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The Role of Actigraphy in the Evaluation of Sleep Disorders

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Summary: This paper, which has been reviewed and approved by the Board of Directors of the American Sleep Disorders Association, provides the background for the Standards of Practice Committee's parameters for the practice of sleep medicine in North America.

The growing use of activity-based monitoring (actigraphy) in sleep medicine and sleep research has enriched and challenged traditional sleep-monitoring techniques. This review summarizes the empirical data on the validity of actigraphy in assessing sleep–wake patterns and assessing clinical and control groups ranging in age from infancy to elderly. An overview of sleep-related actigraphic studies is also included. Actigraphy provides useful measures of sleep–wake schedule and sleep quality. The data also suggest that actigraphy, despite its limitations, may be a useful, cost-effective method for assessing specific sleep disorders, such as insomnia and schedule disorders, and for monitoring their treatment process. Methodological issues such as the proper use of actigraphy and possible artifacts have not been systematically addressed in clinical research and practice. **Key Words:** Actigraph—Diagnosis—Insomnia—Monitoring—Movement—Sleep—Sleep disorders.

1.0 BACKGROUND

The motor-activity levels of animals and humans have been a focus of scientific investigation for many years. In 1922, Szymansky conducted the first sleep study utilizing an objective method to monitor motility (1). Many methods, based on different technologic solutions such as photographic monitoring, video recording, electroencephalogram (EEG) movement artifacts, static charge-sensitive and pressure-sensitive mattresses, bed and body transducers have been used since then to monitor activity during sleep. Some of these methods and others like step counters, photoelectric cells, stabilimeters, ultrasound and infrared detectors have also been used to study activity during wakefulness. Body movements or motility patterns have been of interest for many scientific disciplines and much technologic ingenuity has been invested in developing measurement methods.

Advances in technology resulted in sophisticated devices that miniaturized these monitoring systems to the size of a digital wristwatch. An exhaustive historical account of the technical and statistical considerations and empirical findings of activity monitoring in medicine has been compiled by Tryon (2). The present review focuses on the newest available technology used in sleep research, namely the actigraph (also referred to as an actometer or actimeter). The actigraph is based on miniaturized acceleration sensor that translates physical motion to a numeric representation. This nu-

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meric representation is sampled frequently (e.g. every 10th of a second) and aggregated at a constant interval, usually referred to as the epoch (e.g. 1 minute). These epoch-by-epoch samples are stored in the internal memory of the device for a prolonged period (e.g. 1 week) until the stored information is downloaded to a computer. Some devices enable the user to modify the working features of the device (e.g. sampling frequency, sensitivity, the use of high- or low-frequency filters), whereas others provide a fixed, unchangeable working mode.

The unique feature of actigraphy that differentiates it from early technologies is the ability to attach the device to the wrist (or ankle) of an individual for prolonged periods of time and provide continuous activity data with little interference or few limitations imposed on the subject. Only research directly related to, or significantly relevant to, sleep medicine will be reviewed.

2.0 OBJECTIVES

The present review is focused on a critical examination of the existing empirical data with regard to the potential clinical and research use of actigraphy in sleep medicine. The review is divided into three main sections: 1) studies focused on evaluating the validity and reliability of actigraphic measurement of sleep, 2) experimental and clinical studies using actigraphy in sleep medicine and related areas and 3) methodologic issues in actigraphic sleep–wake studies. Special attention is given to areas of research and clinical practice in which actigraphy may play a significant role in assessment and treatment follow-up. Because sleep medicine overlaps to some extent with other domains such as occupational medicine, psychiatry and clinical psychology, sleep-related studies in these domains are included in the present review.

3.0 METHODS

This review was commissioned by the Standards of Practice Committee of the American Sleep Disorders Association. The review is based on a computerized literature search of the MEDLINE and PSYCHLIT databases (years: 1970–1994). This search included key words that are commonly used in actigraphic research, including "actigraph", "actometer" and "actimeter", "activity level", "motility" and "body movements". In addition, the reference list of each identified manuscript was searched for additional relevant citations. Actigraphs are not identified by brand names here. Interested readers are referred to the original papers for specific actigraph information.

This review is based primarily on papers that have been published in peer-reviewed journals, but it does include some studies that were only published in abstract form or presented in meetings if the abstract addressed a topic of major importance and no other more extensive reports on that issue were available. To stress this aspect of the review, we chose to identify these studies in the text as "preliminary" or "abstract report".

All of the authors involved in this review completed American Sleep Disorders Association conflicts of interest statements.

4.0 Reliability and validity of actigraphic assessment of sleep

Since the late 1970s, a growing number of studies have demonstrated the validity of modern actigraphy in distinguishing between sleep and wakefulness, and in providing useful and reliable measures of sleep–wake organization and sleep quality. These studies have addressed normal and clinical samples from individuals ranging in age from infancy to adulthood (Table 1). Validation studies have all been based on concomitantly obtained actigraphic and polysomnographic (PSG) recordings. PSG has been used as the gold standard in these studies. Typically, the subject comes to the laboratory for a full PSG study and has at least one actigraph attached to the wrist (or ankle in the case of young children) in addition to being hooked up with conventional electrodes. PSG data are scored according to traditional scoring criteria and compared epoch-by-epoch with the actigraphic raw data.

4.1 Manual scoring

Manual scoring is based on visual inspection of raw actigraphic-activity data and judgment whether the subject is asleep or awake in any given time during the study period. This scoring procedure occurs independent of the PSG-scoring procedure. Eventually the two scoring systems (PSG and actigraphy) are compared on an epoch-by-epoch basis to determine agreement rates or correlations between measures derived from the two methods.

In their first pilot study on wrist actigraphic measures of sleep, conducted with only five normal subjects, Kripke et al. (3) showed that actigraphically derived sleep measures could reach high levels of agreement with EEG sleep measures: minutes of sleep, $r = 0.98$; total sleep period, $r = 0.95$; and minutes of wake within sleep, $r = 0.85$.

Mullaney et al. (4) demonstrated that a trained scorer can manually score actigraphic data to distinguish sleep from wakefulness with 91.6% agreement with EEG-based scoring for a mixed group of 39 adult patients,

TABLE 1. *A review of the reliability studies with modern actigraphy*

Study[a]	Sample[b]	Sample size	Age	S/W[c]	SEF[c]	DUR[c]	Comments[d]
Kripke (3)	N	5	NA	NA	0.98	0.95	
Mullaney (4)	N	53	18–66 yr	96.3	0.81	0.97	HS TST
	P	32	18–66 yr	91.6	0.95	0.82	HS TST
Webster (5)	N	14	College	93.9	NA	NA	AS IDT
	N+P	14	College	93.4	NA	NA	AS IDT
Sadeh (6)	N	13	20–76 yr	90.2	0.91	NA	AS
	SAS	25	20–76 yr	85.7	0.63	NA	AS
	INS	16	20–76 yr	78.2	0.79	NA	AS
	C/P	13	3–13 yr	89.9	0.81	NA	AS
Sadeh (7)	N+P/C	11	12–48 mo	85.3	NA	NA	AS
Hauri (8)	INS	36	24–69 yr	82.1	NA	NA	AS
Cole (11)	N+P	51	NA	88.0	0.82	0.90	AS SLT
Sadeh (12)	N	36	10–25 yr	91.2	NA	NA	AS
Sadeh (13)	N	41	Newborn–12 mo	95.3	NA	0.95	AS

[a] Studies are identified by the first author's name. Only papers published in peer-reviewed journals are included.

[b] Sample: N = normal individuals; SAS = sleep apnea patients; INS = Insomniacs; C = Children and infants; P = heterogeneous group of patients.

[c] Measures: S/W = minute-by-minute agreement for sleep–wake scoring; SEF = correlations between PSG and actigraphic-based sleep efficiencies or sleep percentages; DUR = duration of sleep.

[d] Comments: HS = hand scoring; AS = automatic scoring; TST = Total sleep time was used because statistics for SEF were not available; SLT = sleep latency was used because sleep duration was not available; IDT = including daytime scoring; NA = not applicable or not available.

and agreement of 96.3% for recordings of 63 control subjects. Actigraphic and PSG whole-night sleep measures such as total sleep period, total sleep time, and wake after sleep onset were highly correlated ($r = 0.90$, $r = 0.89$ and $r = 0.70$, respectively). The number of midsleep awakenings was found to be a much less valid measure ($r = 0.25$). Mullaney et al. (4) also found that the minute-by-minute actigraph–PSG agreement was significantly lower for patients (when compared to normal subjects), for older people (age 50 and above vs. younger subjects) and for short sleepers (sleeping 390 minutes or less vs. those who slept more). It should be noted, however, that these studies were not limited to bedtime monitoring and included significant amounts of daytime periods of wakefulness that may be easier to identify than minutes of wakefulness in bed.

4.2 Automatic scoring

Because raw actigraphic data are stored as digitized computer data, computer algorithms have been developed for automatic sleep–wake scoring and automatic generation of summary statistics. The following section describes automatic sleep–wake algorithms that were developed, validated, and incorporated into existing software packages. Most scoring algorithms have been published and are freely available. Most software packages are available on a commercial basis. It should be emphasized, however, that the validity of each algorithm is limited to the specific device and specific mode of operation used in the validation study. One cannot assume that because one device has been validated, all devices are valid regardless of their unique designs and features. One should always compare the algorithm offered for a specific device with the relevant literature on its development and validation to detect unfounded commercial abuse. Similarly, validity should always be considered for unique populations if they were not covered by other validity studies. The validity of actigraphic sleep–wake scoring may be significantly compromised in special populations (e.g. people suffering from movement disorders, tremors or other forms of activity or inactivity patterns).

The procedures involved in algorithm development are similar to those described in the manual scoring section up to the point of data analysis. Once PSG scoring and actigraphic raw data are matched on an epoch-by-epoch basis, a process of mathematic computation is set in motion. In essence, predictive models (based on regression analysis, logistic assumptions or discriminate analysis) are employed to predict the correct PSG sleep–wake scoring on the basis of the relevant activity counts (usually the specific epoch in question and its surroundings). The algorithm that provides the best fit to the PSG scoring is retested (in rigorous studies) with a different set of data to test the robustness of the results.

Webster et al. (5) developed an automatic-scoring algorithm for actigraphic data in a series of three experiments. Their final results indicated that automatic scoring is not only fast and objective, but also yields high agreement rates with PSG scoring (above 93% with a sample consisting mostly of college students).

Sadeh et al. (6,7) conducted two separate studies that demonstrated the validity and the clinical potential of actigraphy. In the first study (6), an algorithm based

on discriminate analysis was developed and validated against PSG with relatively large samples of normal adult subjects, children, insomniacs and sleep apnea syndrome (SAS) patients. Minute-by-minute agreement between actigraphic and PSG scoring was 90.2% for normal adults, 89.9% for children, 78.2% for insomniacs and 85.7% for patients with sleep apnea. The correlations for actigraph- and PSG-based sleep-efficiency indices were also highly significant (0.90 for normal adults, 0.81 for children, 0.79 for insomnia patients and 0.63 for SAS patients). The second study (7) extended the use of the derived scoring algorithm to younger children and infants (1- to 4-year-olds), resulting in 85.3% agreement between actigraphic and PSG sleep–wake scoring agreement.

These two studies (6,7) have also demonstrated another important component of clinical validity. It was shown that clinical and normal subjects could be differentiated solely on the basis of whole-night actigraphic sleep measures. In the first study (6), discriminate analysis was successfully used to classify insomniacs, patients with sleep apnea and normal controls, with a correct assignment rate of 73.5% for the calibration sample (the sample used for developing the discriminate function; n = 34) and 64.6% for the validation sample (the sample studied prospectively; n = 48). Similar validity was demonstrated with sleep-disturbed children (n = 63) and controls (n = 34) in the second study (7). Actigraphic sleep measures significantly differentiated between these two groups. Discriminate analysis resulted in 91.2% and 79.4% correct assignment rates for the calibration and validation samples. Although these correct assignment rates were significantly better than those anticipated from random assignment, they are insufficient for clinical diagnosis per se.

In the most extensive study on actigraphy and insomnia to date, Hauri and Wisbey (8) studied 36 insomniacs, who each slept in the laboratory for three consecutive nights, with simultaneous PSG and actigraphic recordings. These 24- to 69-year-old insomniacs (mean age, 45) were free of hypnotics or other sleep-affecting medications, had home sleep logs indicating either a sleep latency greater than 1 hour or more than 90 minutes of wakefulness during the night at least 3 nights per week and had a Stanford Sleepiness Scale indicating significant daytime sleepiness. Exclusion criteria for the study were: serious psychopathology (mild depression or anxiety was accepted), insomnia secondary to a known medical illness, insomnia secondary to a sleep–wake schedule disorder and insomnia caused by a parasomnia (e.g. fear of nightmares). Data were averaged over the three laboratory nights.

Overall, the average disagreement between PSG and actigraphy was 49 minutes per night [using the algorithm of Sadeh et al. (6)]. The two measures of total sleep per night (PSG and actigraphy) agreed to within 30 minutes in 44% of insomniacs. The two measures agreed to within 1 hour in 75% of insomniacs and to within 2 hours in 94% of the cases. However, in one patient with idiopathic insomnia and in another with periodic limb movement disorder (PLMD), the discrepancy between PSG and wrist actigraphy was greater. These statistics, as much as they demonstrate validity in the technical–scientific sense, should alarm clinicians to the possibility that large discrepancies between actigraphic measures and patients' reports of their sleep may result from the limitation of the method rather than from patients' "misperception".

The agreement between actigraphic and PSG sleep when comparing epoch-by-epoch was 82.1%. Agreement ranged from 96.8% in a patient with psychophysiologic insomnia to only 41.3% in a patient with severe PLMD.

A closer inspection of the data reveals that the discrepancies between polysomnogram and actigram were not random. In patients diagnosed with psychophysiologic insomnia, or insomnia associated with a mental disorder, the actigraph often overestimated total sleep per night, apparently because such patients may lie in bed quietly for a long time without actually falling asleep. In patients diagnosed as having sleep-state misperception, the actigraph agreed much more closely with the patients' estimates of their sleep and disagreed with the PSG evaluation.

Comparing actigraphy with sleep logs, Hauri and Wisbey (8) found that for insomnia associated with mental disorder, psychophysiologic insomnia, or sleep-state misperception, the actigraph came considerably closer to the data obtained from the polysomnograph than did the sleep log in terms of absolute errors (actigraph-PSG assessment). However, correlations for the PSG and sleep-log data were higher than those between PSG and actigraphy data. For idiopathic insomnia and for insomnia associated with periodic limb movements, the actigraph did not seem to show any advantage over subjective sleep logs.

Sources of the discrepancy between actigraphy and PSG were varied and differed among individual patients. Some patients clearly had very restless sleep with many body movements, which the actigraph interpreted as wakefulness. Others had more activated rapid eye movement (REM) sleep with many twitches that looked like wakefulness on the actigraph, without warranting a diagnosis of REM-behavior disorder. Obviously, periodic limb movements during the night would be interpreted as wakefulness if they were strong enough to affect the actigraph. On the other hand, psychophysiologic insomniacs, especially if they had been

trained in relaxation techniques or yoga mediation in the past, often remained motionless without sleeping, as did some depressive patients.

This report by Hauri and Wisbey (8) triggered a considerable controversy on the methods used to assess the benefits of actigraphy over traditional daily logs (9,10) and its validity against PSG. In essence, Chambers (9), who reanalyzed the data of Hauri and Wisbey (8), claimed that when considered for assessing total sleep time, actigraphy does not yield better estimates than daily sleep logs. However, Chambers (9) also reported a night-to-night (or within-subject) correlation of 0.81 between actigraph-derived and PSG-derived sleep time, suggesting a consistent actigraphic estimation error from night to night. He concluded that these results suggest that actigraphy may be most useful for assessing longitudinal treatment or experimental processes. The reader is referred to Chambers' paper (9) and to Hauri and Wisbey's response (10) for an elaborated discussion of other possible methodologic flaws in validation studies.

Recently, Cole and his colleagues (11) conducted a study on automatic sleep–wake identification from wrist actigraph. A number of automatic-scoring methods (using different scoring rules) were compared in this study of 41 subjects (18 normal controls and 23 with sleep or psychiatric disorders). The final algorithm correctly distinguished sleep from wakefulness 88% of the time, resulting in high correlation for actigraphically determined total sleep time ($r = 0.77$), sleep percentage ($r = 0.82$), sleep efficiency ($r = 0.71$), sleep latency ($r = 0.90$) and wake after sleep onset ($r = 0.63$), compared to PSG measures. In both training and validation samples, the actigraph tended to overestimate sleep in comparison to the PSG. For instance, PSG-determined sleep efficiency was 85%, whereas the actigraphic measure was 88.6%. The average sleep latency by PSG was 59.2 minutes compared to 50.1 minutes determined by actigraphy. Although the researchers reported similar results with some unique samples of psychiatric, bereaved and back-pain patients, their samples were too small and heterogeneous to reach any conclusion with regard to these unique clinical groups.

Sadeh et al. (12) conducted a "twin-wrist" actigraphy-validation study concomitantly with PSG in 36 healthy subjects (20 adults and 16 adolescents and children) wearing wrist actigraphs on both dominant and nondominant wrists. They found that activity level measured on the dominant wrist was significantly higher than that measured on the nondominant wrist. There were, however, no differences in the sleep–wake predictions based on algorithms developed separately for each wrist or even when an algorithm developed for one wrist was used to score data derived from the other wrist. Overall agreement rates with polysomnographic scoring ranged between 91% and 93% for the calibration and validation samples. They also found that the actigraphs varied in their sensitivity to a great extent.

Finally, Sadeh et al. (13) conducted a study comparing actigraphic measures of infants' rest–activity states with scoring measures based on direct observations and tracings from a respiratory pad (14,15). Forty-one infants were studied in their natural sleep environment (10 newborns, 11 3-month-olds, 10 6-month-olds and 10 12-month-olds). Three states were identified: wake, active sleep and quiet sleep [equivalent to REM and non-REM (NREM) sleep in young infants, respectively]. Overall, actigraphic sleep–wake scoring reached 95.3% minute-by-minute agreement rate with the observers' sleep–wake scoring. Distinction of quiet and active sleep reached agreement rates ranging from 54% to 87% at different ages (a total of 74.9% for active sleep and 78% for quiet sleep). Correlations between the percentages spent in each state by the two methods ranged between 0.85 and 0.99 for wakefulness, between 0.78 and 0.98 for active sleep and between 0.36 and 0.85 for quiet sleep. The authors concluded that actigraphy provides valid sleep–wake measures during the first year of life and that beyond the newborn period, it also provides valid active vs. quiet sleep-state measures.

It is important to emphasize that in adults, although different activity levels are associated with sleep stages, attempts to identify sleep stages from activity data have been unsuccessful (e.g. 16).

4.3 Agreement rates

The results of these validation studies indicate that for normal subjects the agreement rates between actigraph-based and PSG-based minute-by-minute sleep–wake scoring are very promising (above 90%). The agreement rates for patient samples (i.e. insomniacs or patients with sleep apnea) are somewhat lower, but still highly significant. When evaluating agreement rates, one should consider the base rates (chances of random assignments or educated guess). If one arbitrarily defines all scored minutes as sleep, the agreement rate would be as high as sleep efficiency, which for most subjects is above 80%. Of course, such scoring would be totally meaningless in terms of evaluating sleep–wake patterns. When assessing agreement rates, it is important to reach high rates for wakefulness as well as for sleep thus yielding reasonable estimates of sleep–wake patterns. Another way to test this issue is by correlating global PSG and actigraphic sleep–wake measures (e.g. sleep efficiency). The validity of actigraphic scoring has been thus supported by the highly significant correlations between actigraph- and PSG-based whole-night sleep measures such as sleep effi-

ciency (or sleep percent), sleep duration, sleep latency and other parameters used for comparison in different studies [above 0.80 for most samples in various studies with the exception of the study of Hauri and Wisbey (8) as reported by Chambers (9)]. Of special importance is the conclusion of Cole et al. that algorithms based on different mathematic principles and procedures resulted in similar validity indices (11). When evaluating validity findings in this field, it is important to consider the monitoring period. Sleep–wake differentiation is a more challenging task if only the bedtime period is considered.

4.4. Night-to-night variability

The night-to-night stability (or variability) of actigraphic sleep measures has been assessed in several studies. Hilten et al. (17) studied 99 healthy subjects, aged 50 years to 98 years, with wrist actigraphy and found no evidence of a "first-night effect". However, significant internight and intrasubject variability were noted. In a study of young children, both sleep-disturbed and controls, Sadeh et al. (7) found significant night-to-night correlations among the actigraphically derived sleep measures. A number of measures (i.e. sleep-onset time, sleep duration and the longest continuous sleep period) showed lower stability in the sleep-disturbed children compared to their controls.

4.5 Circadian rhythms

One important aspect of 24-hour-activity recording is the ability to document rest–activity circadian rhythmicity. The ability to obtain measures of circadian rhythms from actigraphic data has been demonstrated in a number of studies (e.g. 18,19). For instance, Lieberman et al. (18) documented circadian patterns in groups of young and elderly normal subjects and demonstrated age-dependent changes of these patterns. Brown et al. (19) also described methods to assess circadian patterns in wrist actigraphic data.

4.6 Developmental trends

One important component in the assessment of a new method for measuring sleep–wake patterns is the extent to which this method reflects well-established developmental trends or reveals new ones. Surprisingly, there has not been any published, cross-sectional or longitudinal actigraphic study that focused on developmental trends from early childhood to adulthood, although extensive studies are in progress. Nevertheless, published studies reflect some developmental trends within a relatively narrow age range. Sadeh et al. (7) reported developmental trends of actigraphic sleep–wake measures in sleep-disturbed and control toddlers aged 9 to 24 months. They found that in the control toddlers, age was significantly correlated with sleep-schedule measures such as sleep-onset time ($r = 0.39$; $p < 0.05$) and nocturnal sleep duration ($r = -0.53$; $p < 0.005$). In contrast, the sleep-disturbed group showed sleep-quality measures that were significantly correlated with age: number of nocturnal wakings ($r = -0.30$; $p < 0.05$); longest continuous period of sleep ($r = 0.32$; $p < 0.01$); and percent of quiet sleep ($r = 0.27$, $p < 0.05$). These trends have all been reported earlier in the literature in studies using different methodologies.

Lieberman et al. (18) reported increased daytime and nighttime activity levels in 40 elderly people (aged 65 to 94 years) compared to those of 29 younger people (aged 19 to 35 years). These findings were explained by the more fragmented sleep of the elderly subjects and their earlier rising times and related daytime activities. As mentioned above, Lieberman et al. (18) also assessed circadian aspects of the rest–activity cycles and found significant group differences. The mean acrophase occurred significantly earlier in the elderly group (1326 hours) compared to the younger group (1513 hours). The amplitude and mean level (mesor) of the rhythms were greater in the elderly group. In contrast to these findings, Renfrew et al. (20) found an opposite developmental trend of decreasing activity levels with age in 43 men (aged 21 to 83 years) monitored continuously over 9 days. Furthermore, Hilten et al. (17) found no age trends in their study of healthy elderly subjects aged 50 to 98 years. These conflicting findings may suggest that age trends in adulthood and elderly age are confounded by study design, subjects' selection criteria (e.g. health status) and other methodologic complications.

4.7 Methodologic considerations

Although validity studies of actigraphy have varied in their sample characteristics, scoring algorithms and procedures, they all used traditional PSG as the gold standard and validated the sleep–wake distinction against concomitantly obtained PSG recordings. Most studies have consistently used the nondominant wrist (or leg with young children) with most of their subjects. Little or no information is given with respect to the treatment of possible artifacts, technical failures or other methodologic issues. These issues will be readdressed in a later section.

5.0 Actigraphy in clinical studies in sleep medicine

Most actigraphic experimental and clinical studies have been conducted in settings that differ significantly

from those of the validation studies. Actigraphy–PSG studies have typically been conducted in sleep laboratories where the subject is under close supervision and control. These circumstances eliminate many potential artifacts and measurement errors that exist in natural settings. It seems likely that the validity of actigraphy might be lower in settings where subjects are free to sleep in a moving vehicle, or in a crib with a rocking device or to remove the device from their wrists without reporting (12). One may argue that the repeated measurements provided by actigraphy compensate for these potential measurement errors, but this argument is yet to be proven. This section describes studies conducted in natural settings. The following studies are not reliability or validity studies in the sense of a comparison against a gold-standard criterion (such as PSG). However, they address the wider perspective of detecting or discriminating well-established or predicted clinical processes in sleep medicine.

5.1 Assessment of insomnia and excessive daytime somnolence

Insomniacs have highly variable sleep patterns (21), often alternating excellent nights with very poor ones in an unpredictable sequence. In addition, many insomniacs are highly affected by the environment in which they sleep—sleeping either considerably worse or considerably better in the sleep disorders center than at home (22). Because of the high variability of sleep–wake patterns of insomnia patients and because of the effects that the sleeping environment may have on their sleep quality, it is extremely difficult to use PSG to assess individuals with insomnia. Some objective assessment of sleep–wake patterns of these patients is necessary, however, because many of them seriously misperceive how they do sleep (23). Wrist actigraphy offers a possible avenue to objectively assess sleep of insomnia patients. Indeed, wrist actigraphy can differentiate insomniacs from normals in the elderly (24), in adults (6) and in children (7).

5.1.1 Assessing insomnia. The efficacy of actigraphy in reliably assessing sleep in people suffering from insomnia and the related problems and controversies have been addressed earlier. An intriguing question involves the actigraph's tendency, at least in some types of insomnia, to relate better to the sleepers' subjective estimates of their sleep rather than to objective PSG measures. In the study of Hauri and Wisbey (8), this phenomenon was observed for sleep-state misperception and, possibly, for idiopathic insomnia. In their preliminary report, Kecklund et al. (25) also described a rather close relation between healthy subjects' subjective reports of sleep quality and actigraphic measures when the subjects' sleep was artificially disturbed on some occasions.

The assessment of insomniacs' sleep may improve by following individual patients over a prolonged time period because some of the factors that may cause errors in actigraphic assessment are then held constant (9). For example, if an insomniac is habitually very restless and the actigraph therefore underestimates sleep, this error will remain constant and actigraphy will accurately assess changes in estimated sleep efficiency but not the absolute number of minutes slept.

Brooks et al. (26) examined the effects of behavioral treatment on the sleep of elderly insomniacs. Nine subjects, aged 60 to 79 years, were treated with sleep-restriction therapy and monitored with wrist actigraphs for three continuous days prior to, and at the end of, the 4-week treatment period. Sleep measures, as derived from actigraphy, were significantly improved. After treatment, subjects spent less time in bed, spent less time in wakefulness after sleep onset and had increased sleep efficiency.

Schmidt-Nowara et al. (27) carried out a study evaluating the efficacy of behavioral treatments of insomnia. They compared a low level of sleep-hygiene instructions with a more intense sleep-hygiene program coupled with sleep-restriction therapy. Their preliminary report indicated that actigraphy was able to document decreased time in bed, decreased total sleep time, decreased sleep latency, decreased wake time after sleep onset and fewer awakenings in the intensively treated group. However, the same changes in these parameters could also be documented by subjective sleep log. The principal difference between actigraphy and sleep logs was the fact that actigraphy found more awakenings and more total sleep time. Schmidt-Nowara et al. (27) felt that the actigraph provided a welcome objective check of the self reports.

From a slightly different angle, Sadeh (28) studied the effects of behavioral guidance for parents of 50 sleep-disturbed infants and young children by using actigraphy and parents' subjective reports. Because parents are most aware of their child's sleep problems if the child "signals" (cries, calls for help, etc.), discrepancies between parents' logs and actigraphy were expected. Both parent reports and actigraphic measures revealed that behavioral intervention was associated with increased percent of time spent in sleep and with reduced number of night wakings. Furthermore, the discrepancies between parents' reports and actigraphic measures increased during the study due to increased parental failure to report night wakings and the children's acquired ability to stay awake and to resume sleep without signaling. The issue of attrition is extremely important when comparing actigraphy with daily logs. Parents who gradually skipped items they

should have completed on the daily logs were more likely to have increased discrepancy with the actigraphic measures of their infants' night wakings. Subjects studied in the laboratory for a few nights under close supervision may complete daily logs much more reliably than those who are studied at home for prolonged periods of time. The parental attrition factor described in the Sadeh study (28) probably plays a role when subjects are requested to document their own sleep for prolonged periods. It is also conceivable that subjects complete daily logs more reliably while they are concomitantly monitored with another method than when they are "free" of any mode of supervision.

5.1.2 Assessment of excessive daytime somnolence. Excessive daytime somnolence is usually the result of an inadequate amount of sleep or some sleep disturbance such as sleep apnea or periodic limb movements. Actigraphic assessment of the patients' natural sleep schedules for extended periods may provide data complementary to PSG evaluation. Such an assessment may indicate whether excessive daytime somnolence is the result of severe sleep curtailment. Actigraphy can document whether patients have followed advice to extend time in bed or modify the sleep–wake schedule.

The direct relationships between actigraphic sleep measures and daytime-activity levels with daytime sleepiness are yet to be explored. Although such relationships are implied from various research findings, there is still a need for a concentrated research effort in this area.

5.1.3 Narcolepsy. Two studies used actigraphs to monitor sleep–wake patterns of narcoleptic patients (29,30). Both studies concluded that sleep attacks during the day could be detected in the fragmented patterns of daytime activity of these patients. The first study compared actigraphic data to daily logs in 14 patients, resulting in good agreement for sleep attacks longer than 5 minutes (29). The authors concluded that shorter sleep attacks could not be differentiated from normal rest. In the second study, with seven patients, narcoleptic symptoms did not improve following bright-light exposure for 10 days. This effect was evident in the subjective as well as the objective measures that included actigraphic monitoring (30).

5.1.4 Summary. The conclusion drawn from the existing research data could be summarized as follows: 1) actigraphy is only marginally acceptable when attempting to measure the exact time that an insomniac is asleep; 2) actigraphy is an appropriate tool for nonintrusive documentation of changes in sleep patterns over prolonged diagnosis and treatment periods; 3) actigraphy is appropriate for documenting whether an insomniac follows certain sleep-hygiene advice, e.g. to curtail time in bed or to regularize wake-up times; 4) evidence shows that wrist actigraphy can document improvement in sleep following behavioral treatment and 5) actigraphy might be useful in assessing daytime sleep and could reflect daytime somnolence in patients suffering from various forms of hypersomnolence.

5.2 Assessment of sleep apnea and respiratory disturbances

Sleep apnea syndrome (SAS). A number of studies have directly and indirectly addressed the idea that SAS resulting in sleep fragmentation has a unique activity component that could be discerned by activity monitoring. Two of these studies have directly addressed the issue of clinical assessment of sleep apnea patients (6,31). Aubert-Tulkens et al. (31) compared actigraphic data of 18 adult SAS patients with those of 22 controls. In their data analysis, sleep–wake measures were not computed, and the calculated movement index (MI; the ratio between the number of epochs with movements divided by time in bed multiplied by 100) and fragmentation index (FI; the ratio between the number of 1-minute epochs with immobility and the total number of immobility epochs of all duration multiplied by 100) were used. SAS patients had significantly higher MI and FI compared to their controls. A follow-up of five of the patients showed treatment improvement reflected in decreased MI and FI indexes (though not supported by a statistical test in this paper).

As described above in the study of Sadeh et al. (6), actigraphic sleep and activity measures significantly differentiated SAS patients from insomniacs and control subjects. The results also suggested some ability of the actigraphic measures to assess the severity of the SAS. Two of the measures, movement density (similar to MI) and the number of consecutive continuous minutes of sleep, explained 30% of the variability in the number of apneas ($p < 0.005$); the best predictor was movement density ($r = 0.448$, $p < 0.01$).

5.2.2 Nasal occlusion. In a recent pilot study, Sadeh et al. (32) examined the effects of nasal occlusion and the resulting respiratory disturbances on activity measures of 37 normal subjects during sleep. A comparison of nonoccluded baseline nights to occluded nights revealed a significant increase in all measures of activity during the night of the occlusion. Furthermore, the respiratory disturbance index (RDI) was significantly correlated with activity measures such as mean activity level ($r = 0.41$; $p < 0.05$) or number of motionless minutes ($r = -0.51$; $p < 0.005$). The increase in RDI from baseline to occlusion night was highly correlated with the increase in the percent of minutes with activity level ($r = 0.70$; $p < 0.0001$).

5.2.3 Summary. These preliminary results com-

bined with earlier findings suggest that sleep apnea and even less severe forms of respiratory disturbance may have direct manifestations in patterns of motility during sleep and that these patterns could, at least to some extent, be identified with actigraphy. It is not clear, however, to what extent these motility correlates of respiratory disturbances are an integral part of the problem, and whether issues like the source of the disturbance (i.e. central vs. obstructive) or other individual characteristics mediate these manifestations.

The diagnosis of sleep apnea has three major components: 1) identification that a breathing problem during sleep exists; 2) identification of the source of the problem (i.e. central, obstructive or mixed syndromes) and 3) evaluation of the severity of the problem (i.e. frequency, level of oxygen desaturation). Whereas actigraphy cannot provide sufficient data for the full diagnosis and understanding of sleep apnea, there are some data suggesting that it could be used for large-scale screening purposes or treatment follow-up, in situations when a complete laboratory evaluation is not a practical option. Studies using actigraphy for prospective screening and validation are needed to determine the clinical value of this method. It is likely, however, that such a screening procedure will identify other sleep disturbances as well, and a final diagnosis could only be made after a full polysomnographic study.

5.3 Assessment of transient and chronic schedule disorders

Schedule disorders, whether they are transient or chronic, require, almost by definition, extended examination of sleep–wake cycles for prolonged periods. In most of these cases, preservation of the natural sleep environment is an important factor in the assessment, whereas more specific measures of sleep architecture or other physiologic phenomena are not always required. Considering the potential advantages of actigraphy in assessing schedule disorders, it is surprising that only limited research data have been published to date on this topic, particularly with clinical populations.

5.3.1 Chronic schedule disorders. Chronic schedule disorders are more prevalent in blind people due to their lack of sensory input of the dark–light cycle. Tzischinsky et al. (33,34) have documented, with the use of actigraphy, sleep–wake patterns of blind children and adolescents and demonstrated a relationship between these rest–activity patterns and patterns of melatonin secretion. Furthermore, in an intervention study of one blind man suffering from severe schedule disorder, actigraphic measures revealed significant improvement of sleep–wake patterns following melatonin treatment (34).

5.3.2 Transient schedule disorders. Sleeping in the laboratory, which is shielded from environmental influences such as noises, light and variations in ambient temperature, may greatly distort sleep characteristics. Sleep-laboratory studies of the daytime sleep of rotating shift workers, for instance, ignored the fact that in most cases shift workers' bedrooms are neither soundproof nor air-conditioned. Therefore, laboratory studies on shift work investigate sleep under idealized conditions that are rarely met in everyday life. Here, long-term sleep monitoring in the natural environment is imperative to obtain a reliable picture of sleep quality.

Walsh et al. (35) used actigraphs to assess daytime sleep after administration of triazolam or a placebo in a study of a simulated night shift following sleep at home. Daytime sleep following triazolam administration was longer compared to placebo administration, and this effect correlated with improved nighttime alertness as measured by multiple sleep-latency test and subjective reports.

Tzischinsky et al. (36) conducted an actigraphic investigation of the sleep of rotating-shift workers in two factories: oil refineries and a microelectronics factory. In their preliminary report, the authors documented that both age and shift-system characteristics, such as the length of the rotating cycle and its direction, significantly affected sleep length and sleep quality. In another study (37), actigraphic monitoring before and after reversing the direction of the shift schedule from counterclockwise to a clockwise direction showed improvement in workers' sleep organization and a tendency toward an improvement in measures of sleep quality. Buck et al. (38) investigated the sleep of 16 air-crew members before and after the crews flew different routes crossing numerous time zones. The researchers found that bedtime motor-activity levels increased and percentage-of-bedtime-immobility periods decreased following east–west flights. This objective finding was coupled with subjective reports of a more-disturbed sleep.

Lavie (39) investigated the effects of midazolam hydrochloride on sleep after long-haul eastward and westward flights. Eighteen subjects wore wrist actigraphs during a 14-day trip from Israel to the U.S.A. and back. Actigraphic monitoring allowed postflight examination of changes in sleep time and sleep quality and demonstrated beneficial short-term effects of midazolam.

5.3.3 Summary. These studies of schedule disorders and adaptation to induced variations from normal sleep–wake schedules illustrate the potential of actigraphy use in conducting longitudinal field studies of human sleep. Information obtained in these studies is limited to activity-based sleep–wake measures that preclude a more sophisticated understanding of changes

in sleep architecture. However, these longitudinal, naturalistic recordings could supplement the much-smaller-scale laboratory studies of these phenomena. In addition, if methodologically validated, actigraphy could potentially be a useful tool for large-scale screening procedures in occupational medicine for identifying workers who can better adapt to rotating shift work or other circumstances that challenge their normal sleep patterns.

6.0 Actigraphy in sleep-related domains

The possibility of investigating sleep in various medical conditions has appealed to many researchers and has led to numerous studies. Actigraphy has not been validated for sleep–wake scoring for various medical conditions, and the interpretation of the study is somewhat questionable.

6.1 Sleep in psychiatric and other medical conditions

Sleep is a sensitive barometer of emotional status and psychiatric condition. Sleep difficulties have been associated with emotional states and psychiatric diagnoses related to anxiety, affective dysregulation (depression, manic states and bipolar disorders), post-traumatic-stress disorder and other more specific behavioral disorders such as attention deficit and hyperactivity disorder (ADHD). The evaluation of a sleep disorder is often mixed with the assessment or consideration of the psychiatric condition. Information from traditional PSG has not always yielded consistent results with respect to the relationships between sleep disorders and psychiatric disorders or psychologic well-being. A growing number of actigraphic studies have demonstrated that longitudinal study of sleep–wake patterns in an individual's natural settings with the additional integral component of daytime-activity levels (which is also a crucial component in many of these disorders) sheds additional light on the relationship between sleep–wake patterns and psychiatric status.

Affective disorders received most of the attention vis-à-vis rest–activity cycles. A significant number of actigraphic studies were conducted on patients with affective disorders (e.g. 40–45). In general, these studies showed that affective disorders were associated with altered sleep–wake organization.

Multiple activity-based studies focused on children diagnosed with ADHD. Only a few focused directly on sleep and found that the sleep of ADHD children differs from the sleep of normal children (46–48).

Sleep has also been studied with actigraphs for patients with medical conditions like arthritis and dementia and found to be significantly disrupted compared to sleep quality in normal controls (49–53).

These studies indicate that the assessment of sleep–wake or rest–activity patterns and daytime-activity levels in psychiatric and medical conditions adds an important dimension to the evaluation of these conditions. The increasing awareness and attention given to chronobiology in medicine highlight the need for effective research tools such as actigraphy, as well as other ambulatory methods of measuring sleep.

6.2 Measuring environmental effects on sleep

Multiple environmental factors or stimuli can affect sleep or activity during sleep. For instance, a preliminary report indicated that nighttime motor activity measured in the sleep laboratory is lower than activity measured at home (54). Many environmental factors may exert influence on sleep and activity. Among these are noise (55), temperature (56), sleep restriction (57), sleep setting (58) and psychologic factors such as induced or situational stress or anxiety (59).

6.3 Assessment of medical interventions—drug studies

Actigraphy has been used in research studies assessing the effects of drugs, including the effects of stimulant (46–48,60–62), antidepressant (43,44,63,64), antipsychotic (65) and hypnotic medications (66–75). In addition, actigraphy has been used for a pilot study to assess the effects of nutrition on sleep (76).

Stimulants are used, somewhat paradoxically, for treating hyperactive children, and actigraphically derived findings indicate that stimulants do indeed produce measurable reductions of activity and changes in sleep, in hyperactive children (46–48,63–65) and even normal adults (62).

Antidepressant and antipsychotic drug effects on affective disorders and schizophrenia have also been investigated with actigraphy (43,44,60,61), In most studies, actigraphic measures reflected the anticipated drug effect (i.e. increased activity in depressive patients, reduced activity in manic patients).

Not surprisingly, most drug studies using actigraphy focused on the effects of hypnotics (66–75). In most studies, the anticipated decrease in activity (associated with higher sleep quality) has been reported. Hypnotic drug testing has historically used a variety of methods. Subjective patient reports have been widely used, but substantial evidence indicates that such subjective reports may be inaccurate. Subjective reports may suggest benefit when no objective benefit is present. Studies using direct observation of patients, usually in hospitals or nursing homes, have also been criticized for

well-demonstrated imprecision and unreliability. EEG has been widely accepted as a precise method for measuring hypnotic effects, and EEG measurements of sleep latency, total sleep time and midsleep awakenings have recognized validity, but it is questionable whether hypnotic drug effects on the EEG sleep stages have clinical significance.

The major problems with EEG studies of hypnotics are the enormous expense, which has limited many studies to minimal numbers of subjects, and the neglect of parallel placebo groups, rebound phenomena and long-term effects. Much of the precision of EEG methods is lost in within-subject night-to-night variability, which limits the value of very precise measurements for a small number of recording nights. For studies of hypnotic effects, the relative sensitivity of EEG and actigraphic techniques is unknown. Although it appears that at least half of hypnotic prescriptions are refills, and as many as three quarters of hypnotic prescriptions go to chronic users (77), long-term use (whether nightly or intermittently) has never been studied with EEG techniques, presumably because costs and other difficulties would be prohibitive. Actigraphic recording of hypnotic effects may have sufficient precision and objectiveness to reliably measure the germane effects while being inexpensive enough to permit long-term studies of an adequate size of subject group.

6.4 Summary

These studies of diverse medical and psychiatric conditions exemplify the possible difficulties in interpreting actigraphic data. When assessing sleep–wake or rest–activity patterns, researchers should consider those conditions with known potential effects on motility patterns. How can we reliably distinguish actigraphic counts attributable to purposeful gross trunk movements or limb movements, to tremor, dyskinesia, or restless akathisia? How can we reliably distinguish reduced actigraphic counts that may be attributable to sedation or to Parkinsonian stiffness? Whereas the clinical importance of increased daytime activity in hyperkinetic patients or retarded depressives may be reasonably evident, the interpretation of increased actigraphic counts in schizophrenics is hardly unambiguous. In some schizophrenics, sedation may be desired, whereas in other patients (or in the same patient at another phase of his or her illness), sedation may be considered an adverse side effect. Nevertheless, actigraphs seem to have sensitively demonstrated a distinction between two antipsychotic drugs that was not evident by other clinical means of measurement. Finally, the demonstrated ability of actigraphy to measure specific time- and dose-related effects of various hypnotics suggests that this method is appropriate for longitudinal, naturalistic studies of the long-term effects of hypnotics and their withdrawal.

7.0 Methodologic issues

Although the use of actigraphy pervades sleep research and sleep medicine, many methodologic issues have not been met with systematic investigation or with a set of standards of practice.

7.1 Reliability and validity

Despite serious efforts to establish actigraphy as a reliable and valid method to study sleep, there is still much to be desired in this domain. Most validation studies have been conducted in sleep laboratory settings against PSG, whereas most applications occur in natural sleeping environments where supervision and standardization are lacking. Does actigraphy remain as reliable under such circumstances? How can one identify "unit off" periods (that could erroneously be scored as sleep)?

Similar concerns pertain to the use of actigraphy with populations for which it has not been validated. Most validation studies were conducted on normal subjects and sleep-disordered patients. Some attention was also given to psychiatric patients. However, actigraphic studies have been extended to many other medical conditions without the required validation. If, for example, patients suffering from arthritis or Parkinson's disease are being studied, changes in activity levels might be related to the dynamics of processes related to pain and movement disorder rather than to sleep per se.

Another unresolved issue, raised by Chambers (9), is the issue of what are the advantages of actigraphy over the use of daily logs. Without listing the arguments again, we believe that actigraphy and daily logs are complementary and should always be used concomitantly. Actigraphy can provide objective rest–activity information that the subject is often unaware of or unable to report in detail. Daily logs provide essential information for editing the actigraphic data (placement, removal, possible artifacts, etc.) in addition to reporting subjective sleep-related experiences (e.g. "the infant was crying for a long time when he woke up", "this time I could not fall back to sleep because I was anxious about missing my flight in the morning").

7.2 Units of measurement

Since the actigraph (or its earlier technologic equivalents) was introduced as a research device, different units of measurement have been introduced to reflect the data collected. Many researchers have used some

measures of activity counts that are to some extent arbitrary and relate to the physical features of the analog movement detector as well as to the sampling rates and summary interval used. Because different researchers have used different devices with distinct physical and electronic features, such measures preclude interstudy comparison, and the results are hard to interpret. The introduction of sleep–wake algorithms and the demonstrated validity of these algorithms enabled interpretation of activity data in terms of sleep measures reflecting sleep–wake schedule as well as sleep quality. The use of these algorithms facilitates comparison between studies and increases the interpretability and communicability of actigraphic studies among sleep researchers. Nevertheless, the use of different devices and different scoring algorithms remains a confounding factor in such comparisons.

The facts that device sensitivity may vary considerably and that sleep-scoring algorithms are relatively robust to such variations (12) also support the development and application of sleep–wake-scoring algorithms.

7.3 Actigraph placement

The issue of standard placement of the device for actigraphic recordings has not been properly addressed. Although common practice is to place the actigraph on the nondominant wrist in adults, this practice has not been consistently maintained despite some evidence that activity levels of different limbs may vary significantly and that different body movements are not measured in all potential sites (e.g. 12,78). Studies focused on developing and examining the validity of sleep–wake-scoring algorithms have not challenged this issue. The validation study that addressed placement found that sleep–wake-scoring algorithms may be robust to significant variations in activity level (12), but this issue must be tested and standardized. Placement may therefore be of greater importance with direct measures of activity levels rather than derived sleep measures. These issues are relevant to other body placements of actigraphs that have been in use (i.e. trunk, ankle, pocket). Ankle placement has not been in common use and has not been systematically investigated, but it could conceivably overcome some of the artifacts associated with wrist actigraphy and may more appropriately reflect gross movements in wakefulness. On the other hand, PLMD may cause significant distortion when ankle placement is used.

Lack of standardization of placement in actigraphic studies can lead to an increased between-subject variability, biased results or results that are incomparable between studies.

7.4 Artifacts

Another issue that has not been addressed properly is that of artifacts. Only two published manuscripts raised this issue in an effort to train professionals to identify technical and situational artifacts (12,79). Artifacts may result when patients place their wrists on or under their head or stomach during sleep (breathing artifact), from having an active bed partner, or possibly from having an unusual mattress or bed (e.g. waterbed, rocking instrument for a crib). Some devices have shown sensitivity to humidity or temperature, and some fail for unknown reasons. Because most popular devices are based on mechanical components that detect movement and translate it into an analog signal, they are subject to mechanical changes in sensitivity. Therefore, these components require standard methods of calibration and tests of sensitivity; otherwise the user may be subjected to unidentified drifts in sensitivity that cannot be accounted for in the experimental or clinical design.

Sleep research has been traditionally focused on solitary sleep, although in "real life" a great proportion of people share a bed with a partner. McKenna and colleagues (80) have demonstrated that the sleep of infants cosleeping with their mothers differs significantly from those who sleep alone. In their recent large-scale naturalistic actigraphic study, Pankhurst and Horne (81) have shown that cosleeping is indeed an issue. For instance, although only 5% to 6% of the 30-second sleep epochs contained movements, about a third of them were common to both partners.

The sleeping surface may also affect activity recordings. Spring mattresses or waterbeds may inflate activity levels and facilitate the recordings of one's sleeping partner's activity. To date, only one actigraphic pilot study addressed this issue and, in a preliminary report, described that activity level during sleep was influenced by the sleeping surface (82).

7.5 Individual differences

There are individual differences in activity levels as a function of age and gender and possibly of other individual characteristics such as weight (e.g. 7,17,19,83). These individual differences could conceivably be confounding or target variables in actigraphic studies. Regardless of the specific purpose of the study, these factors should be taken into consideration in any research design that is based on activity measurement.

Another individual feature that should be considered when assessing sleep efficiency or sleep quality is the individual sleep duration or time in bed. As mentioned above, extension of time in bed could result in

decreased sleep efficiency (57), which should be then interpreted accordingly. Between-subject comparison must take sleep duration into consideration.

8.0 Future research

This review has identified a number of areas for future research. These areas include methodologic and other issues related to the use of actigraphy in sleep medicine.

8.1 Methodologic issues

As indicated above, the issue of artifact identification, including the identification of specific activity patterns associated with specific artifacts and possibly the inclusion of automatic algorithms that alert to the possibility of such artifacts, should be further explored and documented. The role of cosleeping, sleeping surface and other potential factors in activity recording should be studied and considered, because the control over these aspects is lost in studies based on ambulatory monitoring. The extent to which actigraph placement affects the accuracy of sleep–wake identification and artifact appearance should be further assessed.

Once more, systematic comparisons of actigraphic and daily-logs data with valid criteria for prolonged periods are needed to resolve the controversies over the advantages and complementary role of these methods in various populations.

Another crucial research need is for validation studies that evaluate actigraphic sleep assessment with unique populations in natural environments. The pervasive assumption that, if validated against PSG in the sleep laboratory, actigraphy is valid for any population in any circumstances, may represent a major methodologic flaw.

Finally, although attempts to develop scoring algorithms to identify specific sleep stages (REM–NREM) have not been successful in adults (e.g. 16), preliminary data suggest that algorithms might be possible in infants to distinguish between active and quiet sleep states (13).

8.2 Sleep medicine issues

The potential use of actigraphy for large-scale screening purposes and longitudinal follow-up in sleep medicine seems to be the most important aspect of actigraphy. Sufficient information supports the use of actigraphy in the assessment of insomnia and sleep-schedule disorders. However, there are crucial questions regarding the domain of sleep-related breathing disorders. How well can actigraphy be used for identifying breathing disorders? Could actigraphically detected breathing difficulties be distinguished from breathing artifacts? Are there individual differences or disorder-related factors that determine the extent to which body movements reflect these problems?

TABLE 2. *The role of actigraphy in the assessment of sleep disorders: empirical studies demonstrating validity or anticipated results*[a]

Phenomenon	Reference number
Sleep schedule	3–8, 11–13
Sleep efficiency	3–8, 11–13
Sleep states (in infants)	13
Circadian rhythms	18, 19, 24
Respiratory disturbances	6, 31, 32
Daytime sleepiness	—[b]
PLMD	—[b]
Clinical syndromes	
Insomnia	6, 7, 8, 24, 26
Sleep apnea	6, 31, 32
Schedule disorders	33, 34, 36–39, 42
Narcolepsy	29, 30
Parasomnias	—[b]
Treatment studies	
Behavioral	26, 27, 28
Medication	34, 60–75

[a] Numbers represent reference numbers of papers in the reference list.
[b] No empirical support available.

9.0 Conclusions

The role of actigraphy in the assessment of sleep disorders have been strongly supported in some areas and only partially supported or rejected in others. Table 2 summarizes our conclusions based on the weight of the published empirical evidence.

The following statements summarize our impressions and best judgment on the role of actigraphy in the evaluation of sleep disorders. Actigraphy provides a cost-effective method for longitudinal, natural assessment of sleep–wake patterns. The method can be used to distinguish between wakeful and sleep states, with wide margins of error for subjects lying awake motionless (e.g. insomnia patients). Despite differences in its accuracy level, actigraphy can assess sleep–wake schedules in normal and sleep-disturbed patients. Actigraphy can be used to assess the rest-activity patterns of insomniacs and individuals with schedule disorders who require repeated, longitudinal monitoring (or when a more elaborated sleep analysis is not required). Although actigraphy is sensitive to sleep-related respiratory disturbances, it is not suitable for assessing such disturbances. A clinical diagnosis and consideration of treatment should always be based on full-laboratory testing. Finally, actigraphy is not suitable for clinical assessment in cases in which the subject may have some underlying motivation to feign a sleep problem

(e.g. insurance claims, avoiding undesired jobs or military tasks).

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