as estimated by actigraphy [17]. In another study, researchers examined the effects of coffee consumption on the rate of melatonin secretion, as reflected by urinary excretion of 6-sulphoxymelatonin (6-SMT), and sleep quality as assessed by actigraphy [41]. The results showed that drinking regular caffeinated coffee, compared to decaffeinated coffee, caused a decrease in the total amount of sleep time and the quality of sleep, and an increase in the length of time of sleep induction. Caffeinated coffee caused a decrease in 6-SMT excretion throughout the following night. Apparently, actigraphic sleep measures offer objective sleep parameters which also reflect effects from sleep-preventing factors.

In terms of gender difference in healthy adults, Jean-Louis et al. [20] stated that women in their study slept more than men, as reported in other studies. In addition, they had better sleep quality than men as demonstrated by higher sleep efficiency, shorter sleep latency, and lower frequency of sleep/wake transitions. Another study by Jean-Louis et al. [22], analyzed actigraphy data in a large sample (n = 273) of community-dwelling residents, and the results showed significant gender differences in sleep variables estimated by wrist actigraphy.

The influence of a bed partner was reviewed in two related studies by Pankhurst and Horne [33]. Both involved the use of wrist actimetry and morning sleep logs in subjects aged 23–67 years. In the first study, 46 pairs of bed partners were monitored for 8 nights to assess the extent and concordance of their body movements, and whether the latter exhibited age and gender differences [33]. The researchers stated that participants sleeping with bed partners had a greater number of movements than subjects who slept alone, and movements decreased during the temporary absence of the usual bed partner. Reyner et al. [35] reported that sleep period time was markedly longer for women, and that most reported awakenings were < 5 min. Women reported more awakenings, more total time spent awake during the night and poorer sleep quality; all these findings were most evident in older women, who also took longer to fall asleep than any other group [35].

3.6.2 Actigraphy Studies of Children

Actigraphy has been increasingly used in children, particularly in studies involving children with behavioral or psychiatric conditions. Cortese [10] performed a meta-analysis of subjective (i.e., based on questionnaires) and objective (i.e., using PSG or actigraphy) studies comparing sleep in children with attention-deficit/hyperactivity disorder (ADHD) versus controls [10]. The authors reviewed 16 studies, providing 9 subjective and 15 objective parameters, and including a total pooled sample of 722 children with ADHD versus 638 controls. The results showed that the objective parameters – sleep onset latency (on actigraphy), the number of stage shifts/hour sleep, and the apnea-hypopnea index – were significantly higher in children with ADHD compared to controls. Children with ADHD also had significantly lower true sleep time on actigraphy [10]. These results lay the groundwork for future evidence-based guidelines on the management of sleep disturbances in children with ADHD.

Actigraphy has been used in several studies to provide a more quantitative measure of sleep disruption among traumatized children. Sadeh [36] reported that those who were physically abused had decreased sleep efficiency compared with non-abused inpatients or sexually abused children. They hypothesized that for sexually abused children, the structured and supervised sleep environment of the inpatient setting was actually perceived as safer, given that many had experienced sexual abuse in sleep-related contexts in their communities (e.g., in their bedrooms, or during the night), and they were able to sleep more soundly in this setting [36]. Glod [14] also used actigraphy to compare 15 volunteers, 19 abused children and 10 non-abused children with depression. Abused children were more active than either the non-abused children or children with depression, and were twice as active as the non-abused children. Abused children took three times longer to fall asleep and had poorer sleep efficiency compared with non-abused children, and also had longer sleep latencies than depressed children. There were no differences in total sleep time or number of nocturnal awakenings. They also found that physically abused children had more impaired sleep efficiency than those who were sexually abused. The physically abused children also trended toward having greater sleep onset latency and increased levels of nocturnal activity [13].

Finally, some studies assessed the validity of actigraphic sleep wake scoring in infants and very young children [15, 42, 43]. For example, So and colleges found that actigraphy was a valid method for monitoring sleep in infants who are younger than 6 months [43]. However, some of these studies reported problems of low sensitivity for actigraphic sleep measures in children's sleep study. In general, validity data which are derived from devices or scoring algorithms developed for adults should not be generalized to children. As for applying actigraphy in children's sleep studies, additional age-specific validation studies are mandatory [18, 29].

3.6.3 Actigraphy in Studies of Older Adults

Actigraphy is particularly useful in studies of older adult populations, both in the community and in the nursing homes. Spira [45] investigated the association between elevated symptoms of anxiety and indices of objectively measured sleep quality in a large sample of older community-dwelling women, before and after adjustment for potential confounding factors. The results showed that elevated anxiety symptoms were associated with poor sleep efficiency and greater time spent awake after sleep onset, after accounting for numerous potential confounding factors and significant depressive symptoms [45]. This result is consistent with observations from studies of younger populations. Elevated levels of anxiety have been linked to worse actigraphic sleep in children and younger adults undergoing surgery, and in premenopausal women [4, 23, 24, 45].

Fetiveit and Bjorvatn investigated the possible effect of bright-light treatment on daytime sleep and waking among nursing home dementia residents [12]. The results showed that actigraphic measurements of average nap duration and total nap duration during the day period were both significantly reduced with bright-light treatment. No significant changes were found in sleep/wake measurements (actigraphy and nursing staff) between pretreatment and baseline recordings taken 8 months before the main experiment. Alessi et al. used wrist actigraphy estimations of sleep as an outcome variable in a controlled clinical trial of physical activity in nursing home residents [2]. The results showed no significant improvement in sleep associated with improved physical function. Alessi also conducted another study which found no significant differences in nighttime sleep variables between subjects taking psychotropic medications and subjects not on these medications in a nursing home setting [1].

Generally speaking, actigraphy is increasingly being used in clinical research involving individuals of various ages, who are of normal health or with a variety of health conditions, and in a number of different settings. In the majority of these studies, actigraphy is used to measure sleep and activity rhythms that might not otherwise be available using traditional (e.g. PSG) techniques.

There is growing literature regarding the use of actigraphy with children. For example, actigraphy has been used to demonstrate differences in the sleep of abused children and those with depression or non-abused children. Actigraphy has also been used to test treatment effects of melatonin therapy in children with severe neurological disorders [14].

Finally, actigraphy has been used extensively in studies involving the elderly, particularly in the nursing home setting. These studies have demonstrated significant sleep disruption among nursing home residents, and sleep and circadian rhythm disturbances have been shown to be more severe among residents with severe dementia.

Taken as a whole, these clinical studies demonstrate increasing use of actigraphy in a variety of populations, conditions and settings. However, the majority of these studies do not report adequate details of the technical aspects of the specific actigraphic devices used. However, it seems clear from these trials that the use of actigraphy enables studies involving multiple days and nights of testing, and allows populations that might otherwise not be studied, such as patients with dementia or young children, to participate in research studies and clinical trials of sleep/wake activity and circadian rhythms.

3.6.4 Current Trends in Actigraphy Research Studies

Recently, new products have been introduced into the market. For example, SOMNOmedics of Germany released a new product called the SOMNOwatch The SOMNOwatch is available with several add-on sensors, allowing it to be used along with the actigraphy apparatus, as a PLM/RLS recorder, respiratory screener, sleep recorder, movement analyzer, long term ECG and EEG recorder. Additional fields of application include monitoring training, sport and rehabilitation, and even the detection of sleep walking. In addition, the same company also provides another multiple channel system (add-on) called SOMNOwatch PLUS. The SOMNOwatch plus respiratory option, for example, includes built-in sensors to monitor variables such as activity, body position, ambient light, as well as a patient marker with additional parameters, such as CPAP/BiPAP pressure, pulse rate and abdominal effort [44].

Recently, researchers have begun to measure three-dimensional activities (e.g. fall risk). In 2008, Stone and colleagues studied actigraphy measured sleep characteristics and risk of falls in older women [46]. This study was the first to examine the relationship between objective estimates of sleep duration and fragmentation and subsequent risk of recurrent falls. Results shows short nighttime sleep duration and increased sleep fragmentation are associated with increased risk of falls in older women, independent of benzodiazepine use and other risk factors for falls [46]. The limitation of this study is the cross-sectional study design, and that ultimately falls remain unpredictable and there is no way to anticipate or alert caregivers or health professionals in advance. Hopefully newer technology can utilize three-direction acceleration and could transmit signals to cell phones or servers, which may help reduce the burden on caregivers and improve patient well-being.

3.7 Limitations

Comparisons of actigraphy and PSG have found the former technique to be valid and reliable in normal, healthy adult populations [3]. Actigraphy is best for estimating total sleep time. However, as sleep became more fragmented, the actigraph becomes less accurate in the detection of sleep and wakefulness. Newer studies agree with previous research (e.g. [52]) in suggesting that actigraphy may overestimate sleep and thus underestimate wakefulness, particularly during the day when an individual is more likely to sit quietly while awake. In an effort to reduce this error, early investigators developed secondary algorithms that rescore sleep epochs as wake if adjacent to many wake epochs. Besides, although actigraphy has been utilized to evaluate sleep measures of primary sleep disorders, e.g. disordered-breathing sleep, periodic limb movement disorders, we should realize that actigraphy is only used to provide sleep parameters in patients with established diagnoses not to make diagnoses.

Some research suggests that actigraphy consistently overestimates total sleep time and number of awakenings during the night when compared to subjective report measures (e.g. sleep logs); however interpreting this phenomenon is very difficult. First of all, PSG and self-reported sleep logs are not highly correlated, therefore it is possible that the actigraphy data is in fact more accurate than the sleep log estimation. It is difficult to determine which measure is more reliable, but according to Ancoli-Israel et al.'s 2003 review, many studies (especially in insomnia) use subjective measures as the final outcome variables, since researchers believe that the patient's subjective reports are more important than objective data. This statement seems to suggest that neither PSG nor actigraphy is needed for sleep examination – but it is important to remember that actigraphy has the ability to collect data over a period of several days and nights. It is seems reasonable to suggest that both methods (subjective and objective) can be used to collect participant's sleep information. When there is agreement between the two methods, confidence is increased in the results of both. When there is disagreement, it may reveal problems with one or the other. Clinicians can use this information and conduct cognitive behavioral therapy to try to improve the patient's sleep behavior and therefore improve their sleep quality. For example, one study conducted by Tu and colleagues [48], found in their research that some Chinese dementia caregivers returned their actiwatch and said:

> I bet I had poor sleep over these days, and the watch can speak for me!

However, when the participant's actigraphy data were analyzed, Tu et al. were surprised to find that their sleep effiency was almost 92%. By comparing their score to their Pittsburgh Sleep Quality Index score and sleep log, it was ascertained that these participants spent lots of time falling asleep and therefore felt their sleep was poor. Clinicians can use this objective information to open a discussion with the patient to teach them coping skills and change their sleep behavior to improve their quality of life.

3.8 Summary

In summary, although actigraphy is not as accurate as PSG for determining some sleep measurements, there is general agreement that actigraphy, with its ability to record continuously for long time periods, is more reliable than self-reported sleep logs which rely on the patients' recall of how many times they woke up or how long they slept during the night. In addition, actigraphy is more reliable than observations which only capture short time periods, and can provide information obtainable in no other practical way. It can also have a role in the medical care of patients with sleep disorders.

In conclusion, the latest research suggests that in the clinical setting, actigraphy is reliable for evaluating sleep patterns in patients with insomnia, for studying the effect of treatments designed to improve sleep, in the diagnosis of circadian rhythm disorders (including shift work), and in evaluating sleep in individuals who are less likely to tolerate PSG, such as children and the demented elderly. In addition, when using actigraphy in clinical research, it is recommended that investigators refer to suggestions in the article of Berger et al. [5], which systematically reviews the pros and cons of using actigraphy, and makes concrete suggestions for implementing actigraphy in research reports including, the choice of instrument, selection of pertinent variables, sampling, and data processing and analysis. The body of knowledge regarding objective measurements of sleep, activity, and circadian rhythms will grow when researchers plan studies that address the methodological challenges related to procedures and reporting results. This applies to research with healthy individuals and persons with primary and comorbid insomnia, such as those with cancer. Understanding relationships between subjective sleep measures and objective actigraphy measures of sleep, activity, and circadian rhythms is essential to enhance our understanding of the physical and mental health outcomes in various populations of children and adults with sleep disturbances. Those issues are now being addressed, and actigraphy may now be reaching the maturity needed for application in the clinical arena.

References

1. Alessi CA (1995) Psychotropic medications in incontinent nursing home residents: association with sleep and bed mobility. J Am Geriatr Soc 43(7):788
2. Alessi CA, Schnelle JF, MacRae PG, Ouslander JG, Al-Samarrai N, Simmons SF et al (1995) Does physical activity improve sleep in impaired nursing home residents? J Am Geriatr Soc 43(10):1098–1102
3. Ancoli-Israel S (2003) The role of actigraphy in the study of sleep and circadian rhythms. American Academy of Sleep Medicine review paper. Sleep 26(3):342
4. Baker A, Simpson S, Dawson D (1997) Sleep disruption and mood changes associated with menopause. J Psychosom Res 43(4):359–369
5. Berger AM, Wielgus KK, Young-McCaughan S, Fischer P, Farr L, Lee KA (2008) Methodological challenges when using actigraphy in research. J Pain Symptom Manage 36(2): 191–199
6. Blackwell T (2005) Actigraphy scoring reliability in the study of osteoporotic fractures. Sleep 28(12):1599
7. Broughton R (1996) Home assessment of sleep disorders by portable monitoring. J Clin Neurophysiol 13(4):272
8. Chen KY, Bassett DRJ (2005) The technology of accelerometry-based activity monitors: current and future. Med Sci Sport Exerc 37(11):S490–S500
9. Cole RJ, Kripke DF, Mullaney DJ, Gruen W, Gillin JC (1992) Technical note automatic sleep/wake identification from wrist activity. Sleep 15(5):461
10. Cortese S (2009) Sleep in children with attention-deficit/hyperactivity disorder: meta-analysis of subjective and objective studies. J Am Acad Child Adolesc Psychiatry 48(9):894
11. El Baz M (1998) Evaluation of actiwatch actimeter vs polysomnography in 29 patients with obstructive sleep apnea syndrome. J Sleep Res 7(Suppl 2):75
12. Fetveit A, Bjorvatn B (2005) Bright-light treatment reduces actigraphic-measured daytime sleep in nursing home patients with dementia: a pilot study. Am J Geriatr Psychiatry 13(5): 420–423
13. Giannotti F (2006) An open-label study of controlled-release melatonin in treatment of sleep disorders in children with autism. J Autism Dev Disord 36(6):741
14. Glod CA (1997) Increased nocturnal activity and impaired sleep maintenance in abused children. J Am Acad Child Adolesc Psychiatry 36(9):1236
15. Gnidovec B (2002) Actigraphic assessment of sleep-wake rhythm during the first 6 months of life. Clin Neurophysiol 113(11):1815
16. Hauri PJ, Wisbey J (1992) Wrist actigraphy in insomnia. Sleep 15(4):293–301
17. Hindmarch I (2000) A naturalistic investigation of the effects of day-long consumption of tea, coffee and water on alertness, sleep onset and sleep quality. Psychopharmacology 149(3):203
18. Insana SP, Gozal D, Montgomery-Downs HE (2010) Invalidity of one actigraphy brand for identifying sleep and wake among infants. Sleep Med 11(2):191–196
19. Jean-Louis G, von Gizycki H, Zizi F, Spielman A, Hauri P, Taub H (1997) The actigraph data analysis software: I. A novel approach to scoring and interpreting sleep-wake activity. Percept Mot Skills 85(1):207–216
20. Jean-Louis G, Mendlowicz MV, von Gizycki H, Zizi F, Nunes J (1999) Assessment of physical activity and sleep by actigraphy: examination of gender differences. J Womens Health Gend Based Med 8(8):1113
21. Jean-Louis G, Zizi F, von Gizycki H, Hauri P (1999) Actigraphic assessment of sleep in insomnia: application of the Actigraph Data Analysis Software (ADAS). Physiol Behav 65(4–5):659–663
22. Jean-Louis G, Kripke DF, Ancoli-Israel S, Klauber MR, Sepulveda RS (2000) Sleep duration, illumination, and activity patterns in a population sample: effects of gender and ethnicity. Biol Psychiatry 47(10):921–927

23. Kain ZN (2002) Sleeping characteristics of children undergoing outpatient elective surgery. Anesthesiology 97(5):1093
24. Kain ZN (2003) Sleeping characteristics of adults undergoing outpatient elective surgery: a cohort study* 1. J Clin Anesth 15(7):505
25. Kushida CA, Chang A, Gadkary C, Guilleminault C, Carrillo O, Dement WC (2001) Comparison of actigraphic, polysomnographic, and subjective assessment of sleep parameters in sleep-disordered patients. Sleep Med 2(5):389–396
26. Kripke DF (1978) Wrist actigraphic measures of sleep and rhythms* 1. Electroencephalogr clin neurophysiol Evoked potential 44(5):674
27. Lichstein KL (2006) Actigraphy validation with insomnia. Sleep 29(2):232
28. Littner M (2003) Practice parameters for the role of actigraphy in the study of sleep and circadian rhythms: an update for 2002. Sleep 26(3):337
29. Montgomery-Downs HE, Crabtree VM, Gozal D (2005) Actigraphic recordings in quantification of periodic leg movements during sleep in children. Sleep Med 6:325–332
30. Mullaney DJ, Kripke DF, Messin S (1980) Wrist-actigraphic estimation of sleep time. Sleep 3(1):83–92
31. Natale V (2009) Actigraphy in the assessment of Insomnia: a quantitative approach. Sleep 32(6):767
32. Ohayon MM (2004) Meta-analysis of quantitative sleep parameters from childhood to old age in healthy individuals: developing normative sleep values across the human lifespan. Sleep 27(7):1255
33. Pankhurst FP, Horne JA (1994) The influence of bed partners on movement during sleep. Sleep 17(4):308–315
34. Powell SM, Jones DI, Rowlands AV (2003) Technical variability of the RT3 accelerometer. Med Sci Sport Exerc 35(10):1773–1778
35. Reyner LA, Horne JA, Reyner A (1995) Gender- and age-related differences in sleep determined by home-recorded sleep logs and actimetry from 400 adults. Sleep 18(2):127–134
36. Sadeh A (1995) Sleep and psychological characteristics of children on a psychiatric inpatient unit. J Am Acad Child Adolesc Psychiatry 34(6):813
37. Sadeh A (2010) The role and validity of actigraphy in sleep medicine: an update. Sleep Med Rev 15(4):259–267
38. Sadeh A, Hauri PJ, Kripke DF, Lavie P (1995) The role of actigraphy in the evaluation of sleep disorders. Sleep 18(4):288–302
39. Sanchez-Ortuno MM, Edinger J, Means MK, Almirall D (2010) Home is where sleep is: an ecological approach to test the validity of actigraphy for the assessment of insomnia. J Clin Sleep Mid 6:21–29
40. Sharpley AL (1988) Evaluation of first night effect using ambulatory monitoring and automatic sleep stage analysis. Sleep 11(3):273
41. Shilo L, Sabbah H, Hadari R, Kovatz S, Weinberg U, Dolev S et al (2002) The effects of coffee consumption on sleep and melatonin secretion. Sleep Med 3(3):271–273
42. Sitnick SL (2008) The use of actigraphy to study sleep disorders in preschoolers: some concerns about detection of nighttime awakenings. Sleep 31(3):395
43. So K (2005) Actigraphy correctly predicts sleep behavior in infants who are younger than six months, when compared with polysomnography. Pediatr Res 58(4):761
44. Somnomedics K, Germany. Somnowatch manule. From http://www.s-med.co.uk/PDF-s/sow_eng.aspx. Accessed 10 Mar 2010
45. Spira AP (2009) Anxiety symptoms and objectively measured sleep quality in older women. Am J Geriatr Psychiatry 17(2):136
46. Stone KL, Ancoli-Israel S, Blackwell T, Ensrud KE, Cauley JA, Redline S et al (2008) Actigraphy-measured sleep characteristics and risk of falls in older women. Arch Intern Med 168(16):1768–1775
47. Teicher MH (1995) Actigraphy and motion analysis: new tools for psychiatry. Harv Rev Psychiatry 3(1):18

48. Tu YC, Wang P-C (2010) Test a theoretical model of the stress process in female dementia family caregivers with positive aspects of caregiving, coping style and sleep. Paper presented at Taiwan Association of Clinical Psychology Annual Conference, Taipei, 27 Mar 2010
49. Tworoger SS, Davis S, Vitiello MV, Lentz MJ, McTiernan A (2005) Factors associated with objective (actigraphic) and subjective sleep quality in young adult women. J Psychosom Res 59(1):11–19
50. Vanhelst J, Zunquin G, Theunynck D, Mikulovic J, Bui-Xuan G, Beghin L (2009) Equivalence of accelerometer data for walking and running: treadmill versus on land. J Sports Sci 27(7):669–675
51. Vallieres A, Morin C (2003) Actigraphy in the assessment of insomnia. Sleep 26(7):902
52. Webster JB, Kripke DF, Messin S, Mullaney DJ, Wyborney G (1982) An activity-based sleep monitor system for ambulatory use. Sleep 5(4):389–399