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Review

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The role of actigraphy in sleep medicine

Behavior in the home setting plays an important role in many sleep-related disorders. Despite the availability of actigraphy, longitudinal disease and treatment courses are usually recorded using subjective reports (e.g., sleep logs/sleep diaries).

Actigraphy has been used for more than 60 years to objectively measure sleep–wake rhythms [1]. The procedure makes it possible to measure and evaluate movement and other parameters such as light exposure over a prolonged period of time.

In recent years, actigraphy has been increasingly used in the clinical setting. Modern medical actigraphs are more accurate and reliable due their improved piezoelectric motion sensors, lithium batteries, and enhanced storage capacities.

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Current devices are able to record motor behavior over periods of up to months. Their improved waterproofing and low weight make them suitable for prolonged use under natural conditions, even on moving surfaces (e.g., on ships) [2]. Thus, insight can be gained into the motor phenomena of activity and rest phases as well as of circadian rhythms.

Since the cost of wrist actigraphy is not reimbursed, this method has not enjoyed wide acceptance to date. The present article provides an overview of its main clinical applications (**Table 1**).

If one puts the main measuring instruments used in sleep medicine in order of accuracy, modern actigraphs rank below the accuracy of polysomnography for the majority of variables measured. Their chief advantage lies in the cost-effective collection of objective data over prolonged periods of time, usually 7–14 days, under everyday conditions. Particularly when investigating insomnia, hypersomnia, and circadian rhythm disorders, longer measurement periods significantly improve validity [4]. For a correct assessment of the sleep onset spectrum, it is important to have a detailed knowledge of the different assessment procedures (**Fig. 1**). This plays a special role, for example, in the assessment of insomnia patients, as there can be considerable discrepancies between sleep protocols and actigraphy findings.

Actigraphs

Technical features

Newer actigraphs record motion in up to three axes. The recorded data are usually processed in a frequency range of 0.25–3 Hz with band-pass filters before they are saved. As a general rule, the epochs used in actigraphy devices can be freely selected; in sleep medicine practice, they are usually 30 or 60 s.

For adaptation of the scoring algorithms, empirical values or laboratory

Table 1 Overview of investigation methods used in sleep medicine

Investigation method	Advantages	Disadvantages
Sleep questionnaire	Brief and economical to use Low patient burden	Recall bias Limited reliability in some patient groups (children, dementia, malcompliance, language barriers/difficulties in understanding) Partially relies on patient's ability for introspection
Sleep diary	Documents day-to-day variability Less bias than questionnaires Records everyday behavior (home setting)	Greater patient burden Needs to be completed daily Influenced by expectations
Actigraphy	Objective information Documents day-to-day variability Records everyday behavior (home setting)	Limited determination of sleep onset latency (SOL) Higher costs compared to diary, problems regarding reimbursement Additional diary-keeping is useful
Polysomnography	Gold standard for the diagnosis of numerous sleep disorders and the evaluation of their treatment Records actual sleep physiology, structure, quality, and quantity	High patient burden High costs Laboratory environment with first-night effect (altered sleep due to the first night of polysomnography) Unable to investigate sleep in context

Table 2 The most important variables in the sleep diary and actigraphy report

Sleep diary/event marker	Light off (sleep attempt starts) Light on (sleep attempt ends) Length of sleep attempt	
Actigraphy	**Night:** *Sleep onset time* *Sleep onset latency* (SOL; reported bedtime to sleep onset time) *Sleep offset time* *Sleep opportunity* *Total sleep time* (TST) *Night awakening* (frequency, duration) *Sleep efficiency* (TST/sleep opportunity) *Evaluation of ultradian rhythms* [13]	**Day:** *Number of sleep episodes* (naps, daytime sleep) Percentage of *daytime sleep* in a 24-h period

Table 3 Suggested procedure for actigraphy in a sleep centre. (Adapted from [14])

A: Initial consultation: the actigraphy device is issued at the sleep center
1. Use of the actigraphy device is explained Event markers (marking bedtime and getting-up time) are demonstrated
2. Actigraphy directions for use (waterproofness, when to take the device off, etc., setting event markers, etc.) are explained and given to the patient
3. Keeping a sleep diary is discussed (recording sleep opportunity, sleep attempts, naps, etc.)
4. Sample actogram is explained (data recording process explained to patient)
5. Patient signs confirmation of receipt—patient provided with postage materials needed to return the device
B: Preparing the follow-up visit (return of actigraph by post, data preparation)
1. Downloading of raw data from actigraph
2. Data cleansing with sleep diary and event marker
3. Definition of sleep opportunity in software (main sleep phase, recording naps and daytime sleep episodes)
4. Selection of score settings, actogram printout, and datasheet
C: Follow-up consultation: discussion of findings with patients
1. Detailed daily history on sleep behavior
2. Determination of distorted perception regarding sleep times (e.g., mismatch between actigraphy and sleep diary in insomnia patients)
D: Report generation, treatment planning
E: If necessary, follow-up of treatment outcome upon completion of therapy

standards are used. The fact that there are as yet no standardized scoring recommendations negatively affects the objectivity of scoring and inter-rater reliability [6].

Data acquisition and cleansing

Wrist actigraphy usually measures day–night rhythms in daily life over 1–4 weeks [7]. The ideally waterproof devices are worn on the non-dominant hand for 24 h.

Additional information such as subjective total sleep time and quality can be recorded in a sleep diary. This can be used when discussing findings with the patient, in order to reconstruct everyday situations together with the patient and correlate these with the recorded actigraphy [8].

The use of actigraphy event markers as soon as a sleep attempt begins (eye closure, corresponding to actigraphy lights-out) and ends (opening eyes in the morning, getting out of bed, corresponding to

actigraphy light-on) has proven successful.

At the same time, sleep opportunity, which is often spent on other activities (e.g., watching TV, reading, eating) can be distinguished from actual sleep attempts. Nighttime sleep interruptions, such as visits to the toilet, are not marked by patients.

Thus, the actigraphy system is able to record the length of sleep, which is needed later to calculate the actigraphy variables (see **Table 2**; [9]).

After downloading the actigraphy data, manual data cleansing should be performed. This makes it possible to significantly improve the actigraphy report [10]. Sleep-related data are then calculated, and an actogram generated with visualization of the day–night rhythm (see **Fig. 2**). In clinical practice, automated analysis is generally used to this end [11, 12].

The graphic representation of the actogram (see example in **Figs. 2 and 3**) can be readily used in the consultation process and compared with the patient's subjective perception.

Actogram interpretation

An example actogram of a care home resident recorded over a 1-week period is presented in **Fig. 2**.

Case study

Actigraphy in social jetlag phenomenon

An extract from a 3-week actigraphy of a patient with social jetlag (SJL) is presented in **Fig. 3**.

Actigraphy vs. wearables in sleep medicine practice

In sleep medicine consultations, patients often present measurements that have been recorded using smartphones or commercially available wearables.

A number of points need to be considered when interpreting these data:

1. These devices are often unvalidated compared to standard sleep medicine methods (actigraphy or polysomnography) [15].
2. Analysis software is subject to a continuous process of review, hampering its use in research projects [16].
3. The software's evaluation algorithms are generally not known or cannot be modified [16].
4. At present, professional actigraphy devices are superior to commercially available wearables in terms of data acquisition and security, as well as their evaluation algorithms [17].
5. The sensors used to measure motor activity are not scientifically validated.
6. The threshold values for measuring motor activity differ from manufacturer to manufacturer. Data visualization is not transparent.
7. Statements on sleep structure and quality that are not scientifically validated are often made based on the measurement of movement frequency.

Thus, medical actigraphy devices continue to be recommended for clinical use [18]. Due to the widespread use of wearables and smartphone apps, their validation will remain an important challenge in the coming years for medical societies, some of which have set up their own task forces [19–21].

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The role of actigraphy in sleep medicine

Abstract

Actigraphy has been used for more than 60 years to objectively measure sleep–wake rhythms. Improved modern devices are increasingly employed to diagnose sleep medicine disorders in the clinical setting. Although less accurate than polysomnography, the chief advantage of actigraphs lies in the cost-effective collection of objective data over prolonged periods of time under everyday conditions. Since the cost of wrist actigraphy is not currently reimbursed, this method has not enjoyed wide acceptance to date. The present article provides an overview of the main clinical applications of actigraphy, including the recommendations of specialist societies.

Keywords

Circadian rhythm · Sleep-disordered breathing · Insurance, health · Polysomnography · Sleep initiation and maintenance disorders

Stellenwert der Aktigraphie in der schlafmedizinischen Versorgung (englische Version)

Zusammenfassung

Seit mehr als 60 Jahren wird die Aktigraphie eingesetzt, um den Schlaf-Wach-Rhythmus objektiv zu erfassen. Zunehmend werden verbesserte moderne Geräte angewendet, um schlafmedizinische Erkrankungen im klinischen Rahmen zu diagnostizieren. Aktigraphen sind zwar weniger genau als die Polysomnographie, aber ihr größter Vorteil liegt in der kostengünstigen Sammlung objektiver Daten über längere Zeiträume unter Alltagsbedingungen. Da die Kosten der Handgelenksaktigraphie derzeit nicht erstattet werden, hat dieses Verfahren bisher keine breite Akzeptanz erlangt. In der vorliegenden Arbeit wird ein Überblick über die wesentlichen klinischen Anwendungen der Aktigraphie sowie über die Empfehlungen der Fachgesellschaften gegeben.

Schlüsselwörter

Zirkadianer Rhythmus · Schlafbezogene Atmungsstörungen · Krankenversicherung · Polysomnographie · Ein- und Durchschlafstörungen

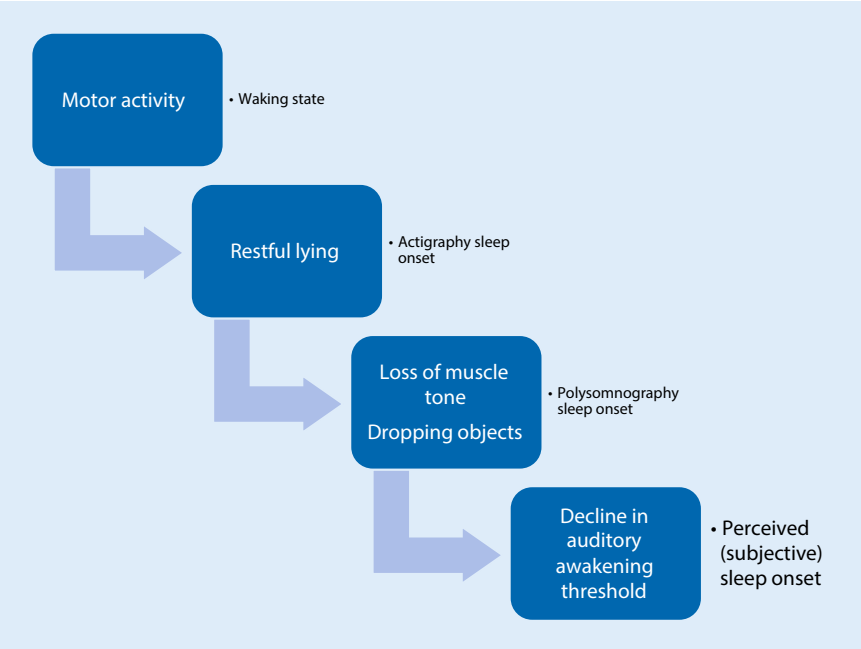

Fig. 1 ▲ Sleep onset spectrum. (Adapted from [5]). The recorded sleep duration heavily depends on the measurement method used

Recommendations

ICSD-3 recommendations on the use of actigraphy

The current version of the International Classification of Sleep Disorders (ICSD-3) recommends actigraphy as a diagnostic tool to supplement classic sleep questionnaires and sleep diaries. Particularly in circadian rhythm disorders does actigraphy have an important role (◘ **Table 4**).

Recommendations on clinical use of actigraphy (AASM task force)

In 1995 and 2002, the American Academy of Sleep Medicine (AASM) classified actigraphy as a suitable research instrument but deemed its clinical benefit to be unclear. Manual evaluation of actigraphy data was recommended [23, 24].

In 2018, based on current evidence, the AASM issued new recommendations on the use of actigraphy in clinical routine (◘ **Table 5**; [25]).

Reimbursement aspects

In Germany, actigraphy has not as yet been included in the catalog of services covered by health insurers. To date, it has been billable to the patient as an individual health service (IGeL). A revised catalog of services for privately insured patients includes actigraphy for at least 7 days as a reimbursable service. A policy decision in this regard is pending.

In Switzerland, actigraphy is included in the catalog of mandatory health insurance services, assuming the investigation is carried out at a sleep center recognized by the Swiss Society for Sleep Research, Sleep Medicine, and Chronobiology (SGSSC). If this is not the case, the costs need to be cleared with the health insurance's medical officer before the investigation is performed.

No provision is made in primary care for the reimbursement of actigraphy in Austria at present.

Discussion

In healthy populations, actigraphy is able to reliably and adequately record total sleep time and sleep onset time within a 24-h period. Particularly in the case of longitudinal measurements, these results can be placed in a wider context: variances in sleep duration and time of sleep onset; weekly structure (SJL); diagnosis of non-24 syndromes by means of period analysis; estimation of chronotype (relation between time of sleep onset and natural light-dark change [photoperiod] and extent of SJL).

In recent years, actigraphy has been increasingly crystallizing as a clinical tool to diagnose disorders in sleep medicine [26]. In combination with a sleep diary, important information on sleep behavior in the home setting can be obtained over periods of 1–4 weeks with good cost efficiency.

When combined with detailed patient history taking, actigraphy is able to estimate the main sleep-related variables: total sleep time (TST), sleep efficiency (SE), and wake time after sleep onset (WASO) can be determined in numerous sleep disorders.

There are limitations to the use of actigraphy alone for the sleep assessment [27]. It underestimates TST in patients with severe daytime sleepiness, in patients with lower sleep fragmentation, and in patients with more severe sleep-disordered breathing. Actigraphy overestimates TST in patients with high sleep fragmentation, milder severity of sleep-disordered breathing, and short sleepers.

Thus, e.g., motionless wakefulness, as is more common in insomnia patients, is challenging to identify with this method. In order to record the high variability in sleeping patterns in insomnia patients, longer recording periods should be chosen [4].

Actigraphy generally shows good concordance with subjective patient reports on day–night rhythms (e.g., sleep-onset and sleep-offset times). However, there can be significant discrepancy between sleep quality variables such as WASO or SE and the patient's subjective perception. This mismatch needs to be taken into account at the treatment design stage, in order to be able to develop sustainable treatment plans together with the patients.

The automated evaluation algorithms currently used could be further refined in the future once data collection processes have been adapted to additionally use artificial intelligence [28].

In the authors' opinion, the factors that remain essential for the successful application of actigraphy in sleep medicine include the clarification of reimbursement

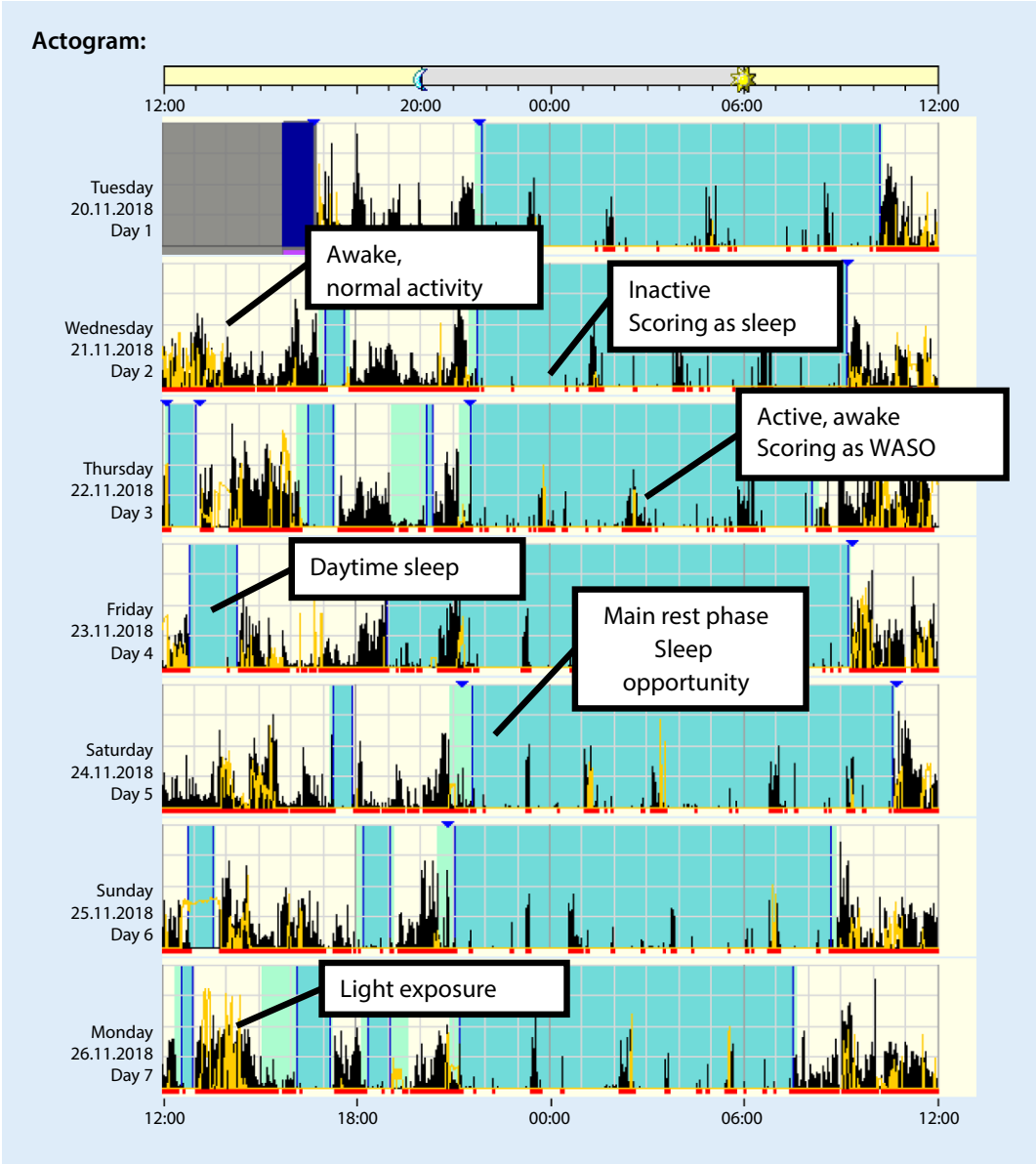

Fig. 2 ◀ Sample actogram of a care home resident recorded over 1 week. Subjective sleep maintenance disorder and prescription of hypnotics by general practitioner. Actogram interpretation: long main sleep phase with marked nighttime activity, numerous daytime sleep episodes, little light exposure, irregular daytime activity, physiological sleep efficiency. Treatment: restriction of bedtime initiated, age-appropriate daytime activity established, measures taken to activate the patient in the home environment with outdoor activity. *WASO* wake after sleep onset

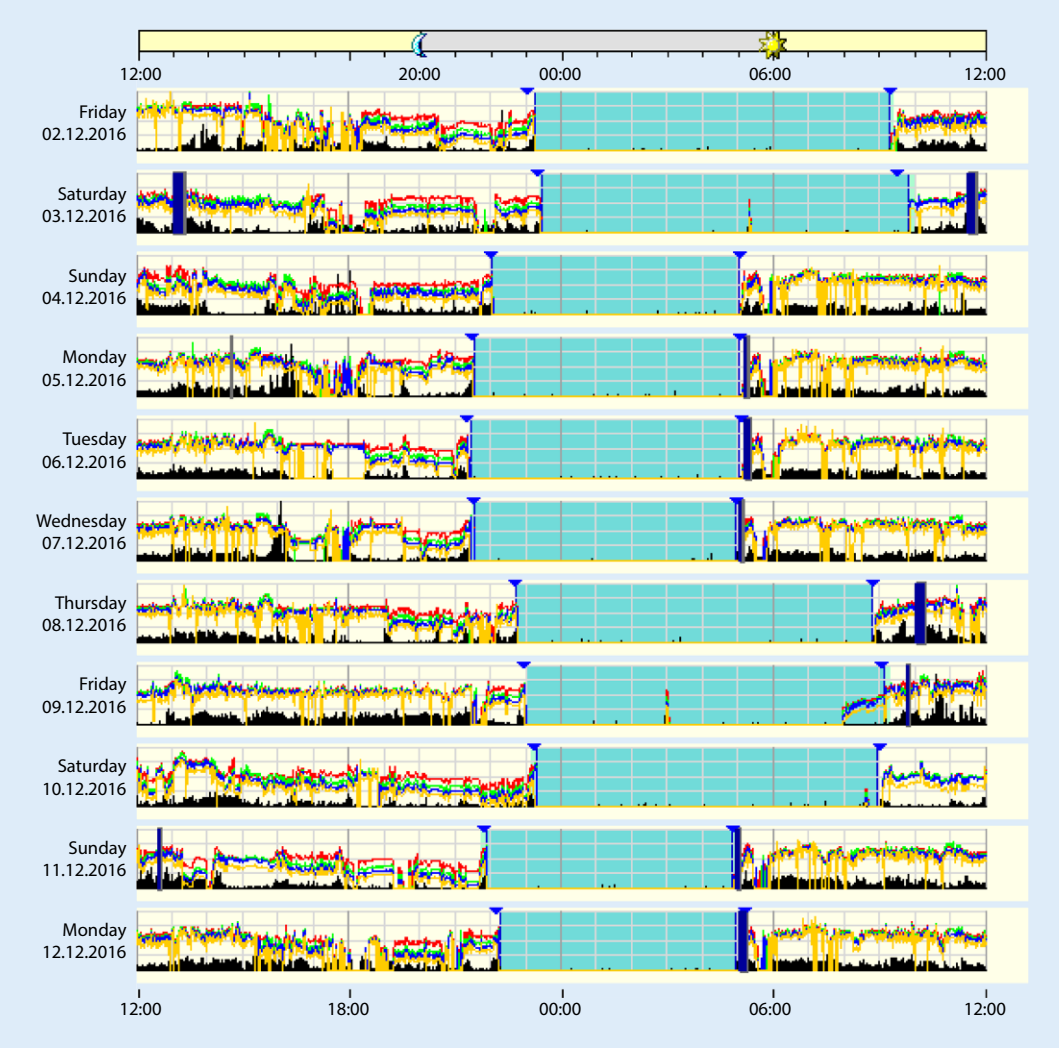

Fig. 3 ◀ Extract from 3-week actigraphy. The social jetlag phenomenon is evident: patient with daytime tiredness and subjectively perceived non-restful sleep. Visibly longer sleep opportunity at weekends. Sleep history with clearly divergent data, sleep diary not reliably kept. The *blue triangles* represent actigraph event markers placed by the patient at light out and light on. This makes it possible to measure the length of the sleep attempt (sleep opportunity)

Table 4 Recommendations in accordance with the third edition of the International Classification of Sleep Disorders (ICSD-3) [22]

Actigraphy: areas of application (ICSD-3)	
Multiple sleep latency test (MSLT)	"Strongly recommended," 1–2 weeks before an MSLT to document a sufficient number of sleep times
Idiopathic hypersomnia	Documentation of sleep duration using actigraphy and sleep diary, average over a minimum of 7 days: sleep time ≥ 660 min/24 h
Behaviorally induced insufficient sleep syndrome (BISS)	If the correctness of the sleep diary is called into doubt, actigraphy should be performed for at least 2 weeks
Normal variant: long-sleeper	Actigraphy to complement sleep diary recommended Criterion for adult long-sleeper: > 10 h sleep/24 h averaged over at least 1 week
Sleep–wake rhythm disorders Delayed sleep–wake phase disorder Advanced sleep–wake phase disorder Irregular sleep–wake rhythm disorder Non-24-hour sleep–wake rhythm disorder Shift work disorder Circadian sleep–wake disorder not otherwise specified (NOS)	If available, actigraphy for at least 7, but ideally 14 days including work/school days and weekends/leisure time

Table 5 Recommendation of the AASM's 2018 task force [25]

Insomnia (adults)	*Actigraphy useful to improve the differential diagnosis and when objective estimates of sleep parameters are important for clinical decision-making:* Recommended in non-response to cognitive behavioral therapy In cases where an increase in hypnotic dose is required, particularly if the validity of patient reporting is questionable Helpful in paradoxical insomnia Actigraphy can be helpful in longitudinal assessments of disease course
Insomnia (children)	*There is evidence that actigraphy yields objective data that differ significantly from patient-reported data.* *It can also be used in developmental disorders and autism spectrum disorders.* *Actigraphy is not subject to reporting bias on the part of the carer*
Circadian rhythm sleep–wake disorders (adults)	*Actigraphy is particularly helpful in the assessment of sleep-onset and sleep-offset times, as well as in the evaluation of treatment response*
Circadian rhythm sleep–wake disorders (children)	*It can also be used in developmental disorders and autism spectrum disorders.* *Actigraphy can record objective data that differ significantly from carer-reported data (sleep diary, etc.)*
Actigraphy that can be integrated in polygraphic devices	*This can improve the estimation of total sleep time compared to polygraphy alone*
Actigraphy to monitor sleep duration prior to carrying out a multiple sleep latency test (MSLT)	*Actigraphy can be performed 7–14 days prior to conducting polysomnography/MSLT in order to rule out insufficient sleep syndrome*
Investigation of insufficient sleep syndrome	*Recording over a period of 2–3 weeks is recommended depending on the clinical problem*
Strong recommendation **against** the use of actigraphy instead of electromyography in the investigation of periodic leg movements	*The majority of studies available to date have demonstrated a significant difference (over- or underestimation of the number of periodic leg movements) compared to standard electromyography*

issues and the further development of evaluation standards.

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Declarations

Conflict of interest. J. G. Acker, C. Becker-Carus, A. Büttner-Teleaga, W. Cassel, H. Danker-Hopfe, A. Dück, C. Frohn, H. Hein, T. Penzel, A. Rodenbeck, T. Roenneberg, C. Sauter, H.-G. Weeß, J. Zeitlhofer, and K. Richter declare that they have no competing interests.

For this article no studies with human participants or animals were performed by any of the authors. All studies performed were in accordance with the ethical standards indicated in each case.

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Fachnachrichten

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