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CLINICAL REVIEW

The role and validity of actigraphy in sleep medicine: An update

Avi Sadeh*

The Adler Center for Research in Child Development and Psychopathology, Department of Psychology, Tel Aviv University, Tel Aviv 69978, Israel

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SUMMARY

Activity-based sleep-wake monitoring or actigraphy has gained a central role as a sleep assessment tool in sleep medicine. It is used for sleep assessment in clinical sleep research, and as a diagnostic tool in sleep medicine. This update indicates that according to most studies, actigraphy has reasonable validity and reliability in normal individuals with relatively good sleep patterns. The validity of actigraphy in special populations or with individuals with poor sleep or with other sleep-related disorders is more questionable. The most problematic validity issue is the low specificity of actigraphy in detecting wakefulness within sleep periods reported with certain devices or samples. Overall, the recent literature adds to previous reports in demonstrating that actigraphy is sensitive in detecting unique sleep patterns associated with specific sleep disorders as well as with other medical or neurobehavioral disorders. Furthermore, actigraphy is sensitive in detecting sleep changes associated with drug treatments and non-pharmacologic interventions. Recent developments include the development of devices specially tailored to detect periodic limb movement in sleep and the introduction of new devices and algorithms. Because of the limitations of actigraphy, it is recommended to use complementary assessment methods (objective and subjective) whenever possible.

Introduction

Over the last two decades actigraphy has become a major assessment tool in sleep research and sleep medicine. The rate of relative growth in number of scientific publications that include actigraphy (see Fig. 1) exceeds the rate of growth in publications that include polysomnography (PSG) (from an actigraphy-PSG ratio of about 1:10 in 1991 to a ratio of about 1:4 in 2009). This increase reflects the growing appeal of actigraphy to clinicians and researchers in sleep medicine. Earlier reviews and guidelines introduced by the American Sleep Disorders Association (ASDA) have established the use of actigraphy as a reliable and valid sleep assessment method in specific domains of sleep research and sleep medicine.[1–6] The current review is an update based on the literature published after the previous review published in 2002 in Sleep Medicine Reviews.[6] It is based on a literature search that included Pubmed, Social and Science Citation Index databases and covers only articles published in peer-reviewed journals (excluding meeting abstracts or proceedings). Because of the large number of papers published each year, this review covers only papers that address methodological issues related to the use of actigraphy in sleep medicine and those that are directly related to clinical applications in sleep medicine. Thus, dozens of papers, addressing the use of actigraphy in assessing sleep in specific conditions or populations were not included.

Actigraphy is based on small wrist-watch like devices that monitor movements for extended periods of time. The raw activity scores (e.g., in 1-min epochs) are translated to sleep-wake scores based on computerized scoring algorithms. There are different commercial devices in the market and each device has its own measurement characteristics and therefore requires appropriate sleep-wake scoring algorithms and validation studies. To avoid commercial pitfalls, this review will not address specific devices or comparisons, but the readers are strongly advised to consider the presented issues and their relevance to the specific device they are using or planning to use.

Reliability and validity issues

The strengths and limitations of actigraphy in sleep assessment have been repeatedly outlined.[1–6] In this section, additional information is provided with regard to the main established topics and some new ones.

Validation of scoring algorithms

Previous work has established the reliability and validity of actigraphy in sleep-wake detection, particularly in normal populations

* Fax: +972 3 6408074.
E-mail address: sadeh@post.tau.ac.il.

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Abbreviations

AHI	Apnea-hypopnea index
CBT	Cognitive-behavioral therapy
MPH	Methylphenidate
PLMD	Periodic limb movements disorder
PLMS	Periodic limb movements in sleep
PSG	Polysomnography
SDB	Sleep-disordered breathing
SE	Sleep efficiency
SOL	Sleep onset latency
TIB	Time in bed
TST	Total sleep time
WASO	Wake after sleep onset

of infants, children and adults.[1–3] However, recent publications have raised new concerns about the validity of sleep-wake scoring algorithms in specific populations or specific devices.[7–11] For instance, Sitnick et al.[8] compared minute-by-minute sleep-wake scorings based on actigraphy and videosomnography in young children. They reported 94% overall agreement, 97% sensitivity (percent of PSG identified sleep minutes scored as sleep minutes by actigraphy), and 24% (very low) specificity (percent of PSG identified wake minutes scored as wake minutes by actigraph). Similarly, Insana et al.[7] compared sleep-wake scorings based on actigraphy and PSG in infants and found low specificity because of poor wake identification. De Souza et al.[11] reported relatively low specificity (34% and 44%) in their comparison of PSG and two actigraphic scoring algorithms in healthy volunteers. Paquet et al.[10] compared two actigraphic sleep scoring algorithms in a study of 15 healthy participants studied for 3 nights with concomitant PSG and actigraphy. They found that increasing wakefulness during the sleep period compromises the minute-by-minute actigraphy-PSG correspondence because of the relatively low specificity of the sleep-wake scoring algorithms. The authors concluded that "the very low ability of actigraphy to detect wakefulness casts doubt on its validity to measure sleep quality in clinical populations with fragmented sleep".

These examples demonstrate a crucial issue. Although actigraphy provides high sensitivity, the detection of wakefulness during sleep episodes is relatively poor with: a) some devices; b) some scoring algorithms; or c) some specific populations. This is a major issue which relates to the combination of high sensitivity and low specificity in sleep-wake detection. To clarify this issue, we can assume that we have a 10-hour sleep period with a 1-hour of

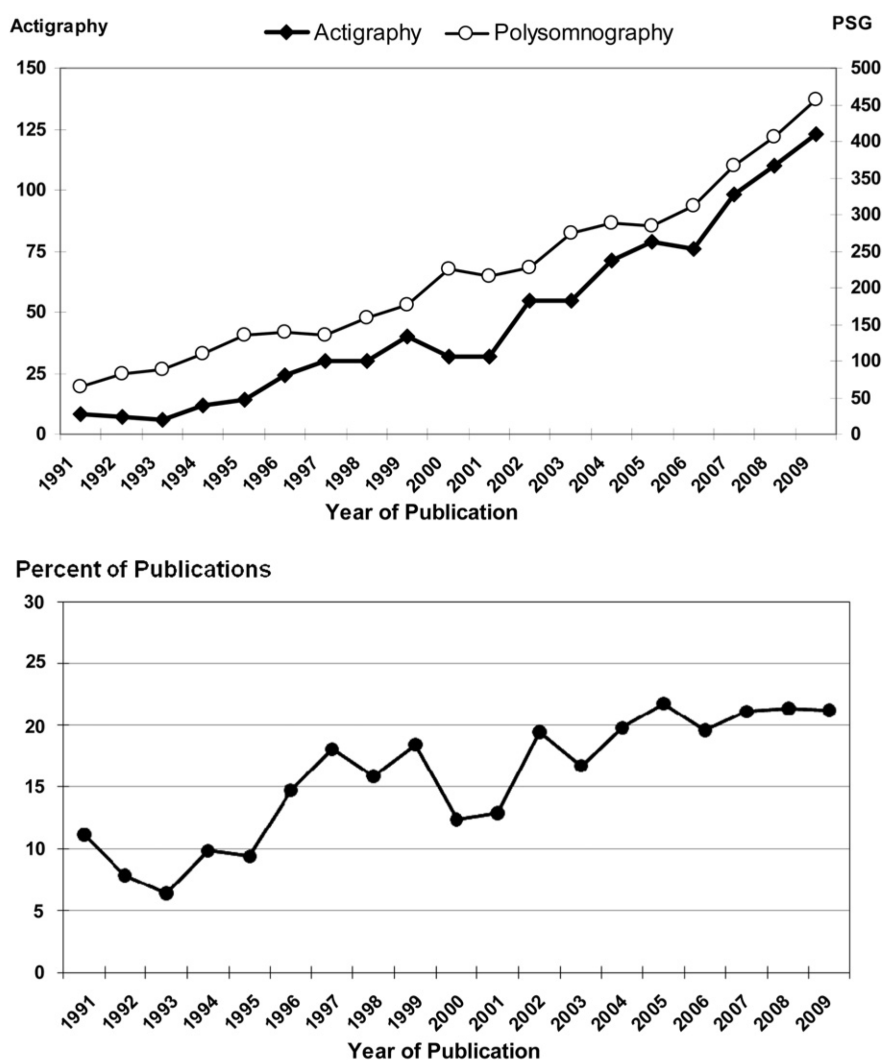

Fig. 1. The number of scientific publications that include actigraphy or actimetry and sleep in comparison to those which include polysomnography in their title or abstract (upper panel). These data are based on the ISI database and do not include meeting abstracts and proceedings. Note the different Y scales for actigraphy (on the left) and PSG (on the right). The lower panel presents the percentage of actigraphy publications from all polysomnography and actigraphy publications in each year.

wakefulness and sleep efficiency (SE) would therefore be 90%. If we use a very simple sleep-wake algorithm rule which states that every minute should be scored as sleep, we automatically achieve a very high agreement rate and high sensitivity because 90% of the total epochs (and 100% of the sleep epochs) will be scored correctly. However, the specificity would be zero as none of the wake minutes would be detected. These proportions of only 10–20% of wake epochs are very common in validation studies conducted in sleep laboratories during a nocturnal sleep period and therefore it is relatively easy to obtain high sensitivity for sleep scoring. The art of developing scoring algorithms relies on maximizing both specificity and sensitivity or increasing the area under the Receiver Operating Characteristic (ROC) curve. This ability is also related to the sensitivity of the device to detect relatively small movements associated with wakefulness in bed. If a specific actigraph is less sensitive to relatively small movements during the sleep period it may lead to lower specificity. Considering this issue, it is sometimes unclear why conclusions claiming good validity are made for specific sleep-wake scoring algorithms while the low specificity or wake detection ability reported in the same article is practically ignored.[12]

In this context, it is important to note Tryon's review[13] on the validity of actigraphy for sleep assessment. Tryon illustrates that the validity of actigraphy is acceptable in comparison to many other medical tests and indicates that the PSG-Actigraphy discrepancy should be partially attributed to PSG reliability issue and that portions of this discrepancy are predictable and can be corrected. Overall, Tryon postulated that claims about the limited accuracy of actigraphy for inferring sleep are not supported by the available research findings.

Another methodological issue that has been repeatedly raised is the lack of standard equipment, procedures and analytic methods in the applications of actigraphy which preclude comparisons and conclusions across studies. For instance, Berger et al.[14] used a literature review of 21 studies using actigraphy in adult patients with cancer to demonstrate the variability in reporting methods, sampling procedures, data processing and analyses used in these studies and to offer standardized protocols. A related issue is the relative difficulty in comparing the performance of different actigraph devices and algorithms. A recent small study assessed the validity of two popular actigraphy devices in comparison to PSG.[15] Both devices underestimated sleep onset time (SOL) and provided similar validity indices. More similar studies are needed to compare the performance of different devices for sleep assessment in different populations or under unique conditions.

Validity of actigraphy in special populations and conditions

A growing tendency in research on the validity of actigraphy is to assess actigraphic sleep-wake scoring in more challenging samples including infants, adolescents and adults with breathing disorders and individuals with medical disorders.

A number of studies assessed the validity of actigraphic sleep-wake scoring in infants and very young children.[7,8,16,17] For instance, Gnidovec et al.[17] developed and tested a new actigraphic sleep-wake algorithm for infants (aged 1, 3 and 6 months) and demonstrated good validity in comparison to sleep-wake scoring based on direct observations only at the ages of 3 and 6 months. As mentioned above, some of these studies reported low sensitivity problem which cast serious doubts about the validity of the specific devices or algorithms.

In adolescence, a large-scale study compared total sleep time derived from actigraphy and PSG in youngsters with and without sleep-disturbed breathing.[18] The authors also compared three different modes of actigraphic data collection (zero crossing, time above threshold, and proportional integration mode). They reported that the time above threshold method provided the best results. Overall, actigraphy underestimated sleep time in comparison to PSG. Better correspondence was found for girls in comparison to boys. Increase in apnea-hypopnea index (AHI) was associated with more PSG-Actigraphy discrepancy. Hyde et al.[19] assessed the validity of actigraphy in assessing sleep in children (age range: 1–12 years) with sleep-disordered breathing and reported high epoch-by-epoch agreement rates with PSG sleep-wake scoring. As reported in other studies the authors reported relatively low specificity (or ability to detect waking epochs, ranging between 39.4 and 68.9%) but concluded that actigraphy is a reliable method to assess sleep in children.

Laakso et al.[20] compared actigraphy and PSG in children with intellectual deficits and motor handicaps. They reported that in healthy children with no sleep disorders there was a good correspondence in sleep time assessment; whereas in the sleep disturbed and the handicapped children significant discrepancies existed between measures derived from PSG and actigraphy. Another study examined the validity of actigraphic sleep assessment in comparison to PSG in patients with tetraplegia.[21] The findings indicated that similar validity (based on hand movements) was obtained from normal controls and patients with C5-C7 tetraplegia. In patients with C4 tetraplegia, comparable results to normal controls were obtained with head movement monitoring. Overall, these findings suggested that actigraphy is a viable option for sleep assessment in patients with tetraplegia.

Another challenging population for actigraphy is older adults or elderly people. Mehra et al.[22] assessed actigraphic sleep in a large sample of women ($N = 455$, age range 76–93 years) who were assessed with PSG at different times. They reported significant associations between actigraphic sleep measures and PSG-based classifications of sleep disorders such as periodic limb movements in sleep (PLMS) and sleep-disordered breathing (SDB). However, the authors concluded that the discriminant ability of the actigraphic measures is insufficient to be used for diagnosis, but can provide information for identifying individuals at risk for PLMS and SDB.

Finally, in another study assessing sleep in unique conditions, Signal et al.[23] compared actigraphy and PSG sleep-wake scoring in flight crew members during in flight and layover sleep episodes. They reported good actigraphic-PSG correspondence on sleep duration but moderate to poor correlations for sleep efficiency (SE) and SOL. This was not surprising considering the fact that on epoch-by-epoch comparison, low specificity was observed.

Based on the studies reported above on the validity of actigraphy against PSG it can be concluded that the most eminent threat to the validity of actigraphy in assessing sleep is the low specificity reported in many studies. Specificity (or accuracy in detecting wakefulness) lower than 60% (reported in many studies) is likely to compromise all derived sleep indices of true sleep time, sleep efficiency, wake after sleep onset, etc. It can be argued that the aggregated data derived from actigraphy over multiple nights (at least 4–5 nights or more as recommended by Acebo et al.[24]) may compensate, to some extent, for compromised accuracy on a single night, but this is yet to be established by proper research. The use of Kappa estimates of reliability that take into account chance agreement may better represent agreement rates between actigraphy and PSG.

Another important point that deserves attention is that actigraphic validation studies against PSG are based, almost with no exceptions, on "time in bed" period (usually in a sleep lab) whereas the main advantage of actigraphy is in documenting sleep-wake patterns continuously over 24-h periods across days. Thus, validation studies should consider expanding the comparison period to cover longer periods in and out of bed with extended wakefulness periods.

Comparing subjective and actigraphic sleep measures

Another common comparison related to actigraphic validity is the comparison between actigraphy and subjective reports. For instance, Kawada[25] compared actigraphy and 24-h reports on sleep-wake patterns in young adults. He reported agreement rates of 77.5% for wake and 86.1% for sleep. However, because of measurement failure during wakefulness, he concluded that sleep diary may be more valid for detecting sleep-wake cycle.

Sleep diaries and caregivers' reports are very common in sleep studies in young children and in disabled adults. Hoekert et al.[26] compared actigraphic sleep measures to those obtained from caregivers' reports on sleep in elderly and demented individuals resigning in homes for the elderly. Overall, they found good correlations between actigraphic and reported sleep schedule measures ($r = .88$ for sleep onset time, and $r = .92$ for sleep offset time). The correlation for assumed sleep time was lower ($r = .46$) with caregivers overestimating assumed sleep (between sleep onset and sleep end) by an average of 96 min. The authors concluded that actigraphy and caregivers' reports can play complementary role in assessing sleep in demented elderly people.

So et al.[27] compared actigraphic and diary measures in assessing sleep in infants during the first year of life. They found good overall correspondence between the methods but the parental sleep diaries overestimated sleep in comparison to actigraphy. With regard to the correspondence between actigraphy and parental reports on infant sleep, it is interesting to note that externally induced motion was found to occur in 40% of the recording time in infants and to significantly alter actigraphic data.[28] Sadeh[29] compared actigraphic sleep measures to parents' reports on a sleep questionnaire and sleep diary of sleep-disturbed infants and controls. High actigraphy-sleep diary correlations were found for sleep schedule measures (.96 for sleep onset time and .87 for sleep period), whereas the correlation for the number of night-wakings was significantly lower (.49). Holly et al.[30] compared parental reports and actigraphic recordings of school-age children and found that parents' reports on night-wakings were poorly correlated with actigraphically detected night-wakings. Iwasaki et al.[31] compared actigraphy, parental daily logs and sleep questionnaire in assessing sleep of 5-year-old children. Parental sleep schedule variables correlated well with actigraphic measures, although reported sleep periods were longer than those detected by actigraphy. Significant discrepancy was found for night-waking frequency. Equivalent findings have been reported in a similar study in 4–7 year old children.[32] Finally, Wolfson et al.[33] compared actigraphy and survey sleep measures in a large sample of adolescents and found good correlations for sleep onset and sleep offset times ($r = .70$ and $r = .77$, respectively for school nights). However these correlations dropped significantly during the weekends ($r = .48$ and $r = .52$, respectively). Furthermore, the correlations for total sleep time were significantly lower ($r = .53$, for school nights, and $r = .31$ for weekends).

Another interesting issue is the stability of actigraphic sleep measures over time. Knutson et al.[34] have studied daily and yearly variability of actigraphic sleep measures in adults. They found high intra-subject correlations (over a year) for the actigraphic sleep measures: .76 for total sleep time (TST), .93 for SOL, and .90 for SE. Interestingly, actigraphic sleep measures were significantly more variable on a daily basis than on a yearly basis. In another longitudinal study in early adolescence, Sadeh et al.[35] reported somewhat lower yearly correlations for actigraphic sleep measures mostly ranging between .60 and .77, but still indicating significant stability in this age period of substantial maturational changes in sleep patterns.

Overall, it can be concluded that actigraphic sleep variables demonstrate reasonable test-retest reliability in the form of relative good stability over time (days and even years between measurements). There is reasonable support for the validity of actigraphy measures of sleep schedule and sleep period in comparison to subjective reports on these measures. When actigraphic sleep quality measures (night-wakings, wake after sleep onset, sleep efficiency) are considered, the correspondence with subjective reports is relatively poor. However, it is not clear from these studies, to what extent these discrepancies should be attributed to inaccuracy of actigraphy versus inaccuracy of subjective reporting. Studies comparing actigraphy versus subjective reports with simultaneous PSG may help in clarifying this issue.

New validation and data analysis approaches

Most sleep-wake scoring algorithms are based on a combination of linear compilations of activity levels (in predefined windows around the scored minute) and smoothing or other logical decisions. A new approach, based on artificial neural networks and decision trees, have shown promise in sleep-wake scoring in infants and some advantage over more traditional scoring algorithms.[36] Based on this approach, the authors reported 86.9% accuracy, 94.1% sensitivity and 65.5% specificity in healthy infants and somewhat lower precision in clinical samples.

Another new actigraphy-based approach to assess infant sleep-wake patterns has been introduced by Sazonov et al.[37] They attached the sensor to the diaper rather than to the infant's ankle (as done in most earlier validation studies) and reported similar indices of validity to those obtained by ankle placement. Similarly, Enomoto et al.[38] assessed the validity (compared to PSG) of a new device designed for waist placement and demonstrated similar validity indices to those reported for wrist actigraphy. Furthermore, new actigraphy devices have been introduced and validated (e.g.,[39]).

Chae et al.[40] reassessed the specific criterion for actigraphy defined sleep onset and found that the best criterion (with their specific dataset and device) was 5 min of inactivity. This criterion provided the best actigraphy-PSG correspondence for SOL, TST and wake after sleep onset (WASO). This is an important finding, because different criteria have been used in the past (e.g., 10 or 15 min of sleep or immobility).

These studies indicate that the search for new methodologies and algorithms is an ongoing effort which hopefully will enable the field to overcome some of its shortcomings.

Actigraphic assessment of sleep disorders

Assessment of insomnia

The role of actigraphy in the evaluation of insomnia has been documented in earlier reports.[1–3,41] The main consistent conclusion has been that actigraphy overestimates sleep time (as manifested in shorter SOL and WASO) because of efforts of individuals with insomnia to fall asleep by lying in bed motionless for extended periods. New studies have replicated, challenged and extended these earlier reports.

Lichstein et al.[42] conducted a PSG-Actigraphy validation study, based on one laboratory night, with the largest sample ($N = 57$) of individuals diagnosed with insomnia. Contrary to other studies, no significant PSG-Actigraphy differences were found on the means of any of the sleep measures including TST, SE, WASO, number of night-wakings, and SOL. Medium to high PSG-Actigraphy correlations were found on the first 4 measures. The authors concluded that actigraphy (with the specific setup used in their study) provides satisfactory objective sleep measures in individuals with insomnia.

Vallières and Morin conducted a study assessing the correspondence of PSG, actigraphy and diary measures in assessing sleep in 17 participants with chronic primary insomnia.[43] The comparison was based on 2 baseline and 2 post-treatment nights. The findings reflected reasonable actigraphy-PSG correspondence which overall surpassed the diary-PSG correspondence. As in most other studies, actigraphy underestimated SOL in comparison to PSG.

Along similar lines, Siversten et al. assessed the accuracy and clinical utility of actigraphy in comparison to PSG in older adults treated for chronic insomnia.[44] The sample included 34 participants with chronic primary insomnia (mean age: 60.5 years). The study compared cognitive-behavioral therapy (CBT), drug intervention and placebo control. When compared to PSG, the actigraphic epoch-by-epoch sleep-wake scoring demonstrated high sensitivity to sleep (95.2%) but low ability to detect wakefulness (specificity: 36.3%). As pointed earlier in the discussion of algorithm validation, the authors reported that the accuracy of the sleep-wake scoring was dependent on PSG-determined sleep efficiency. Poorer sleep was associated with poorer accuracy.

Another recent study reassessed the validity of actigraphy in assessing insomnia.[45] Thirty-one participants diagnosed with primary insomnia were compared to 31 controls using actigraphy and PSG monitoring at their homes. As reported in earlier studies, in comparison to PSG, actigraphy underestimated sleep latency. No differences were found between actigraphy and PSG estimates of WASO, TST and SE. Medium to large correlations were found between most of the PSG and actigraphic sleep measures. For instance, the correlations for sleep latency were .57 and .80 in insomnia patients and controls, respectively. The correlations for WASO were .85 and .78, for TST: .92 and .93; and for SE: .77 and .81, respectively. 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 et al. assessed the validity of actigraphy in distinguishing between 126 insomnia patients and 282 normal controls.[46] They found significant group differences in actigraphic sleep measures. In comparison to the controls the insomnia patients had significantly longer SOL and WASO, shorter TST, increased number of night-wakings and, lower SE. Furthermore, they found that a linear function based on 3 actigraphic measures (number of night-wakings longer than 5 min, TST, and SOL) discriminated well between individuals with insomnia and controls.

Considering the high night-to-night variability in sleep patterns in insomnia, it has been suggested that a period of at least one week is needed to provide reliable estimates of sleep.[47] In a study comparing PSG and actigraphic scoring of sleep time and SE, Van Someren has demonstrated improved reliability and reduction in PSG-Actigraphy measures discrepancy with the growing number of monitored nights. Buysse et al.[48] also noted the high night-to-nigh sleep variability as demonstrated by subjective and actigraphic measures.

Considering these studies and earlier ones, it can be concluded that actigraphy provides sleep assessment with reasonable sensitivity to detect group differences between clinical groups of individuals with insomnia and controls. These findings suggest that actigraphy can provide meaningful data in the assessment of insomnia. It is however, very important to remember that large discrepancies between subjective reports of insomnia patients and actigraphy measures should not be automatically attributed to inaccurate patients' reports, and are also likely to occur because of the inability of actigraphy to detect motionless wakefulness which is quite common in insomnia.

Assessment of PLMS, sleep-disordered breathing and narcolepsy

One of the recent developing applications for actigraphy is the assessment of PLMS.[49–56] To detect PLMS, actigraphy is usually used in a high resolution mode (short epochs; e.g., 5-sec intervals) and compared to EMG data derived from a simultaneous actigraphy-PSG study. In an earlier study, Sforza et al.[54] reported high correlation between actigraphy and PSG in detecting movement but actigraphy significantly underestimated leg electromyographic activity and therefore, was not recommended for regular diagnostic purposes. More recently, Sforza et al.[53] reported better results with a device specially tailored to detect limb movements and PLMS with high time resolution. The actigraphic measure of PLMS from this was highly correlated with PSG-defined PLMS ($r = .87$) and both sensitivity and specificity for detecting PLMS index >10 were in an acceptable range, .88 and .76, respectively. The authors concluded that this new methodology is highly reliable and can be used for assessment. Similarly, King et al. reported excellent validity indices for documenting PLMS in comparison to PSG.[49] However, an attempt to replicate these findings with children (ages 4–12 years) failed to reach acceptable validity and the authors concluded that the method is not accurate enough for assessing PLMS in children.[50]

Actigraphy has never been considered as a valid tool to assess SDB although some actigraphic measures are correlated with SDB indices.[1–3] Some recent studies suggest that actigraphy may assist simplified polygraphy in diagnosing SDB.[57,58] For instance, Elbaz et al.[57] compared PSG-derived AHI to an estimate derived from simple respiratory polygraphy (with time in bed (TIB) as an estimate for sleep duration) and an estimate based on simple polygraphy and actigraphy-based TST. The results indicated that the use of actigraphy-based estimate TST improved the validity of the AHI estimate based on simple polygraphy. A similar study indicated that the contribution of actigraphy to assess TST for the calculation of AHI was a relatively minor one.[58]

Gagnadoux et al.[59] compared PSG- and actigraphy-based TST estimates in sleep apnea patients and found very good correspondence with a correlation of .90 and a mean difference in TST estimate of only 2.5 min. Furthermore, they used actigraphy to assess the daily use of nasal continuous positive airway pressure (nCPAP) as a function of TST. The use of nCPAP as a proportion of TST ranged between 41 and 100% (mean = 82%), and the authors suggested that actigraphy can be used to improve the assessment of treatment compliance.

Another disorder that is not often studied with actigraphy is narcolepsy. Middelkoop et al.[60] have demonstrated that actigraphic measures of daytime and nighttime uninterrupted immobility were able to distinguish between non-medicated patients with narcolepsy and controls. More recently, Bruck et al.[61] have replicated this finding and have also shown that the actigraphic measure of uninterrupted immobility can distinguish between non-medicated patients with narcolepsy and controls. Furthermore, they have shown that treatment with stimulants normalized this measure. These studies suggest that actigraphy may help in the diagnosis of narcolepsy. Furthermore, actigraphy is used to assess behaviorally induced insufficient sleep which is an essential component of the assessment of narcolepsy.[5,62]

In considering medical disorders, it can be concluded that recent studies have provided additional support regarding the role of actigraphy as a supplementary tool in the assessment of these disorders. They also underscore some of the existing limitations of actigraphy in taking a more leading role in diagnosing these conditions.

Assessment of sleep-schedule disorders

Previous reviews on actigraphy and/or sleep-schedule disorders have concluded that actigraphy is a good tool for assessment of these disorders.[1–3,5,63–65] However, no new validation studies have focused on this specific topic. Considering the repeatedly demonstrated high validity of actigraphy in assessing sleep schedule measures (sleep onset, rise time, TST) it is quite compelling to assume that actigraphy can provide an objective picture of the individual's sleep-wake schedule and therefore facilitate the diagnosis of these disorders.

Actigraphic assessment of interventions for sleep disorders

Assessment of non-pharmacologic interventions for insomnia

Recent studies on insomnia treatment have replicated earlier findings and demonstrated that actigraphy is sensitive to intervention effects as reflected in improvement of actigraphic sleep measures.[43,44,66,67] For instance, Sivertsen et al.[44] reported that actigraphy detected the changes in total sleep time and WASO, but failed to detect the PSG-identified improvement in SOL and SE. The authors concluded that the clinical utility of actigraphy in older adults with insomnia is still suboptimal and requires the use of supplementary assessment methods.

Another study focused on the assessment of CBT for insomnia using actigraphy and sleep diary data.[66] In this study, CBT was compared to sleep hygiene education in patients with primary insomnia and patients with insomnia associated with other psychiatric disorders. Actigraphy and sleep diaries were used to assess sleep during baseline, post-treatment and 6-month follow-up periods. Actigraphy reflected superior intervention effects for CBT as manifested mainly in significant reduction in WASO and increase in SE. In another study assessing CBT for insomnia, Manber et al.[67] also reported that actigraphy detected significant improvement in all actigraphic sleep measures including WASO, TST, and SE.

Espie et al.[68] demonstrated that a CBT-based intervention conducted by primary care nurses was effective in improving sleep in comparison to treatment as usual. Actigraphy detected significant improvement in WASO, whereas sleep diaries detected also significant improvement in SOL and SE. Taken together, these studies demonstrated the sensitivity of actigraphy in detecting changes in sleep associated with behavioral intervention for insomnia. Finally, Harris et al.[69] demonstrated that brief sleep retraining was effective in improving sleep in patients with chronic primary insomnia as evidenced by subjective and actigraphic measures.

Subjective perception of sleep is often highly distorted in individuals suffering from insomnia and they tend to overestimate SOL and underestimate sleep time. The usefulness of actigraphy for correcting such distortions has been demonstrated in a clinical study.[70] In this study sleep of 40 patients suffering from insomnia was monitored at home for 3 days using sleep diaries and actigraphy. Using the collected data, half of the sample (randomly assigned) received feedback on the subjective-actigraphic sleep discrepancy and the second half received no such information. Following the intervention sleep was again monitored for additional 3 days. In comparison to the no-feedback group, participants who received discrepancy feedback were more accurate in their SOL estimation on the post intervention nights and reported less anxiety and preoccupation with sleep. The results demonstrated the potential of actigraphy in correcting subjective distorted perceptions about sleep as an essential component in the therapeutic process with insomnia patients.

It is important to note that not all studies using actigraphy to assess effects of non-pharmacologic interventions provided positive results. For instance, Ouslander et al.[71] assessed the effects of an intervention based on sleep hygiene rules, evening bright light exposure and sleep promoting conditions in community nursing homes. Actigraphy did not detect any changes in sleep associated with the intervention, but nor did polysomnography in a subsample. Because of the failure of both actigraphy and polysomnography in detecting changes in sleep it would be reasonable to conclude that the intervention failed to produce change.

Overall, these recent findings and the accumulative knowledge from older studies suggest that actigraphy is a valuable tool in assessing changes in sleep patterns in response to behavioral interventions for insomnia. This is particularly true at group level. At the individual level, actigraphy can still yield substantial errors in assessing motionless wakefulness.

Assessment of drug interventions

Actigraphy has been often used to assess the effects of drug interventions on sleep patterns.[1–3,72] It has been demonstrated that actigraphic sleep measures are sensitive enough to detect changes related to such interventions. Newer studies continue to provide evidence that supports the validity of actigraphy for such applications. It is beyond the scope of this review paper to cover all studies in this area, but a few examples will serve to illustrate this point. Some of the studies reported earlier on actigraphy in insomnia patients have also tested and demonstrated the sensitivity of actigraphy in documenting drug induced improvement in sleep in these patients.[44] Furthermore, Wilson et al.[73] used actigraphy to assess the effects of temazepam on sleep in patients suffering from insomnia. Actigraphy was sensitive enough to detect sleep changes during periods of drug administration and withdrawal. Paul et al.[74] assessed the effects of melatonin and zopiclone in air crew members coping with adaptation with transatlantic flights and time zone changes. Actigraphic measures indicated that both zopiclone and melatonin had positive impact on sleep patterns and facilitated adaptation. De Castro-Silva et al.[75] studied the effects of 3 mg Melatonin on sleep in patients with cystic fibrosis. Melatonin administration significantly reduced nitrite levels and improved actigraphic SE. Impressive positive impact on actigraphic sleep has been documented with administration of melatonin to children with Asperger's syndrome.[76]

Sleep in other medical and mental disorders

Actigraphy has been used extensively to assess manifestations of altered sleep in individuals suffering from medical or mental disorders and to assess the impact of specific medication for the disorder in improving sleep of these individuals. It is beyond the scope of this review paper to cover the dozens of studies using actigraphy to document sleep in all these conditions. A few examples will serve to illustrate this topic.

Attention deficit hyperactivity disorder (ADHD) is a common neurobehavioral disorder that has been extensively associated with dysregulated sleep and sleep disorders.[77–79] ADHD has been associated with increased likelihood of periodic limb movements disorder (PLMD) and SDB and irregular sleep schedule. Recent actigraphic studies in children and adults provided additional information and validated earlier findings. For instance, Gruber et al.[80] documented increased night-to-night variability in sleep schedule of children with ADHD in comparison to controls. More recent studies have replicated these findings.[81–83] Hvolby et al.[83] also reported longer SOL in children with ADHD. However, Owens et al.[84] failed to find increased night-to-night variability in children with ADHD but reported shorter actigraphic sleep and more disturbed sleep in comparison to controls. In adults with ADHD, Boonstra et al.[85] documented with actigraphy longer SOL, lower SE and shorter bouts of uninterrupted sleep in comparison to controls. However, not all studies have replicated the associations between actigraphic sleep and ADHD. For instance, a study looking at the associations between sleep patterns in typically and atypically developing children with or without ADHD profile, failed to detect any differences in actigraphic sleep measures although significant differences were found in reported sleep patterns.[86] Perhaps different underlying characteristics can explain some of these differences in actigraphic sleep findings in individuals with ADHD.[87] However, an attempt to compare ADHD subtypes has failed to document differences in actigraphic sleep measures.[88] Recent studies have also demonstrated (using actigraphy) the effects of the common drug used to treat ADHD (methylphenidate – MPH) on sleep,[89–91] and the benefits of melatonin treatment for children with ADHD and sleep onset insomnia.[92,93]

Another example demonstrating the sensitivity of actigraphy in detecting distinct sleep patterns is related to acute or chronic pain disorders. Distinct sleep patterns have been documented in pain-related disorders in children[94–96] and adults.[97,98] Yet another example is the case of allergies. Actigraphy has been used to document compromised sleep patterns in patients suffering from allergic rhinitis.[99,100]

New research applications for actigraphy

Many sleep-related research protocols report using actigraphy to verify that their participants followed a certain sleep schedule before coming to the lab for testing (e.g., to exclude prior sleep deprivation or sleep problems). However, a relatively new application of actigraphy is for ambulatory research on sleep restriction or sleep deprivation conducted in the participants, own natural environment. For instance, Sadeh et al.[101] performed a study on sleep restriction/extension in school-age children using actigraphy to document regular sleep schedule of the children and then to verify that they went to sleep 1 h earlier or later (according to random assignment) for 3 consecutive nights. Actigraphy revealed sleep extension or restriction of about 40 min per night, under these conditions. The children's neurobehavioral functioning was assessed using computerized tests at school during mornings after regular sleep and following the 3 nights of sleep restriction/extension. The results showed significant deficit associated with sleep restriction in comparison to sleep extension. Similar protocols have been used in additional studies in children[102–104] and adults.[105]

Conclusions and recommendations

The following conclusions can be derived from this review:

- In comparison to PSG, actigraphy has reasonable validity and reliability in assessing sleep-wake patterns in normal individuals with average or good sleep quality.
- The validity of actigraphy in special populations (e.g., elderly people, individuals with other major health problems or individuals with poor sleep quality) is more questionable.
- The main methodological problem associated with the validity of actigraphic sleep-wake scoring is the relatively low ability to detect wakefulness during sleep periods reported for certain devices, algorithms and populations.
- Actigraphy has good agreement with subjective reports on sleep schedule parameters. With regard to sleep quality measures (e.g., night-wakings or SE) there is relatively low correspondence between actigraphy and reported sleep measures.
- Special actigraphy devices and algorithms for the assessment of periodic limb movements have shown some promise in validation studies and can be used for screening purpose in large populations.
- Actigraphy is sensitive in detecting compromised or altered sleep patterns in individuals with specific sleep disorders or other medical or neurobehavioral disorders.
- Actigraphy is sensitive to changes in sleep associated with pharmacologic and non-pharmacologic interventions for individuals with sleep disorders or other medical disorders that comprise sleep.
- Movement artifacts and other technical failures should always be considered and managed before using automatic algorithms to analyze actigraphic data.
- It is always crucial to remember that in the final analysis actigraphy only measures movements and not sleep per se, and therefore it is affected by other neurobehavioral systems and control mechanisms that are unrelated to sleep (e.g., disorders of the motor system).

Practice points

1) Actigraphy is a cost-effective method to objectively assess sleep and sleep disorders.
2) Because of many validity issues it is recommended, whenever possible, to use actigraphy in concert with complementary objective and subjective methods to reduce uncertainties associated with actigraphy and to obtain more detailed information beyond the limited data derived from body movements.
3) It is important to refer to the literature for information on the validity of the specific device and algorithm used with the specific population under study. Different devices have unique physical characteristics and scoring algorithms and one cannot assume that all devices automatically fit to the general view that actigraphy is valid for sleep assessment.
4) In assessing reports on validity of actigraphy one should look for high sensitivity and at least a reasonable sensitivity (not below .60) in the epoch-by-epoch PSG-actigraphy comparisons. General agreement rates may be misleading. One should also look for additional reliability statistics such as Kappa estimates of reliability, correlations between actigraphy- and PSG-derived measures or Bland–Altman plots.
5) Extended monitoring (5 days or longer) reduces the inherent measurement errors in actigraphy and increases reliability.
6) Actigraphy appears to be sensitive to clinical interventions in sleep medicine. It provides objective data on the efficacy of the intervention. Clinical interventions are usually based on an extended process over days and weeks and therefore have good fit with the advantages of actigraphy for long-term monitoring.

Research agenda

1) In light of the limited validity of actigraphy in special populations or in individuals with compromised sleep or movement-related disorders, it is important to pursue the efforts to improve or develop new tailored algorithms to overcome this major limitation of actigraphy. It is also recommended to expand the comparison between actigraphy and PSG to cover extended periods of in and out of bed activities to correspond more closely to the way actigraphy is commonly practiced (24/7 monitoring).
2) Continue development and validation of devices specially tailored to detect PLMS, breathing-related movements and SDB detection.
3) Continue development of additional information channels on the devices, including light, temperature, removal detection and perhaps different frequency

filters for movement detection to enable better identification of artifacts, breathing-related movements, PLMS and other clinically viable data (e.g., light exposure).
4) Explore methods for automatic detection of potential movement artifacts for better reliability of the data.
5) Pursue and expand research on various clinical populations. Particularly missing is more research on sleep-schedule disorders and diagnostic criteria for actigraphy-based identification of these disorders.

Conflict of interests

The author has no conflict of interests to disclose.

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