Diagnostic Methods

H.-G. Weeß

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At first sight only, sleep disorders are simple and easily accessible diseases. Actually, they are complex disorders that require intensive and thorough diagnostics. The genesis of sleep disorders, in particular in older individuals, is multifactorial, and so an interdisciplinary approach is necessary. According to the *International Classification of Sleep Disorders* revised in 2014 (ICSD-3), about 50 sleep disorders may be distinguished. Sleep disorders may be based on single medical, physiological, psychological, psychopathological, or pharmacological factors, but frequently they only become obvious through the interaction of different etiological conditions. The following chapter describes the whole spectrum of diagnostic methods in sleep medicine, starting with history taking and continuing to device-related diagnostics in adults. Herein, the description of the core elements of diagnostic methods in sleep medicine, that is, polygraphy and polysomnography, is the focus. The standard measurement parameters of polysomnography are defined based on the criteria of the DGSM (Deutsche Gesellschaft für Schlafforschung und Schlafmedizin, the German Society of Sleep Research and Sleep Medicine). These criteria are complemented by the scoring rules for polysomnography and polygraphy (home sleep apnea testing), which are revised by the American Academy of Sleep Medicine (AASM) almost yearly. The parameters to be reported for polysomnography and polygraphy as well as the indications of polysomnography are described for different sleep disorders according to the evidence-based criteria of the AASM. Further, typical polysomnographic particularities of different sleep disorders are depicted in detail. A description of Specific diagnostic methods for children is given in ► Chap. 11.

Regarding the interdisciplinary nature of sleep disorders in the diagnostic process knowledge of internal medicine, pneumology, cardiology, neurology, psychiatrie, psychology and otolaryngology (ENT) is essential. Often the most frequent sleep disorders, such as insomnia and sleep-related breathing disorders, coincide. A single-sided focus of diagnostics and therapy on only one disorder does not address the patients' complaints in these cases.

2.1 History Taking

Structured clinical interviews lead to a higher validity of the patient's history.

Free clinical interviews in the context of medical history taking may lead to underestimating or overlooking significant symptoms.

Also, *standardized sleep questionnaires* for self-assessment of the quality and quantity of sleep, daytime impairments, observations of the bed partner, as well as information about potential origins of sleep disorders allow objectifying the medical history and are suitable to facilitate the diagnostic process and to make it more economical (► Sects. 2.3 and 2.8).

Regarding the exploration of sleep disorders, five basic principles should be considered:

- Even seemingly harmless sleep disorders require diagnostic attention because, for example, severe sleep-related breathing disorders may cause only light symptoms during the day, or untreated chronified insomnia disorders can be associated with an increased risk for developing cardiovascular diseases, metabolic diseases, or psychiatric disorders.
- To establish a relationship of trust between the therapist and the patient, first a symptom-oriented approach is recommended. Trusting relationships require time on both sides.
- The patient should be involved as a "scientific coworker" in his own interest. Especially in cases of psychogenic sleep disorders, patients are prone to base their sleep problems on merely organic origins. Possible impairments of well-being or mood swings during the daytime are considered more as sequelae of the sleep problem and less as their origin. A sleep diary (► Sect. 2.3) might be helpful to explain the correlation between the patient's mental condition during the daytime and ability to sleep at night.
- In cases of psychogenic triggers, an empathic, respectful approach should be the focus. Confronting the patient with the psychological conditions that trigger or maintain the sleep disorder should be undertaken very carefully.
- The subjective symptoms are more important than the objective findings. Polysomnography (PSG) is an important diagnostic tool for identification of the origins of sleep disorders and their severity. Nonetheless, polysomnographic parameters do not always correlate directly with the experiences and complaints of the patient (► Sect. 2.7).

2.1.1 Sleep-Related Personal Anamnesis

The present chapter on history taking is mainly oriented toward the sleep disorders of adults. History taking for sleep disorders in pediatric patients may be significantly different, especially with the background that parents who are interviewed in the context of sleep disorders in children, in the sense of history compiling by a third party, have a central role. ▶ Chapter 11 provides the necessary information for the special methods of history taking in children,.

The medical personal history is the beginning of the diagnostic process of sleep disorders. Intensive data collection strengthens the patient's impression of being taken seriously and increases the understanding of the diagnosing physician. Even at the beginning of the diagnostic process, structured sleep diaries may be helpful (▶ Sect. 2.3).

Assessment of Sleep-Related Complaints

- Bedtimes and their regularity
- Behavior and conditions before going to bed and after getting up in the morning
- Subjective duration of sleep onset
- Subjective extent and characteristics of wake time after sleep onset
- Particular phenomena such as snoring, sleep apnea (▶ Chap. 4), or sleepwalking (▶ Chap. 7) that occur during sleep should be reported by the bed partner as a third party (▶ Sect. 2.1.2)
- Sleep–wake structure, especially sleep-promoting or sleep-disturbing behavior during daytime and at night
- Particular life situations or diseases at the onset of the disorder
- Duration of the complaints
- Chronic or temporary occurrence of the complaints
- Psychophysiological arousal during and before the sleep phase (▶ Sect. 3.2.2)
- Cognitive and emotional arousal preceding and during the sleep period (▶ Sect. 3.2.2)
- Anticipatory anxiety regarding sleep and focusing on the sleep problem (▶ Sect. 3.2.2)
- Other factors concerning sleep hygiene (▶ Sects. 3.1.6 and 3.2.1)
- Movement of the extremities (▶ Chap. 8)
- Nightmares and nighttime arousal (▶ Chap. 7)

Assessment of General Daytime Complaints

Mental condition such as irritability, depression, anxiety, etc. (▶ Chap. 10 and ▶ Sect. 0):

- Anticipatory fears regarding sleep and focus on the sleep disorder
- Monotony intolerance: assessing the proneness to fall asleep with potentially circadian or ultradian rhythms (▶ Chaps. 1 and 6), if needed, by means of a sleep diary (▶ Sect. 2.3)
- Sleepiness and fatigue during the day (▶ Sect. 2.1.3)
- Subjective impairments in daytime performance, such as memory impairments, concentration deficits, reduced driving ability, and social life impairments (▶ Sect. 2.8)

Further, the exploration of factors involved in the onset of the sleep disorders is essential. Psychosocial stress (divorce, job change, death of a closely related person, etc.), medical conditions (thyroid disorder, pain syndrome, pharmaceutics, hospital stays, menopause, etc.), lifestyle changes (weight gain, etc.), and sleep-incompatible behavior are frequent origins of sleep disorders.

Analysis of the patient's behavior and general condition, as well as observations by third parties during sleep with regard to snoring, apnea, sleepwalking, or restless legs, may provide important information about the genesis of a sleep disorder.

2.1.2 Sleep-Related History Compiled by Third Parties

The diagnostic process of sleep-related history taking by interviewing third parties includes observers (partners, other patients, nursing staff, etc.) to confirm and describe sleep-related symptoms. In cases of diagnostically unclear complaints, the observations of others may sometimes provide surprising information facilitating the diagnosis or at least a probable diagnosis. Generally, these observations include symptoms that a patient does not perceive consciously. In children, history taking by interviewing others is mandatory (► Chap. 11). Based on the suspected diagnosis, the observer may be involved in systematic observations of the behavior. Especially for the differentiation of pavor nocturnus, nightmares, sleepwalking, nighttime enuresis, nighttime movement disorders (including jactatio capitis nocturna), sleep-talking, bruxism, and neurological sleep disorders [such as Rapid Eye Movement (REM) behavior disorder, and nocturnal cerebral seizures], systematic observation by third parties is indicated.

2.1.3 History Taking Regarding Sleepiness, Fatigue, and Daytime Performance

Daytime impairments associated with fatigue and sleepiness are frequently observed symptoms of sleep disorders; however, they may also occur in the context of other medical conditions or psychiatric disorders. Such symptoms can significantly reduce the patients' quality of life and impair their daytime performance. As a consequence, fitness for work and ability to drive is frequently reduced. Social interactions can be disturbed by sleepiness and also fatigue to the extent that the affected individuals withdraw from their usual social contacts. Hobbies, club activities, and activities with family and friends are given up. The feeling of insufficiency and the lack of self-confidence caused by these missing performances are often triggering factors and the base of developing psychasthenia and depressive disorders.

Although all patients complain about *fatigue* or *daytime sleepiness*, a more detailed exploration reveals differences regarding the quality of sleepiness- or fatigue-related impairments.

Practical Tip

Fatigue describes the subjective feeling of tiredness and exhaustion as it rather occurs in the context of psychosomatic disorders.

Sleepiness, however, has no psychiatric correlation. It often occurs as a sequela of nonrestorative or reduced sleep. Hereby, the increased proneness to fall asleep is characteristic, especially in monotonous situations.

Patients with *psychogenic insomnia disorders* (► Chap. 3) primarily describe the symptoms of fatigue, but they may also suffer from sleepiness. They experience rather the feeling of psychiatric exhaustion that is often enhanced in stress situations. This feeling may be understood as an expression of the chronically increased level of stress. More frequently, a feeling of overstrain occurs. The fatigue-related impairments rarely correlate with situational conditions such as driving a car, meetings, sports, or other activities. Moreover, intrapsychiatric conditions such as increased stress perception can be found. Important differences depending on the time of the day are rarely observed. In situations where sleeping is allowed, sleep onset does not occur.

Thus, the specific examination procedures for assessment of daytime sleepiness such as the multiple sleep latency test (MSLT), the maintenance of wakefulness test (MWT), or also the pupillographic sleepiness test (► Sect. 2.8.1) do not reveal pathological sleepiness values. The nighttime sleep quantity is often reduced because of the longer sleep-onset latencies and frequent wake times during the sleep period.

In cases of *medical sleep disorders* without psychogenic triggers and without increased levels of tension, another clinical picture of daytime sleepiness develops, frequently the result of nonrestorative sleep. It is characterized by a significantly increased proneness to fall asleep during daytime. If daytime sleep is possible, it occurs within a very short time.

In these patients psychological stress leads rather to a reduction of sleepiness. Furthermore, interestingly, motivating tasks or situations may reduce the sleepiness. In monotonous and low-stimulus situations, for example, driving on the

highway, watching TV, or cinema or theater, lectures, or long meetings, sleepiness is observed more frequently. Often significant circadian variations occur with increased sleepiness in the morning after getting up (hangover) and the early afternoon and evening hours. The quantity of night sleep is unchanged or even prolonged. Especially in the evenings and during holidays, longer sleep durations are observed.

In examinations of daytime sleepiness (MSLT, MWT, ▶ Sect. 2.8.1), very often reduced sleep-onset latencies and a pathological test value (pupillary unrest index, PUI) are found. Polysomnography often reveals increased sleep fragmentation with frequent changes of the sleep stages as well as increased percentages of light sleep and reduced percentages of deep sleep.

Of course, many variations exist between the seemingly diametric types of sleepiness and fatigue wherein medical and psychogenic proportions are mixed and interdependent (▶ Chap. 10). The characteristics described here, however, are not only theoretical observations; they also indicate different therapy approaches. Regarding the qualities of sleepiness- and fatigue-related impairments, see ◘ Table 2.1.

◘ Table 2.1 Characteristics of fatigue and sleepiness

Fatigue	Sleepiness
Subjective feeling and perception of reduced performance in physically, psychologically, and mentally demanding situations	Reduction of the central nervous system alertness, i.e., wakefulness
Intrapsychic correlation of fatigue: exhaustion, feeling of overstrain, increase in stressful situations	Urge to sleep, no intrapsychic correlate, under stress, reduction of the sleepiness
In situations where sleep is possible or desired, it does not occur; no daytime sleep episodes	In situations where sleep is possible or desired, sleep occurs; daytime sleep episodes
No intolerance of monotony	Intolerance of monotony
No distinct circadian rhythm	Circadian rhythm
Monotonous situations do not stimulate sleep	Monotonous situations stimulate sleep
Sleep duration at night is normal or reduced	Sleep duration at night is normal or increased, sometimes with sleep fragmentation
Sleep-onset latency during daytime and at night is inconspicuous or prolonged	Sleep-onset latency during daytime and at night is unchanged or reduced
Sleep quantity on weekends or holidays is mostly unchanged	Sleep quantity on weekends or holidays is mostly increased

Fatigue and sleepiness are internationally used terms

2.1.4 Further History Taking for Differential Diagnostic: Assessment of Possible Origins of Sleep Disorders

General practice (GP)-based, psychiatric, neurological, and drug- and substance-related history taking includes current and former complaints, diseases, and substance consumption that might have triggered and maintained the sleep disorder.

In the context of *GP-based history taking*, in particular somatic diseases (endocrine, cardiovascular, neurodegenerative) are interesting as a possible origin of secondary sleep disorders (see ▶ Box 3.2).

The psychiatric history is relevant to assess psychiatric disorders that are frequently characterized by sleep disorders (▶ Chap. 10). About 80% of psychiatric diseases are accompanied by sleep disorders and about 30% of insomnias are based on psychiatric disorders. Special attention should be paid to these conditions:

- Mono- or bipolar affective diseases
- Prepsychotic conditions
- Chronified mood swings
- Substance abuse
- Intrapsychic conflicts
- Social stress situations

Insomnias are often prodromal characteristics of depressive disorders and are also frequently considered as the last symptom to disappear after remission of the depression. In the diagnostic process, the focus is on differentiating subtypes of chronic insomnia to find an adequate indication for therapeutic measures.

History taking and examination with regard to *neurological disorders* aim at assessing possible diseases of the central and peripheral nervous system. Most interesting are the following:

- Dementing processes
- Lesions of the central and peripheral nervous system
- Inflammatory processes
- Systemic diseases
- Other diseases affecting the nervous system

If a respective diagnosis is suspected, further examination such as electroencephalogram (EEG), long-term EEG, evoked potentials, imaging techniques, and laboratory examinations may be required. The indication must not be too strict in this context.

In particular, in cases of neurodegenerative diseases affecting the hypothalamus including the suprachiasmatic nucleus and the subcortical cholinergic, dopaminergic, and serotonergic pathways involved in sleep–wake regulation, important sleep disorders may be observed up to the dissolution of the sleep–wake rhythm. In more than 50% of the cases, dementia is associated with sleep disorders. The severity of dementia and the dissolved daytime rhythm are closely interrelated. A high discrepancy between the objective sleep disorder and the subjective sleep evaluation can be noted. In the context of dementia of Alzheimer's type (DAT), sleep disorders are more frequent than in the context of Lewy body dementia (LBD).

Many pharmaceuticals and medical substances affect sleep. The *drug-related history* includes all drugs available on prescription or obtainable without prescription. Several pharmaceuticals such as beta blockers, contraceptives, some antidepressants, appetite suppressants, or hypnotics may have a negative impact on sleep. Hence, many substances may cause insomnia as well as hypersomnia complaints. Even low doses of stimulants and addictive substances such as alcohol, tobacco, and other drugs may significantly impair sleep ability. The consumption of those substances even additionally and often persistently impairs the sleep ability of patients with sleep disorders compared to healthy individuals.

Practical Tip

The time of the first drug intake is of particular importance because the sleep quality changes in the further course following and might give indications for drug-related sleep disorders.

In the context of medical certificates, for example, on the fitness to drive or to work, urine screening is indicated with regard to stimulating and sedating substances to avoid simulation or dissimulation in the diagnostic process.

2.2 Laboratory Parameters for Sleep Disorders

Because numerous somatic and psychiatric diseases are secondarily associated with sleep disorders, screening regarding defined laboratory parameters is indicated in cases of respective anamnestic indications (◘ Table 2.2). When the

◘ **Table 2.2** Laboratory screening in cases of suspected secondary sleep disorders (further diagnostics and GP-based or internal examination if necessary)

Basic parameter	Additional parameters in cases of respective clinical suspicion
Blood count	Synthesis output by the liver (albumin, cholinesterase, INR)
BSG, CRP	Kidney values (creatinine, urea)
Electrolytes (sodium, potassium, calcium)	Vitamin B_{12}, folic acid, iron metabolism (transferrin situation, ferritin)
Glucose	Daily blood sugar profile, glucose tolerance test, HbA1c
Thyroid parameters (TSH)	–

differential diagnosis of single sleep disorders and their symptoms is established, the determination of further laboratory parameters may be indicated, for example, the values of iron, folic acid, and vitamin B_{12} for the differentiation between idiopathic and secondary restless leg syndrome (RLS). In the context of hypersomnia disorders, the determination of vitamin B_{12} and vitamin D may also be useful.

2.3 Sleep Questionnaire

Validated questionnaires are an important diagnostic tool. The results are relatively independent from the examiner (objectivity) and make the diagnostic process more efficient. In the waiting room, the patient may fill out the questionnaire and the receptionists or nursing staff may evaluate the forms after relevant instruction. The therapist must interpret these questionnaires, including all other findings.

For assessment of daytime sleepiness, the Epworth Sleepiness Scale (▶ Sect. 2.8.1) is applied as a generally accepted procedure in routine diagnostics.

The sleep diary is completed in the evening before going to bed and in the morning directly after arising to assess the patient's subjective quality of sleep and sleep-disturbing behavior. These data are collected:

- Sleep–wake disorder of any origin
- Subjective ability to sleep
- Sleep hygiene (lifestyle habits and behavior with regard to sleep)
- Sleep-disturbing behavior before and during the sleep period
- Condition before and during the sleep period
- Nocturnal particularities
- Consumption of substances

All bedtimes and sleep times, including those occurring during the daytime, should be noted. The estimation of the restorative quality of sleep has to be documented by the patient, as well as sleep-disturbing problems in the job-related and private environment. The consumption of coffee or tea or alcohol, and drug intake, as well as sleep-promoting activities such as use of relaxation techniques, need to be documented.

Practical Tip

The sleep diary is a basic standard for the diagnosis of sleep disorders. It should be kept for a period of at least 2 weeks.

For reasons of the initially enhanced self-observation with regard to sleep behavior and the resulting irritations and secondary increase of tension in the bed situation, the first 7 days are included in the analysis to only a limited extent.

2.3.1 Insomnia Questionnaire

Questionnaires on insomnia inform about the presence, the severity, and the course of an insomnia disorder. Because of the last-mentioned aspect, they are also suitable for therapy evaluation.

The Pittsburgh Sleep Quality Index (PSQI) contains 19 items on self-assessment and 5 questions on observations of third parties, such as the bed partner. Based on the replies, statements can be given on these points:

- Subjective quality of sleep
- Sleep-onset latency
- Sleep efficiency
- Consumption of hypnotics
- Daytime sleepiness
- Incidence of different sleep disorders within the previous 4 weeks

The PSQI validly differentiates between good and poor sleepers. It may indicate the severity of the disorder and thus evaluate the therapy.

Practical Tip

The PSQI is a standard procedure for the routine diagnostics of sleep disorders and provides information about the subjective quality of sleep.

The Insomnia Severity Index (ISI) consists of seven items assessing the type and severity of insomnia complaints of the previous 2 weeks based on a five-step rating scale. Insomnia is valued according to its severity, its impact on the psychosocial performance level during the day, and the subjectively experienced impairments. Furthermore, subjective satisfaction with one's own ability to sleep is assessed.

A score between 0 and 28 is calculated. Between 0 and 7, it is considered as clinically inconspicuous; a score of 8–14 indicates a subliminal insomnia, a score of 15–21 describes a moderate insomnia, and scores beyond 22 are considered as severe. The advantage of this procedure is that it is standardized and a theoretically validated test.

Numerous questionnaires have been developed to assess etiological factors and other aspects of insomnia. A widely distributed tool for the assessment of cognitive misconceptions and misbehavior is the "Dysfunctional Beliefs and Attitudes about Sleep Scale." It refers mainly to individual cognitions that maintain sleep disorders. Other procedures such as the "Presleep Arousal Scale" or the "Glasgow Sleep Effort Scale" assess the psychophysiological level of excitement in the bedtime situation. For better understanding of the impairment of the functional level during daytime, questionnaires assessing sleepiness and fatigue are recommended (▶ Sect. 2.8.1.3.2). Because of the high association of insomnia disorders with psychiatric diseases, psychiatric and psychological questionnaires may contribute to a better understanding of the etiology as well as the impact of an insomnia disorder: these include the "Beck Depression Inventory" as well as the "State-Trait Anxiety Inventory."

2.3.2 Questionnaires for the Assessment of Sleep-Related Breathing Disorders

Various questionnaires have been developed aiming at assessing the risk of sleep-related breathing disorders.

The STOP-Bang questionnaire consists of eight items and is a validated screening tool for the assessment of obstructive sleep apnea. Initially, it was developed for preoperative screening regarding obstructive sleep apnea. It is also validated for the general population. The questionnaire is based on six questions and two measurable values.

- S: Snoring (yes/no)
- T: Tiredness (yes/no)
- O: Observed/observed apnea (yes/no)
- P: Pressure/hypertension (yes/no)
- B: Body mass index (>35 kg/m^2?)
- A: Age (>50 years?)
- N: Neck/circumference at the level of Adam's apple (>43 cm in males and >41 cm in females)
- G: Gender (male yes/no)

Together with the Berlin Questionnaire, the STOP-Bang questionnaire is the most frequently recommended screening tool for obstructive sleep apnea (OSA). Compared to other screening questionnaires, the STOP-Bang questionnaire has the highest sensitivity and specificity for moderate and severe obstructive sleep apnea. A meta-analysis could confirm the high predictive value of the questionnaire. For the general population, a score of 0–2 means a low risk of OSA, with a moderate risk for scores of 3–4 and a high risk for scores of 5–8.

The Berlin Questionnaire supports the identification of obstructive sleep apnea. It is more suitable for exclusion diagnostics than for the assessment of the severity of possibly existing obstructive sleep apnea. Based on 11 items, the patient is classified in categories of high or low risk for obstructive sleep apnea. A review of 19 trials revealed a significant number of false-negative diagnoses based on the Berlin Questionnaire, which limits its application as a diagnostic tool. Furthermore, it was considered as being unsatisfactory regarding a sensitivity of 0.76 and a specificity of 0.45. The accuracy of the questionnaire was valued as too low, with 56% to 70%.

The NAMES test (Neck circumference, Airway classification, coMorbidities, Epworth scale, and Snoring) assesses the neck circumference, an examination of the upper airways, comorbidities, the Epworth score, and nighttime snoring to evaluate the risk of a possible sleep-related breathing disorder in a multidimensional way and to increase the validity of the information. The NAMES2 further includes body mass index (BMI) and gender.

2.3.3 Questionnaire Regarding Restless Legs Syndrome

To support the diagnostic process in the context of the restless legs syndrome (RLS), the RLS diagnose index (RLS-DI) has been developed. This tool constitutes diagnostic and additional criteria of RLS with five questions, each on a three-point rating scale. The overall score allows statements on the probability of the diagnosis. An RLS-DI overall score of more than 11 means a high probability of RLS, and more than 16 means a confirmed diagnosis.

Practical Tip

To assess the severity of RLS, most frequently the International RLS Study Group Rating Scale (IRLS) is used.

The IRLS is a self-assessment questionnaire. It includes ten items that evaluate the severity of the complaints and their impact on the daytime condition. The answers can achieve scores between 0 and 4 each, with higher scores representing more severe conditions and complaints.

Based on the sum score, the severity is defined as follows:

- 0: symptom-free
- 1–10: mild RLS
- 11–20: moderate RLS
- 21–30: severe RLS
- 31–40: very severe RLS

A large international validation trial showed very good test-theoretical quality criteria for the IRLS. the IRLS should only be applied in patients who have a confirmed diagnosis of restless legs syndrome because, in the context of psychiatric and neurological disorders, patients report higher IRLS scores even without the presence of RLS.

2.4 Physical Examination

Regarding all sleep disorders, the physical examination is an important element of the diagnostic process when a medical origin is assumed or has to be excluded. Based on the suspected diagnosis, examination of the head and neck area, heart and lungs, or the neurological system has a major role. The physical examination is indicated in particular in the context of sleep-related breathing disorders (▶ Chap. 4), movement disorders in sleep (▶ Chap. 8), and sleep disorders caused by medical diseases (▶ Chap. 9). It is described in the respective chapters.

2.5 Actigraphy

For more than 30 years, actigraphy has been a method for objective measurement of movements that can be applied in a simple way over longer periods. The actigraph is a tool mostly worn at the wrist or the ankle that measures movement activity. The activity patterns, which are often registered and stored over several days, allow conclusions about the sleep–wake rhythm and also about leg activities during sleep (▶ Chap. 8.2).

Studies based only on the correlation between actigraphy data and polysomnographic data in young healthy individuals revealed a congruence of 91% to 93%. Validation studies mostly refer to correlations between the significant target parameters of polysomnography (PSG) and actigraphy, such as the overall sleeping time or sleep efficiency.

Actigraphy (◘ Fig. 2.1) allows statements about these concerns:

- Sleep habits
- Sleep disorders
- Daytime sleep episodes
- Therapy outcome

By means of keeping a behavior protocol at the same time, for example, the sleep-onset latency, nocturnal wake phases or a prolonged sleep duration may be estimated.

Despite these advantages, actigraphy may not replace PSG. The disadvantage of actigraphy is in particular the lack of precision because indirect measurements only roughly reflect sleep continuity. One frequently observed artifact is the removal of the tool, so that these phases may be misinterpreted as sleep, such as also calm phases during wakefulness, for example, when reading. Also overlapping movements that are externally induced, as, for example, when sitting in a car, may be misinterpreted. The management of the artifacts is only possible with the simultaneous application of a behavioral protocol.

Practical Tip

If periodic limb movements in sleep (PLMS) are confirmed, actigraphy may be applied for diagnostics and therapy because it can provide information about the incidence of periodic limb movements during sleep. Times of going to bed and of getting up should be exactly documented.

In the context of outpatient insomnia diagnostics, actigraphy may provide important information on disturbed sleep–wake rhythm, irregularities of bedtimes, and nighttime behavior.

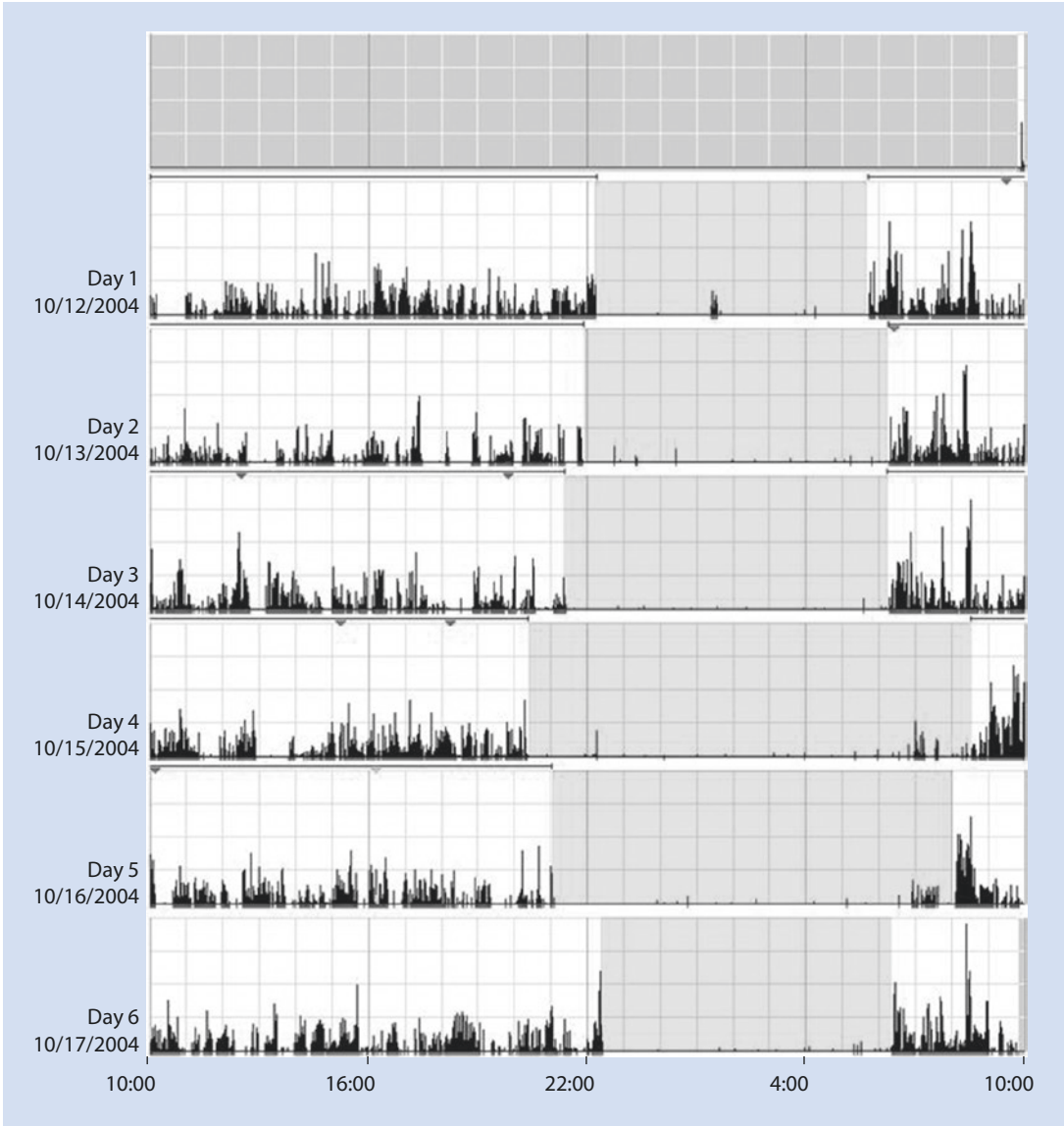


Fig. 2.1 Actigraphy. Measurement during 6 days. Sleep periods are shown in *light gray*

2.6 Outpatient Step-by-Step Diagnostics for Sleep-Related Breathing Disorders and Polygraphy Systems

The necessity of device-related diagnostics in cases of sleep-related breathing disorders (SRBD) is obvious after positive anamnesis of the respective symptoms. The more characteristic symptoms that are found, the more likely is the suspected diagnosis that has to be verified. According to the recommendations of the American Academy of Sleep Medicine (AASM) from 2017 as well as the S3 guideline on non-restorative sleep/sleep disorders—"Sleep-related breathing disorders"—of the German Society of Sleep Research and Sleep Medicine (DGSM, Deutsche Gesellschaft für Schlafforschung und Schlafmedizin), the monitored cardiorespiratory polysomnography is considered as the gold standard of device-related sleep medical diagnostics in the sleep lab. For limited diagnostics of sleep-related breathing disorders, simpler, portable polygraphy systems are also available.

According to the S3 guideline on nonrestorative sleep/sleep disorders of the German Sleep Society (DGSM), the polygraphy devices have to assess the following aspects:

- Respiratory flow rate with thermistor or dynamic pressure sensor
- Respiratory effort by means of induction plethysmography
- Oxygen saturation with pulse oximetry
- Pulse rate
- Body position

For detailed descriptions of the measurement technique, measurement devices, parameters, and their definition, see ▶ Sects. 2.7.1 and 2.7.8. The evaluation is performed based on the current schemes of the AASM in the most recent version by a physician qualified in sleep medicine. Generally, a measurement time of at least 6 h during the sleep period is required for sufficient diagnostic significance; otherwise, the examination should be repeated.

Optimal polygraphy devices are characterized by the following:

- Robust measurement techniques and sensors with long service lives
- Simple sensors that may partly be applied by the patients themselves
- Low susceptibility to artifacts
- Valid automatic evaluation algorithms
- Simple and economic software for editing the automated analysis
- Exhaustive but also clear and freely designable automated findings
- Possible linking to the software used in the practice or the hospital information system by means of different interface technologies (e.g., HL7 interface)

According to the already cited S3 guideline of the DGSM as well as recommendations of the AASM from 2017, the diagnosis of SRBD with unattended polygraphy systems is possible in cases of moderate to strong suspicion and to determine the severity of SRBD. The evaluation should be performed visually by qualified staff. Evaluation by only software-inherent algorithms cannot be recommended. For exclusion diagnostics of SRBD, PSG is recommended because polygraphy is not considered as sufficiently valid for this purpose.

Generally, polygraphy should not substitute PSG for diagnosing SRBD in patients with comorbid disorders that are relevant for this question. According to the S3 guideline of the DGSM, some comorbid diseases are likely to reduce the significance of polygraphy systems and require diagnostic polysomnography:

- Pulmonary diseases
- Psychiatric disorders
- Neurological disorders
- Neuromuscular diseases

In the same way, polygraphy is not recommended for the comorbid appearance of sleep disorders such as these:

- Central sleep apnea
- Insomnia
- Periodic movement disorders in sleep
- Narcolepsy
- Circadian sleep–wake rhythm disorders

The AASM recommends unattended polygraphy in cases of moderate to strong suspicion of obstructive sleep apnea without suspected concomitants:

- Central sleep apnea
- Hyperventilation and sleep-related hypoxemia
- Cardiopulmonary disease
- Significant neuromuscular weakness of the respiratory muscles
- Hypersomnia
- Parasomnia
- Sleep-related movement disorders

Furthermore, it is not recommended when the patient's history reveals stroke or current chronic opiate medication. The AASM also recommends PSG when unattended polygraphy despite strong clinically suspected diagnosis was negative, contradictory, or technically inadequate. In addition, the AASM requires that the evaluation of unattended polygraphy is performed by a physician qualified in sleep medicine, a certified sleep laboratory, or a comparable institution.

It must be realized that, in cases of predominant hypopnea, polygraphy systems are not always able to validly differentiate between obstructive and central sleep apnea (▶ Sect. 2.7.8). Because of the missing EEG channels, they are less exact for the

definition of the severity of sleep apnea compared to polysomnography. Furthermore, the lack of an EEG may lead to the wrong classification of apnea when physiological irregularities of breathing occur during the wake-sleep transition (sleep-onset apnea) and thus provide false-positive results. These limited systems do not provide differential diagnoses of sleep apnea.

In Germany, the healthcare institutions have defined an outpatient stepped care model for the diagnosis of SRBD that seems to be suitable for application in other countries also because of its clear structure and efficiency.

Outpatient Stepped Care Model for the Diagnosis of SRBD

- Step 1: standardized questionnaires regarding specific symptoms and comorbidities of SRBD (▶ Sects. 2.3 and 2.8.1).
- Step 2: clinical examination with sleep anamnesis (▶ Sect. 2.1).
- Step 3: outpatient examination of the patient at home by means of eight-channel polygraphy.
- Step 4: in case of clearly positive outpatient polygraphy findings, therapy by means of nocturnal ventilation or other procedures may be introduced in an outpatient or inpatient sleep lab with polysomnographic monitoring. If the polygraphy findings are not clear, especially with regard to the presence of SRBD or missing differential diagnostic significance, diagnostic polysomnography is performed in the sleep lab in an inpatient or outpatient context.

Taking into account the mentioned limitations of the significance of polygraphy, relevant biosignals of sleep-related breathing disorders are assessed depending on the measurement system during one night at the patient's home (step 3).

The results are usually evaluated on the next day by means of computer-based analysis (◘ Figs. 2.2 and 2.3). In this regard, the American Academy of Sleep Medicine defined algorithms for the standardized evaluation of polygraphic examinations (◘ Tables 2.5 and 2.6).

According the S3 guideline on non-restorative sleep/sleep disorders [chapter "Sleep-Related Breathing Disorders" of the German Society for Sleep Research and Sleep Medicine (DGSM) and the recommendations of the American Academy of Sleep Medicine (AASM)], positive unattended polygraphic findings at home may lead directly to the initiation of a nocturnal ventilation therapy in a sleep lab under polysomnographic conditions (step 4). In case of inconclusive polygraphic results diagnostic polysomnography is performed prior to the beginning of therapy.

Recently, randomized controlled trials have been published on the initial therapy induction showing that CPAP/APAP adaptation may be performed in certain subgroups even without polysomnographic monitoring in a sleep lab. The expenses for an outpatient initial titration on nocturnal ventilation might be lower, but the consecutive costs in cases of reduced compliance are higher. This procedure can only be discussed for simple, uncomplicated cases of obstructive sleep apnea. Further studies are necessary to identify predictors of the treatment success even in the long-term course.

Follow-up and therapy controls may take place by means of polygraphy systems. In patients with unclear therapeutic success, and high cardiovascular risk, and patients with other sleep disorders in comorbidity, PSG controls might be indicated.

More recently, further outpatient examination procedures have been developed that seem to be suitable to provide diagnostic information to the presence of sleep-related breathing disorders, as, for example, peripheral arterial tonometry (PAT) and pulse transit time or pulse wave analysis.

Peripheral arterial tonometry (PAT) assesses variations of the vascular tonus at the finger during sleep. The peripheral vascular tonus and the peripheral vascular resistance are influenced by the sympathetic nerve activity. Hereby, the respiratory indices (desaturation index, AHI, RDI) measured by means of PAT correlate significantly positively with the sleep-related parameters assessed by polysomnography. In the current version, dated 2020, the AASM describes PAT as an

Fig. 2.2 Depiction of 5 min of polygraphy measurement for obstructive sleep apnea. Repeated mixed and obstructive apneas (see figure, *Flow*), associated O_2 desaturations (see figure, *SpO_2*), and apnea-terminating accelerations of the heart rate are found as expression of arousals

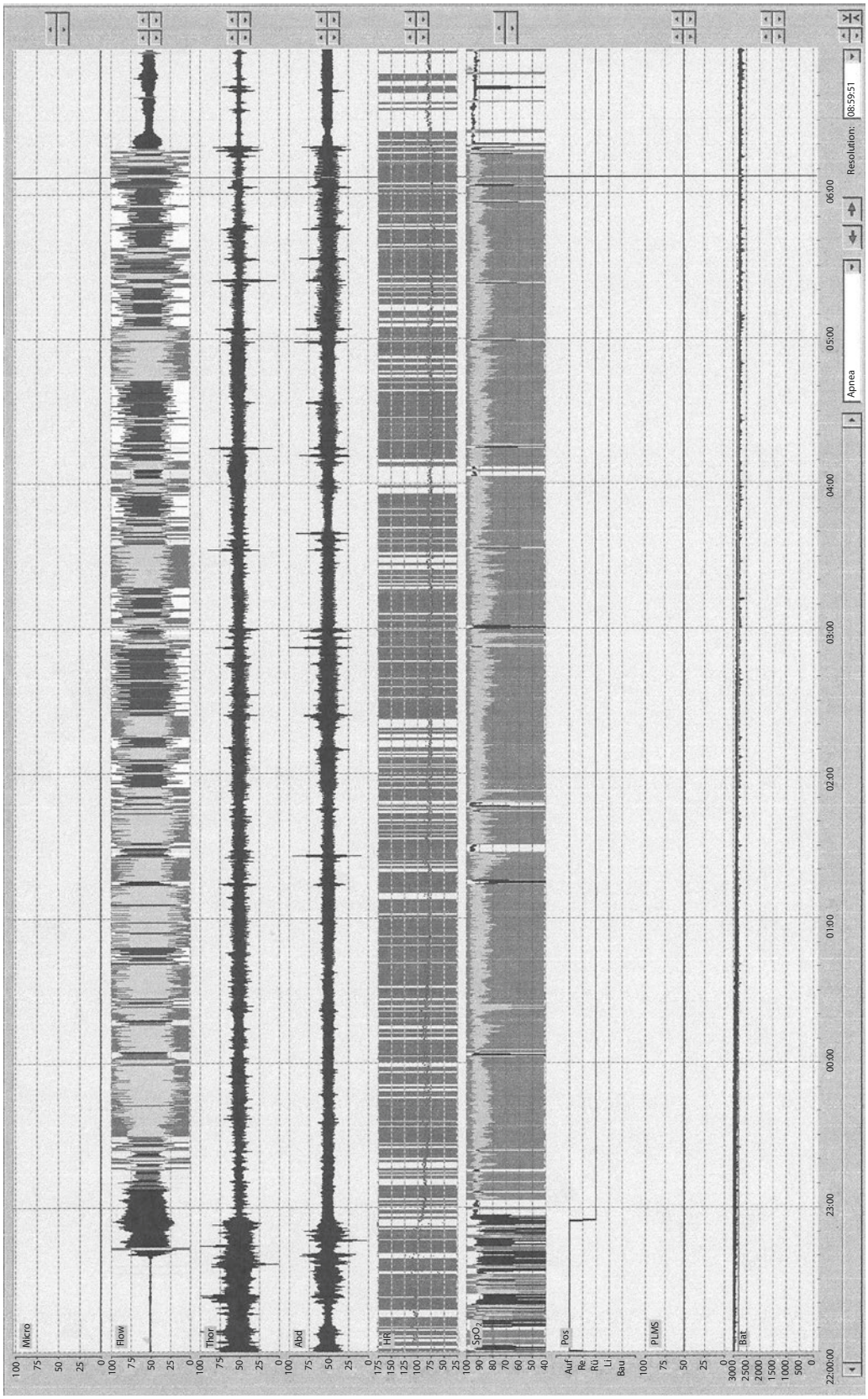


Fig. 2.3 Depiction of an entire night of polygraphic examination for obstructive sleep apnea. Obstructive, mixed, and central apneas in the oronasal airflow are assessed (see figure, *Flow*). Furthermore, repetitive HbO_2 desaturations (see figure, SpO_2) and variations of the heart rate are seen. The patient has a respiratory disturbances index (RDI) of 46.2/h and a desaturation index of 62.1/h

alternative to traditional polygraphic systems provided that these concerns among others are addressed:

- Oximetry and heart rate are documented.
- Raw data are retrievable.
- Automated analysis can be retrieved and edited.

In the future, PAT might be taken into consideration also outside the sleep lab as a method to assess sleep-related breathing disorders.

2.7 Polysomnography (PSG)

Polysomnography (PSG) is the gold standard in the diagnosis of sleep disorders because it can assess sleep and its pathological changes in an objective manner. By means of PSG, the origins of sleep disorders, for example, sleep apnea, periodic limb movements in sleep, or even sleep perception disorders, may be identified and verified that cannot be assessed by any other diagnostic procedure.

Numerous investigations show that the percentage of outpatient diagnoses had to be changed or completed in up to 50% of the cases after performing a PSG. In particular, in sleep-related breathing disorders, the diagnoses had to be modified, or a relevant sleep-related secondary diagnosis had to be added.

Since an expert group of the American Academy of Sleep Medicine (AASM) has published a new classification system (*International Classification of Sleep Disorders*, 3rd Edition; ICSD-3), there is the hope now for an extensive and generally accepted classification system for clinical and scientific sleep medicine, supported by the fact that the ICD-11 provides a separate chapter for sleep disorders.

The *AASM Manual for the Scoring of Sleep and Associated Events* – Rules, Terminology, and Technical Specifications (2007–2020) – is mainly based on those established by Rechtschaffen and Kales [13], in particular with regard to the selection of biosignals for the description of sleep. The arousal classification of an earlier group of the American Sleep Disorders Association (ASDA) is completely included. Independent scoring criteria for the sleep of children and outpatient examinations in cases of suspected sleep-related breathing disorders have been elaborated. The criteria were completed by standardized recommendations for amplifier settings, standardized user interfaces of PC-based systems, data formats, and visual evaluation and diagnosis of PSG. All statements of the AASM were based on empirical evidence, literature reviews, or consensus procedures.

Compared to the criteria of Rechtschaffen and Kales, the scoring rules for sleep were partly simplified. First, the number of the sleep stages to be evaluated was reduced. Rechtschaffen and Kales differentiated deep sleep stages 3 and 4 that were summarized to the sleep stage N3. The sleep stage "movement time" was eliminated. The interval evaluation in blocks of 30-second epochs is maintained. An automated analysis of the sleep stages alone is explicitly not desired. The rules for the first occurrence of a sleep stage at sleep onset (sleep-onset latency) were specified, the less economic 3-min rule for the evaluation of the sleep stages N2 and REM (R) was eliminated, and the definitions of *graphoelements* (K complexes, sleep spindles, vertex waves) for the assessment of single sleep stages was simplified. Graphoelements are characteristic phenomena of EEG patterns that are typical for certain sleep stages. K complexes and spindles, for example, determine the sleep stage N2, while vertex waves are characteristic for the sleep stage N1. Compared to Rechtschaffen and Kales, the classification of the single sleep stages was also modified, probably for better differentiation of both scoring systems. The most important modification is the classification of the numeric sleep stages with an "N" for the new criteria: Rechtschaffen and Kales [13] used an "S" before the numeric sleep stage. For example, stage "S1" (R&K) is now stage "N1."

It must be mentioned critically that precise definitions for the graphoelements are still absent, or their definitions do not always meet the criteria of scientific verification; for example, the time criteria of the AASM for a vertex wave. Generally, the efforts of the AASM with regard to standardization, simplification, and scientific justification of the scoring rules are very welcome; however, they require regular development and revision based on newly acquired scientific knowledge and technical options.

The following paragraphs describe these criteria:

- The basics of the current classification of sleep stages
- The standard biosignals that have to be measured by PSG
- The evaluation and scoring of the results of PSG in the context of most frequently observed disorders

The German Society for Sleep Research and Sleep Medicine (DGSM) has developed quality criteria for the performance of polysomnographies. This publication partly modified and further developed criteria of other European sleep societies. Those criteria refer to the structural aspects of a sleep center, technical- and staff-related equipment, and processes in a sleep center accredited by the DGSM. The criteria of the DGSM may be retrieved on the homepage of the DGSM (► www.dgsm.de) and those of the European Sleep Research Society (ESRS) on ► www.esrs.org.

Each polysomnographic measurement has to be preceded by technical and biological calibration.

The *biological calibration* is necessary for these considerations:

- Delimitation between physiological events during sleep and artifacts
- Verification of the amplifier settings and polarities of the single measurement channels
- Allocation of specific behaviors during sleep to respective measurement patterns

Biological Calibration

- Open versus closed eyes for 20 s each (alpha blockage effect)
- Blinking
- Eye movements to the left and to the right with straight head position
- Rolling of the eyes
- Swallowing
- Clenching the teeth
- Snoring
- Counting to 5 (differentiation between speech and snoring with use of a snoring microphone)
- Forced inspiration
- Forced expiration
- Holding the breath; Müller's maneuver (negative Valsalva maneuver) for assessment of paradox respiratory excursions
- Extension of the left and right big toe

For biological calibration, the patient is lying on his bed and is asked via a bidirectional intercom to perform the aforementioned actions under continuous documentation of the respective biosignals in the PSG.

According to the applicable rules for documentation, the biological calibration with exact labeling is then archived for 10 years together with the polysomnographic measurements of the corresponding night.

Thorough documentation of the polysomnographic files is of high clinical relevance. The night protocol written by the medical staff has to allow a rapid and clear assignment to the patient and the measured night.

The documentation includes these aspects:

- Medication
- Type of therapy
- Biological calibration
- All particular events such as technical defects, artifacts, etc.

Furthermore, it should include detailed observation of the behavior:

- Time of getting up
- Emotional condition
- Sleepwalking, etc.

Medical emergency situations, such as epileptic seizures or cardiac arrhythmia, can be immediately recognized by the measurement and documentation of numerous vital parameters and the presence of qualified personnel. Thus, the sleep lab environment very closely resembles the supervision in an intensive care unit. During measurement, qualified staff is already in a position to eliminate emerging error sources such as electrode and sensor artifacts. In cases of therapeutic PSG with adaptation of ventilation therapy for sleep-related breathing disorders, the medical staff assesses a *titration protocol*.

Practical Tip

The titration protocol includes the type of therapy device and the mask that is used. The applied pressure, ventilation mode, and its modifications are exactly documented, and changes of the ventilation mode are justified by emerging respiratory events, O_2 variations, and cardiac parameters.

Regarding diagnostic and therapeutic options and precision, inpatient PSG is superior to outpatient measurements at the patient's home.

2

2.7.1 Standard Parameters of Polysomnography (PSG)

According to the criteria of the AASM for the assessment of sleep, the polysomnographic standard biosignals for diagnostic PSG include three measurements of the EEG based on the international ten-twenty system with measurements of F4-A1, C4-A1, and O2-A1. As backup or for better detection of the differences, the measurements of F3-A2, C3-A2, and O1-A2 are also recommended (Fig. 2.4): these are unipolar measurements. The longitudinal rows allow the clear identification and definition of graphoelements that show specific patterns in the EEG. Over the frontal measurements, K complexes and delta waves are defined, over the central measurements sleep spindles and vertex waves, and over the occipital measurements alpha waves that are relevant for the definition of the sleep-onset process and arousal reactions.

In addition, the standard PSG includes two measurements of electrooculography (EOG) and electromyography (EMG).

The *EOG* electrodes are placed about 1 cm from the left and right orbita edge of the respective eye, whereby the electrodes in the vertical line are shifted about 1 cm (Fig. 2.5). Beside the registration of slow eye movements (slowly rolling eyes), the electrodes also allow the registration of horizontal and vertical eye movements with lower amplitudes.

Electromyography of the mental and submental muscles ensures an optimal identification of the atony of the skeletal muscles during REM sleep and describes stage-related variations in the amplitude of the muscle tension. One electrode is placed 1 cm above the midline of the chin, and two electrodes are placed 2 cm below the point of the chin (one is placed 2 cm to the right, the other one 2 cm to the left). Bipolar measurement of the mental and submental muscles is performed. The remaining electrode at the submental muscle is used as reserve in cases where the contact impedance of one electrode during measurement decreases (Fig. 2.6).

To identify cardiac events, at least one-channel ECG is registered. As the typical measurement II uses electrodes of the right shoulder and the left

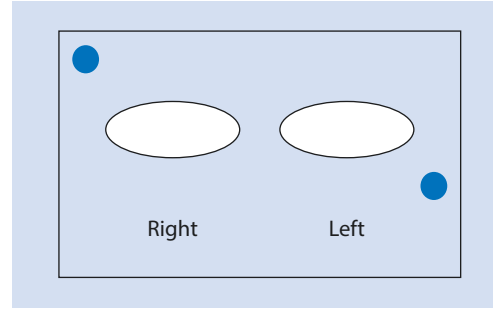


Fig. 2.5 Electrooculography (EOG) Abstand, Leereichen electrode positions

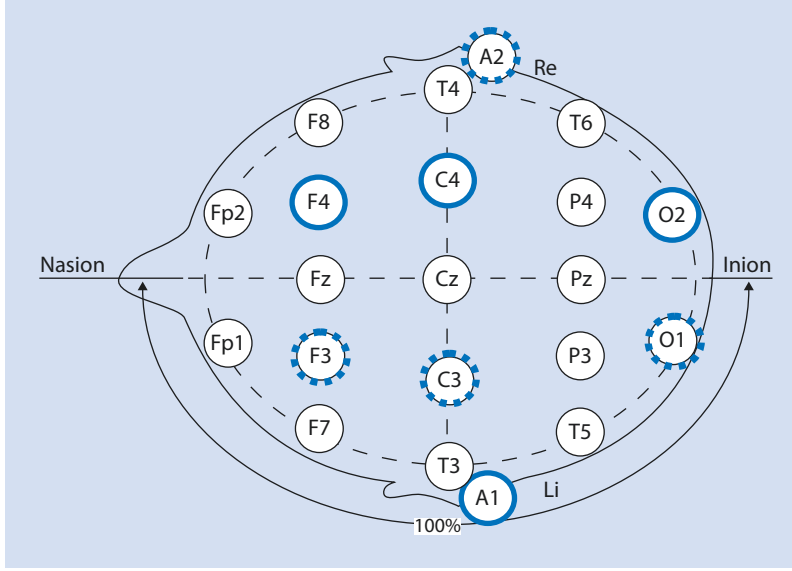


Fig. 2.4 EEG standard electrode positions according to the ten-twenty system. *Dotted circles* represent substitute or backup electrodes

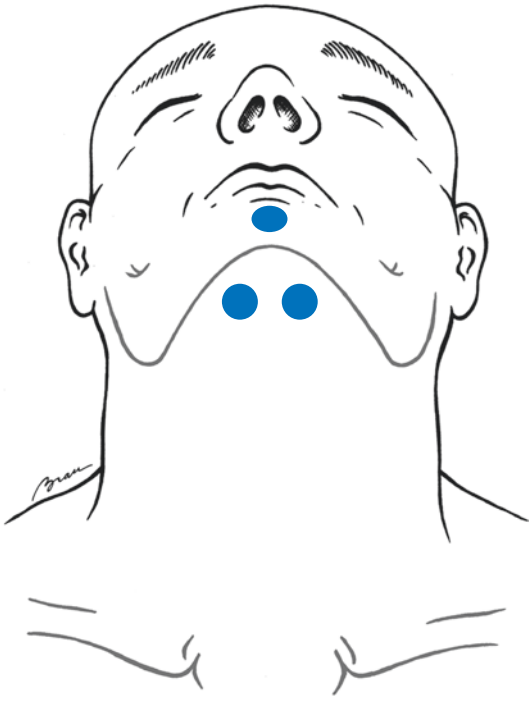


Fig. 2.6 Electomyography (EMG) electrode positions (courtesy of Dr. G. Bran)

leg, the electrodes are applied at the trunk parallel to this axis. This measurement mainly serves for detection of changes of the heart rhythm and their correlation with other PSG parameters (e.g., apneas).

Furthermore, the airflow of mouth and nose are registered separately, and thoracic and abdominal excursions during respiration, arterial HbO_2 saturation by means of pulse oximetry, a (snoring) microphone, and positional sensors are added. These devices serve for assessment of respiratory events and their allocation to the body position during sleep.

Based on the AASM criteria, the registration of the *oronasal airflow* is performed to detect apneas by means of thermistors (thermo-sensors) and hypopneas by means of dynamic pressure measurement (Fig. 2.7). For practical reasons, dynamic pressure measurement has prevailed as diagnostic standard in many institutions. However, the classic nasal cannulas of dynamic pressure measurement usually only allow registration of nasal respiration. Thus, it is recommended in cases of clear mouth breathing to also register the oronasal airflow by means of thermistor. The AASM recommends the use of a combined sensor

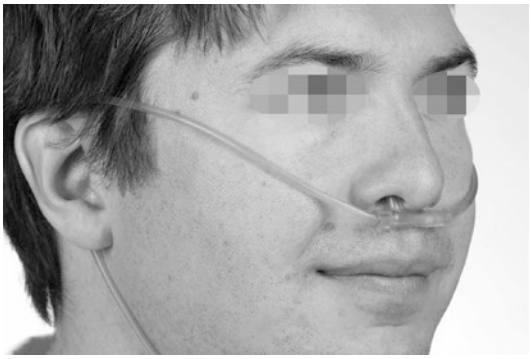


Fig. 2.7 Dynamic pressure measurement by means of nasal cannula

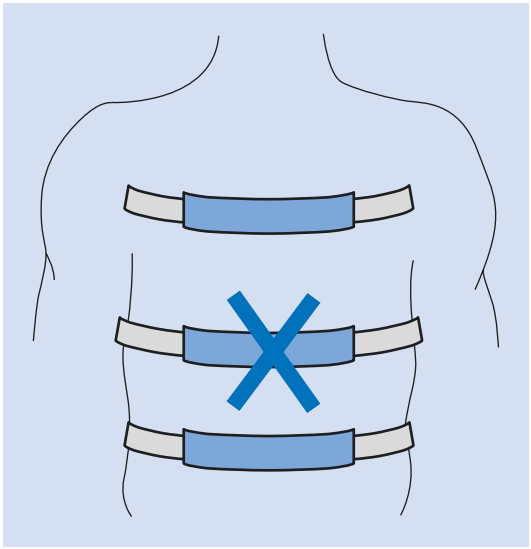


Fig. 2.8 Positioning of the sensors for thoracic and abdominal respiratory excursions

that provides dynamic pressure measurement for the identification of hypopneas and thermistor measurement for the detection of apneas. According to the AASM criteria, it is currently also possible to estimate the oronasal airflow by thoracic and abdominal sensors for inductance plethysmographic measurement (see following).

To assess the *respiratory effort*, piezoceramic sensors with elastic bands are applied at the rib cage and the abdomen (Fig. 2.8). As they do not provide a quantitative signal because of their punctual measurement technique and are suitable only to a limited extent to differentiate central and obstructive hypopneas, inductance plethysmographic sensors are recommended: these are sensors for thorax and abdomen involving the entire

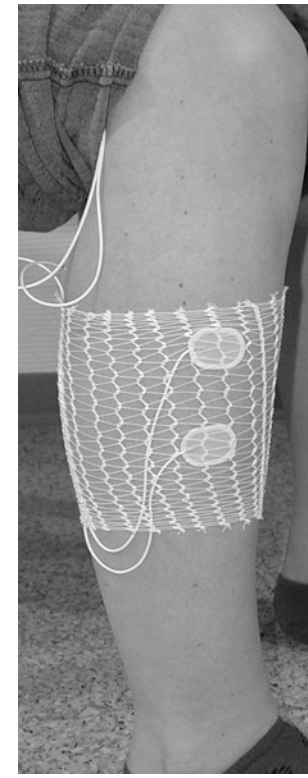
circumference. The signal in this case does not depend on the length and the tension of the sensor but is proportional to the surface that the sensor includes.

During titration or for therapy evaluation in the context of nocturnal ventilation therapy, a device-inherent flow sensor may also be applied.

Esophageal pressure measurement is the gold standard for assessing the respiratory effort. Hereby, one or more pressure sensors placed in a thin and flexible tube at various positions are inserted in the esophagus. The first pressure sensor is placed above and the second below the diaphragm, and the pressure difference sets the signal. In this way, the intrathoracic pressure changes resulting from the respiratory efforts can be quantitatively measured.

The application of an esophageal pressure sensor for clear differentiation of obstructive and central breathing disorders in sleep is not recommended in the clinical routine for practical reasons. However, specific societies (such as DGSM) recommend that specialized labs or sleep centers with focus on pulmonology provide this method and its application if needed. Also, sleep centers in ENT departments apply this method, in particular as multichannel pressure sensors in the pharynx and upper esophagus for identification of possible obstruction sites in patients with obstructive sleep apnea.

Periodic movement disorders in sleep are assessed by means of two electromyograms that are measured at the respective anterior tibialis muscles: these are bipolar measurements. The first electrode is placed four fingerbreadths below the tuberosity of the tibia and one fingerbreadth lateral to the tibia edge. To allow for specific anatomical particularities, the first position should be determined by the patient as instructed by the staff. The second measurement point is about 5 cm in the distal direction. The tibial electrodes should be well fixed to avoid removal by nighttime leg movements (◘ Fig. 2.9)



◘ **Fig. 2.9** EMG electrodes placed at the anterior tibialis muscle

2.7.1.1 Measurement of Blood Pressure During Sleep

Sleep disorders, in particular sleep-related breathing disorders (SRBD), may negatively influence the cardiovascular system. SRBD are associated with hypertension, heart attack, and stroke. For diagnosis of arterial hypertension, measurement of blood pressure at night is crucial (dipper/non-dipper). The diagnosis is recognized eight times more easily by means of nocturnal blood pressure measurement than with a one-time measurement during the day. The nearly exclusively applied means of blood pressure measurements with cuffs are less suitable because of the sleep-disturbing pumping during polysomnographic examination of sleep. Alternative, continuously measuring procedures according to Penaz (Portapres) or invasive arterial blood pressure measurements are generally appropriate for assessing nocturnal blood pressure fluctuation, but the methods are very expensive and thus not applicable for standard polysomnography (PSG) or polygraphy (PG).

The method of pulse transit time (PTT) is a parameter in sleep diagnostics that has been known for several decades. Changes of PTT have been used as markers for autonomous arousals, but the application of PPT for blood pressure assessment is new. It is determined by the time the pulse wave of a cardiac cycle needs to run from a central point of the arterial system into the periphery. Often the R-wave of the ECG is used as

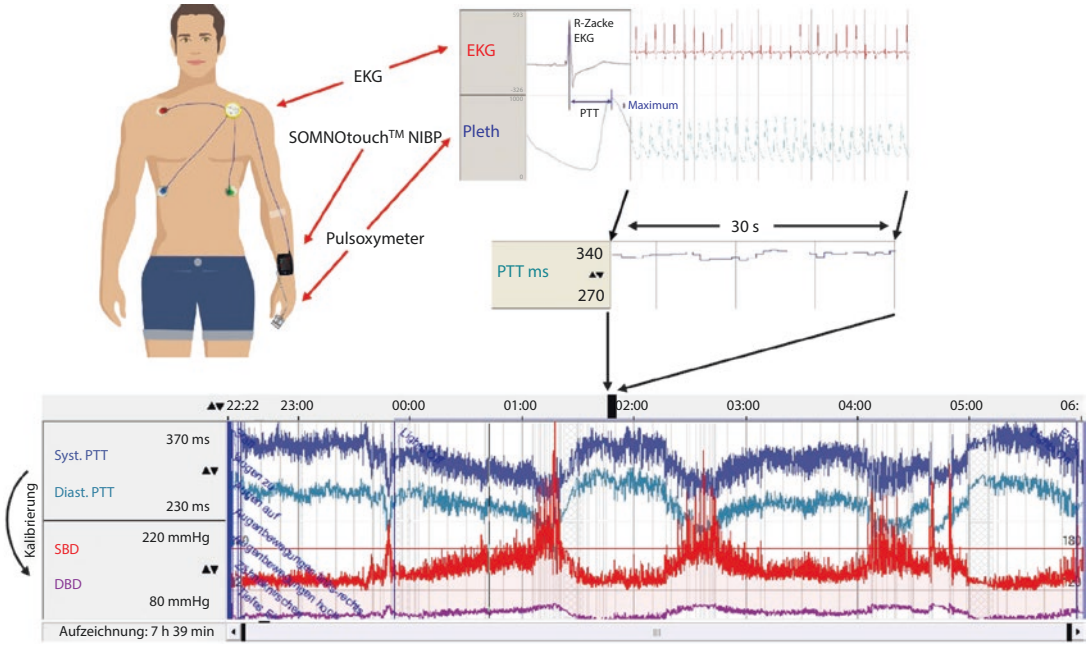


Fig. 2.10 Measurement of the blood pressure based on the pulse transit time (PPT) principle. *Top left:* Scheme for placing the electrodes for continuous blood pressure measurement based on the PPT principle. *Top right:* From the time delay between the R-wave of the ECG and the peripheral pulse wave, PPT can be defined (and documented) for every heart cycle. From the one-point calibration and the nonlinear model, an exact systolic and diastolic pressure can be computed for every PPT value. *Bottom:* Continuous measurement of the PPT or the systolic and diastolic pressure during the entire sleep duration. *PPT* pulse transit time, *SBP* systolic blood pressure, *DBP* diastolic blood pressure, *Pleth* plethysmogram, *ECG* electrocardiogram

the starting time, and the arrival time of the pulse wave in the periphery is measured by means of pulse oximetry. Both signals are assessed in PG or PSG by default. The velocity of the pulse wave is correlated directly with the elasticity or rigidity of the vessel. The elasticity is crucially influenced by the blood pressure. So, considering individual mechanical properties of the vessels, the pulse wave velocity allows drawing conclusions about the blood pressure. Because the central vessels have a different wall structure compared to peripheral vessels, a different elasticity results: the distinction is made between central and peripheral pulse wave velocity.

The individual properties of the vascular elasticity are assessed by means of cuff measurements (calibration), and the blood pressure changes are calculated with sufficient exactness with a patented nonlinear mathematical model [8] (see Fig. 2.10).

Thus, the PPT blood pressure method allows measuring the blood pressure during sleep in a reactionless and continuous way, that is, from beat to beat. During sleep, suprathreshold intrinsic or extrinsic disturbances may generate arousals; as a consequence, a fluctuating increase of the systolic pressure may occur in response to a transitory reduction of the parasympathetic tonus and subsequent heart rate increase (NBPF, nocturnal blood pressure fluctuation). These NBPFs amount to 10–20 s and an average of 29 mmHg ([5]; $n = 878$ NBPFs; see Fig. 2.11).

With an AHI of 60/h, these NBPFs trigger an increase of the average arterial blood pressure of about 10 mmHg at night, which counteracts or even avoids the natural reduction (dipping). In cases of severe SRBD characterized by long apnea/hypopnea and short breathing periods, higher NBPFs may also be generated in REM sleep. A continuous increase of the systolic blood pressure during these periods is characteristic. After an apnea-related increase, blood pressure does not return to its original value. As a consequence, the blood pressure increase potentiates (superposition) and reaches extremely high apnea-correlated values of more than 200 mmHg.

The continuous and disturbance-free measurement of the blood pressure during sleep is a

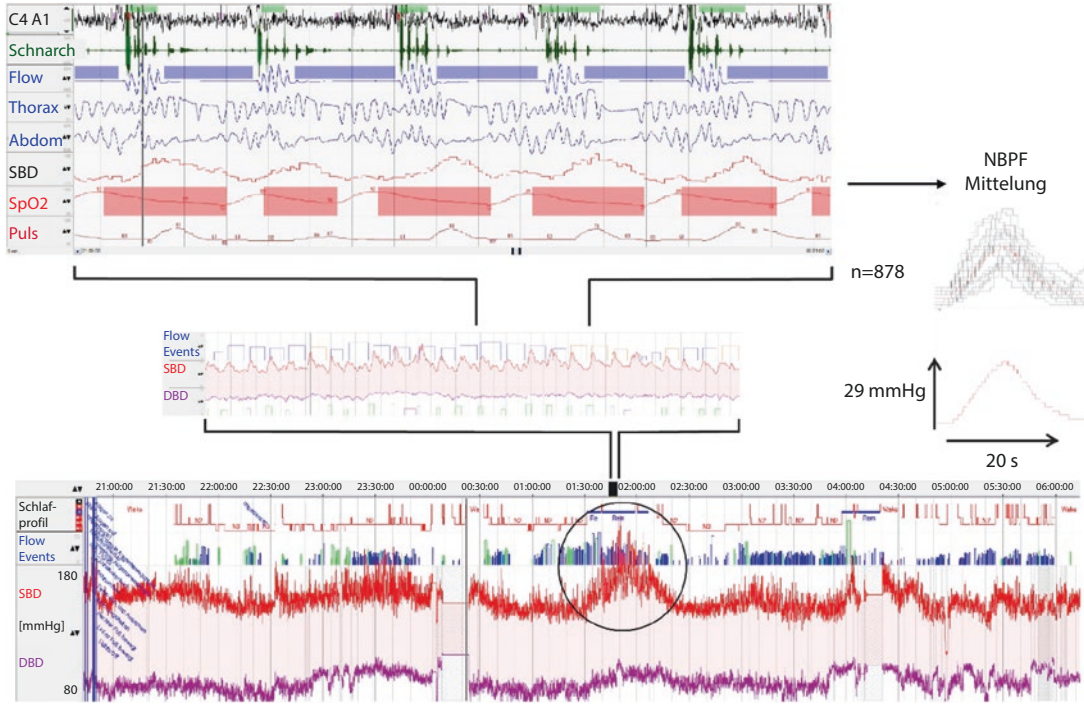


Fig. 2.11 Nocturnal blood pressure fluctuations (NBPFs). *Top left:* NBPFs following obstructive apneas (*green*, arousals; *blue*, apneas; *red*, desaturations). *Top right:* NBPFs averaged over $n = 878$; the average increase is 27 mmHg and the average duration is 20 s. *Bottom:* Blood pressure during the night with REM sleep-related pressure increase over 200 mmHg (superposition, *black circle*; artifact, *gray*). *SBP* systolic blood pressure, *DBP* diastolic blood pressure

clinically significant and, in the future, an indispensable tool to determine the severity of the disease or the severity of the sequelae regarding the cardiovascular system [10].

Digital videometry serves for registering the body position, but mainly also for assessing behavioral particularities during sleep. In this way, especially in cases of parasomnia and epileptic events during sleep, valid statements on the differential diagnosis can be made.

The standard parameters of polysomnography are summarized in Fig. 2.12.

Parameters and Measurements of Standard PSG

- Three EEG: F4-A1, C4-A1, and O2-A1 (as backup measurements or for better detection of lateral differences; also F3-A2, C3-A2, and O1-A2)
- Two EOG: left and right orbital edge
- One EMG: three electrodes (one mental muscle, two submental muscles)
- (Snoring) microphone
- Body position sensor
- Oronasal airflow, with mouth and nose separately assessed (thermistors, dynamic pressure measurement)
- Thoracic and abdominal respiratory excursions (piezo-ceramic elastic belt, induction plethysmography)
- Two EMG, anterior tibialis muscles
- One ECG, at least single channel
- Pulse oximetry, HbO2 saturation
- Videometry with zoom and panning head technique or high resolution for digital zooming

2.7.2 Parameters to Be Reported for Polysomnography (PSG)

In the morning following the nocturnal measurement, the PSG is evaluated by a somnologist or sleep physician or verified if the assistant staff has

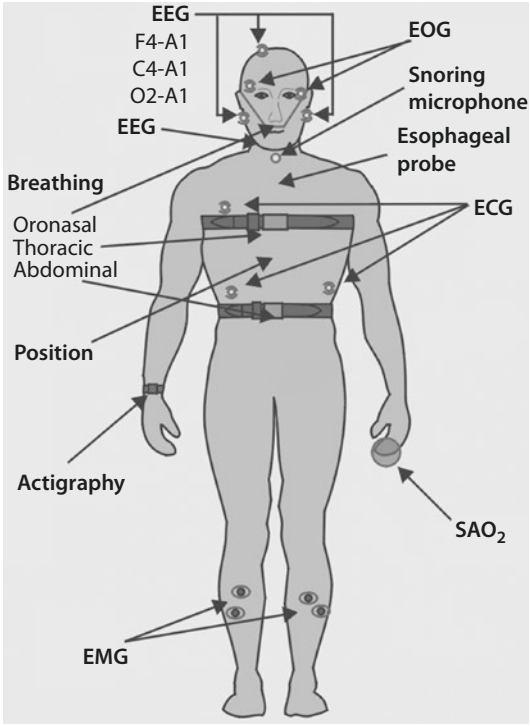


Fig. 2.12 Schematic depiction of the measurement of some parameters of polysomnography, modified according to Weeß [Steinberg R, Weeß H-G, Landwehr R (2010) Schlafmedizin. Grundlagen und Praxis. Uni-Med, Bremen]

preevaluated the files. The evaluation is based on the AASM criteria (▶ Sect. 1.3). In addition, motor (e.g., PLMS, periodic limb movement in sleep), respiratory (e.g., apneas), EEG-related (e.g., arousal), and other important events are differentiated. Evaluation via only software-inherent algorithms without verification by a specialist is not accepted because of the missing validity.

2.7.2.1 Sleep Scoring Data

Based on the classic sleep parameters (EEG, EOG, EMG), the quality of night sleep can be described by means of descriptively statistical parameters.

These statistical values refer to these characteristics (Table 2.3):

- Ability to initiate sleep
- Sleep ability at night
- Qualitative composition of night sleep
- Physiological, cyclic sequence of the sleep stages (sleep fragmentation)

The *sleep period time* (SPT) describes the interval from sleep onset to waking up in the morning.

The *total sleep time* (TST) refers to the actual time slept during the sleep period. Nocturnal wake phases are subtracted from the sleep period time.

The *sleep efficiency* describes the relationship of the time spent in bed sleeping to the overall bedtime given in percentages. Together with the total sleep time (TST) and the sleep period time (SPT), the sleep efficiency is considered as a specific parameter of the nocturnal sleep ability.

The *sleep-onset latencies* for the sleep stage N1, and in particular for stage N2, describe the ability to initiate sleep. It is defined as the time from turning off the light (alternatively, the start of the measurement) to the occurrence of the first epoch N1 or N2. More strict interpretations of sleep onset require the linked occurrence of three epochs of sleep stage N2 for the sleep-onset latency.

The *REM latency* (time between the first occurrence of N1 to the first occurrence of R in minutes) gives information about disorders of the non-REM/REM organization as it may be observed, for example, in the context of narcolepsy and impairments of some psychiatric sleep disorders. Significantly shorter REM latencies, usually of 90 ± 20 min to less than 10 min (so-called sleep-onset REM, SOREM) are an indicator for narcolepsy. Some authors also define SOREM with a latency of 15 or 20 min. In cases of depression, the average REM latency may amount to 50 min, but also to less.

The percentage of single sleep stages, referring to the sleep period time or the *time in bed* (TIB), changes with increased age. The percentage of deep sleep and that of REM sleep are of particular interest in this context.

Although deep sleep seems to have an important restorative function, REM sleep is considered to be highly important for intellectual performance, learning and memory processes, and emotional condition (see ▶ Chap. 1). The percentage of wakefulness during the sleep period is important in the context of insomnia disorders because it describes the extent of the difficulty maintaining sleep in a characteristic way. The percentage of light or superficial sleep (N1, N2) is increased in many sleep disorders with repetitive arousals or in cases of chronic application of hypnotics.

Table 2.3 Statistical parameters of polysomnography evaluation according to AASM (2020)

Sleep parameter	Calculation	Function/significance	Reference values
Time in bed or measurement time	Time span from turning off the light to turning it on (in minutes)	Bedtime, insomnia disorders, sleep deficit syndrome	–
SPT 1	Sleep period time 1: interval from the first N1 to definite waking up (in minutes)	Sleep ability, insomnia disorders	High interindividual variation, 5–9 h, age-dependent
SPT 2	Sleep period time 2: interval from sleep onset (N2) to definite waking up (in minutes)	Sleep ability, insomnia disorders	High interindividual variation, 5–9 h, age-dependent
TST 1	Total sleep time 1: SPT 1 without wake phases (in minutes)	Sleep ability, insomnia disorders	High interindividual variation, 5–9 h, age-dependent
TST 2	Total sleep time 2: SPT 2 without wake phases (in minutes)	Sleep ability, insomnia disorders	High interindividual variation, 5–9 h, age-dependent
SEI	Sleep efficiency index: TST1/TIB × 100	Sleep ability, insomnia disorders	Age-dependent; >85–90%
SOL 1	Sleep-onset latency 1: interval from turning off the light to first occurrence of N1 (in minutes)	Ability to initiate sleep, sleep-onset disorders	<30 min
SOL 2	Sleep-onset latency 2: interval from turning off the light to first occurrence of N2 (in minutes) or N2 linked over 3 epochs	Ability to initiate sleep, sleep-onset disorders	<30 min
SOL N3	Sleep-onset latency 3: interval from first occurrence of N1 to first occurrence of N3 (in minutes)	Sleep quality, sleep cycles, non-REM/REM organization	–
REM latency	Interval from first occurrence of N1 to first occurrence of stage R (in minutes)	Sleep quality, sleep cycles, non-REM/REM organization, narcolepsy	90 ± 20 min
Percentage of wake phases: N1, N2, N3, R	Percentage of single sleep stages referring to TST 1	Sleep quality, physical and psychic restoration, disorders of maintaining sleep	Age- and gender-dependent (Table 2.6)
Arousal index (AI)	Average number of all arousals per hour, referring to TST 1	Sleep fragmentation, global	Age- and gender-dependent (males ↑)
Respiratory arousal index (RAI)	Average number of respiration-related arousals per hour, referring to TST 1	Sleep fragmentation, involvement of respiratory events, sleep-related breathing disorders	<10/h
PLMS arousal index (PLMS-AI)	Average number of PLMS-related arousals per hours, referring to TST 1	Sleep fragmentation, involvement of periodic leg movements, RLS, PLMD	<5/h, classification of the severity
			5 to ≤20/h: mild
			20–60/h: moderate
			>60/h: severe

Table 2.3 (continued)

Sleep parameter	Calculation	Function/significance	Reference values
Endogenous arousal index (EAI)	Average number of endogenous arousals per hour, referring to TST 1	Sleep fragmentation, involvement of endogenous events, insomnia, narcolepsy, etc.	Unclear, see Arousal Index (AI) for orientation
REM interval	Duration of one non-REM/REM cycle	Sleep cycles, non-REM/REM organization, narcolepsy, psychiatric sleep disorders	High interindividual variation, 90 ± 20 min

Table 2.4 Standard values of sleep stage percentages according to age and gender, based on a study by Redline et al. [14] including *n* = 2685 healthy sleepers as controls

Value	Stage 1		Stage 2		Stage 3/4		REM sleep	
Age (years)	Males	Females	Males	Females	Males	Females	Males	Females
37–54	5.8	4.6	61.4	58.5	11.2	14.2	19.5	20.9
95% CI	5.2–6.5	4.1–5.3	60.0–62.8	57.1–60.0	9.9–12.6	12.7–15.9	18.8–20.2	20.0–21.8
55–60	6.3	5.0	64.5	56.2	8.2	17.0	19.1	20.2
95% CI	5.6–7.0	4.4–5.7	63.2–65.9	54.5–57.8	7.1–9.5	15.2–18.9	18.4–19.8	19.3–21.1
61–70	7.1	5.0	65.2	57.3	6.7	16.7	18.4	19.3
95% CI	6.4–7.9	4.4–5.7	63.9–66.5	55.7–58.9	5.7–7.7	14.8–18.6	17.8–19.1	18.4–20.2
>70	7.6	4.9	66.5	57.1	5.5	17.2	17.8	18.8
95% CI	6.8–8.5	4.3–5.6	65.1–67.8	55.6–58.7	4.5–6.5	15.5–19.1	17.1–18.5	18.0–19.6

Evaluation based on the criteria of Rechtschaffen and Kales [13]
CI confidence interval

The standard percentages of the sleep stages (Table 2.4) reveal their dependence on age and show a clear gender effect to the disadvantage of older men regarding deep sleep (N3). It must be taken into account that these standard sleep scoring data are based on the original criteria of Rechtschaffen and Kales. However, the sleep scoring data established by the AASM (2007–2020) should not have resulted in a significant modification of the standard values. Possibly, a reduction of the sleep-onset latency, a slight increase of stage N2 to the disadvantage of stage N1, and a nearly unchanged percentage of REM and deep sleep may be expected. For the moment, more recent standard values based on the AASM criteria are not available.

2.7.2.2 Phenomenology and Classification of Arousals

An *arousal* is understood as sudden frequency change/acceleration of the EEG. It includes theta waves, alpha waves, or frequencies higher than 16 Hz. Sleep spindles with characteristic frequencies between 11 and 16 Hz (mostly 12 and 14 Hz) are excluded.

Arousals may lead to partial, temporary, or complete arousal; they always interrupt sleep and are a typical pathomechanism for many sleep disorders. Regarding diagnostics of sleep disorders, the etiology of the arousals (e.g., respiratory, motor, vegetative, endogenous) plays a major role.

Arousals during sleep are stimulus dependent. They may be triggered by interoception

(psychophysical, sensor, neuronal, vegetative stimuli) or exteroception (acoustic, optic, tactile stimuli).

Regarding the diagnostics of sleep disorders, interoceptive arousals are critical.

- Interoceptive psychophysical arousals may occur in response to dream events, changed blood gas conditions, pH alterations, changes of the muscle elongation receptors, kinesthetic stimuli, or pain
- Interoceptive neuronal arousals develop in the cortex, the limbic system, the hypothalamus, or the reticular system of the brainstem

Arousals are seen in all age groups. As of the fourth decade, the incidence significantly increases; the development of the arousal frequency per hour of sleeping time depends on age. Male subjects show more arousals than females.

The *arousal index* (number of arousals per hour of sleep) describes the fragmentation of night sleep and the dissolution of the physiological sleep cycle. The higher is the fragmentation, the less differentiated or maintained are the sleep cycles. If the arousal index is correlated with motor, respiratory, or endogenous events, it allows conclusions about the contribution of comorbidity to the disorder of the physiological sleep cycle. Hence, the arousal index has a major role for determining the severity and evaluating the therapy success.

Currently, EEG-related arousal analyses are in the focus of polysomnographic diagnostics of sleep disorders. Compared to analytical methods of vegetative arousals, they are systemized, validated, and standardized. For improvement of arousal analysis during sleep, a systematic classification and validation of vegetative arousal reactions would be desirable.

In 1992, the American Sleep Disorders Association (ASDA) developed an upgraded EEG-related *arousal classification* that was internationally acknowledged as a standard. It is based on the classic measurements described by Rechtschaffen and Kales. Additionally, however, the measurement of occipital EEG measurement points (O1-A2, O2-A1, Oz-A1/A2) were recommended because the arousal frequencies can be better detected by occipital assessment. The analytical criteria of the AASM adopt the arousal classification of the ASDA. For classification of arousals according to the AASM [2], the information of frontal, central, and occipital measurements must be taken into account.

Arousal Criteria of the ASDA and the AASM [2]

An arousal is defined as an abrupt EEG frequency shift that may include theta, alpha, or frequencies higher than 16 Hz, except sleep spindles. The minimum length of the frequency acceleration is 3 s.

1. An arousal has to be preceded by at least 10 s of sleep. Arousals may also occur in a wake epoch if this epoch contains, for example, as much as 14 s of sleep. The AASM [2] indicates that arousals may generally also occur in a wake epoch between light out and light on and are included in the arousal index.
2. At least 10 s of sleep have to be registered between two arousals (Fig. 2.13).
3. Arousals may be observed in non-REM sleep only in the EEG, that is, without increasing muscle tonus of the submental EMG. In REM sleep, the arousal has to be accompanied by a submental EMG increase of at least 1 s.
4. An increase of muscle tone alone does not suffice for classification as arousal.
5. Artifacts, K complexes, or delta waves are only considered as arousals when a frequency acceleration of more than 3 s is observed in at least one measurement channel.
6. "Pen blocking" artifacts (overregulation in one channel) are classified as arousals when a frequency acceleration follows.
7. Subsequent EEG and EMG changes with a respective duration of 3 s or less, but summarized as more than 3 s, are not classified as arousals.
8. Alpha interferences in non-REM phases with a length of 3 s or less and a frequency of more than 1/10 s (>0.1 Hz)

are not classified as arousals. Alpha interferences with a length more than 3 s are only classified as arousals when no other alpha interference has occurred in the previous 10 s.

9. Change in sleep stage is not a criterion of arousal.

The criticism regarding the described arousal classification primarily refers to the time criterion for the minimum length of an arousal. Numerous investigations could show that respiratory, motor, or endogenous arousals may also constitute shorter intervals; these are then sometimes called micro-arousals. In these cases, strict interpretation of the ASDA or AASM criteria leads to an underestimation of the arousal incidence and thus to an underestimation of the severity.

2.7.3 Polysomnography (PSG) in Patients with Insomnia

In many cases, but not in all, PSG has a key role in the diagnostics of insomnia. In our own patient cohort, the suspected diagnosis had to be modified after PSG in about 38% of cases. In 2003, the AASM established recommendations for the indication to perform PSG for the diagnostics and therapy of insomnia based on the evidence of scientific data.

According to the criteria of the AASM, insomnia is a relevant disease that requires accurate diagnostics and therapy. Primarily, the diagnosis of insomnia is based on the clinical symptoms by means of intensive medical, psychiatric, and pharmacological history taking and sleep anamnesis (evidence level 1).

Referring to the AWMF guideline on insomnia and the insomnia guideline of the ESRS, PSG is indicated when all other diagnostic measures are exhausted and the medical condition of

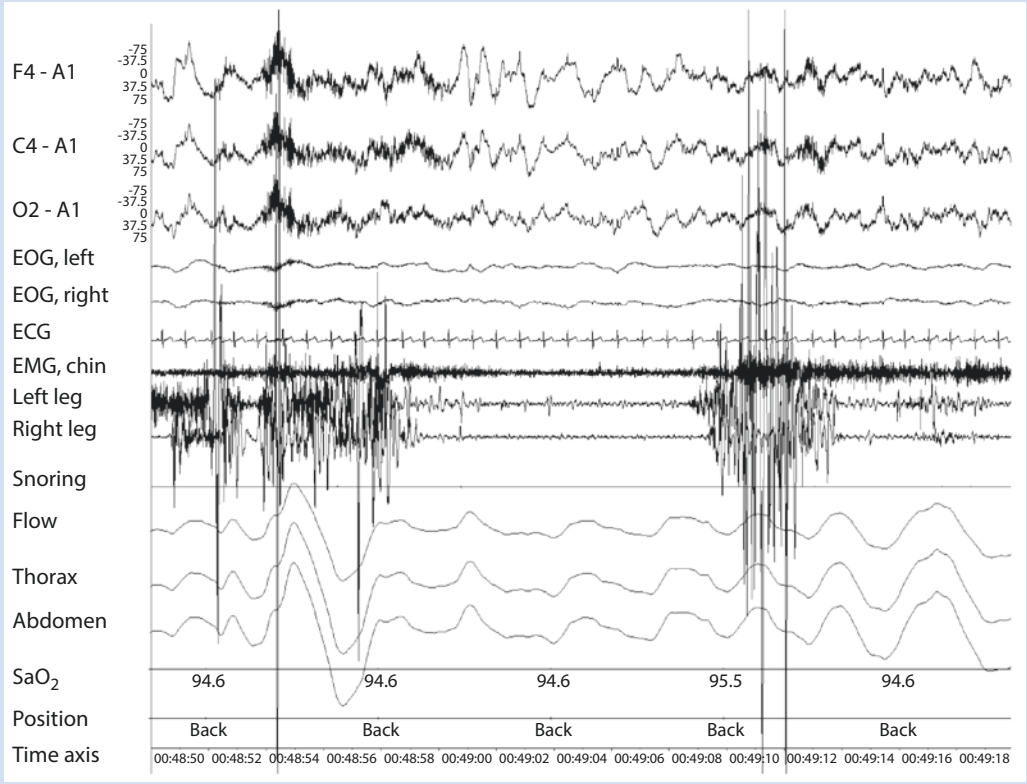


Fig. 2.13 A 30-s epoch of polysomnography. Two arousals with movement artifacts within 10 s. According to the AASM criteria, the second arousal is not counted. The frequency acceleration has to continue for at least 3 s

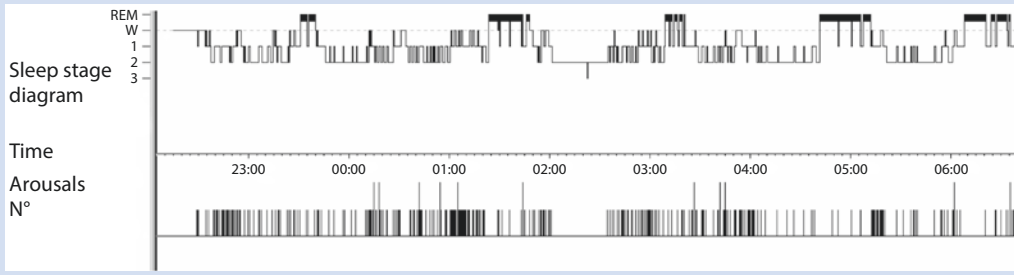


Fig. 2.14 Typical sleep profile of psychophysiological insomnia. It is clearly seen that the deep sleep phase is missing, with an increased number of changes of sleep stage and nocturnal wake phases (sleep stage diagram) resulting from a greater number of nocturnal arousals (arousal N0). It must be considered that the patient perceived sleep onset at 2 AM when the first sleep episode occurred without intermittent arousal. Because of the subsequently increased number of arousals, sleep afterward was not experienced as such, and the patient estimated the actual sleep quantity to be about 1 h in the morning protocol

insomnia is suspected, in particular in the context of sleep apnea syndromes or suspected periodic limb movements. According to the Association of Scientific Medical Associations (ASMA) guideline, PSG may also provide important diagnostic and therapeutic information in therapy-refractory cases as well as in high-risk groups associated with endangerment of self and others, such as professional drivers or subjects working with dangerous machinery. Polysomnography may also lead to further diagnostic and also therapeutic knowledge when a significant discrepancy is expected between the subjectively perceived severity of insomnia and the polysomnographic findings (see also Table 3.2).

The typical sleep profile of insomnia patients is characterized by these factors (Fig. 2.14):

- Prolonged sleep-onset latency
- Increased endogenous arousals
- Prolonged nocturnal wake phases
- Reduction of deep and REM sleep
- Modified sleep cycles

Often an alpha overlap is found in the sleep EEG, which is considered to be an expression of a chronically increased tension level. However, it is a nonspecific phenomenon that is also observed in other psychiatric disorders.

It is noteworthy that often a discrepancy is observed between objective polysomnographic findings and the patient's subjective perception of the ability to sleep. In these cases, frequently structural changes of sleep such as micro-arousals or the aforementioned alpha overlaps are found in the sleep EEG. Not least because of this fact, the evaluation criteria of PSG, even after revision by the AASM, are controversially discussed with regard to their clinical applicability, especially for insomnias.

The apparently disturbed perception of sleep, however, can also be explained based on several recent experimental findings in healthy sleepers and subjects suffering from disturbed sleep.

During the sleep-onset process, the probability of perceiving sleep onset is only clearly increased with the occurrence of the first sleep spindle. Subjects who were awakened before the first sleep spindle report significantly more often not to have slept at all. In the course of the night, the sleep perception depends not only on the depth of sleep but also on its continuity. Individuals who underwent experimental triggering of arousal in similar intervals as they occur in insomnia patients reported comparably linked wake phases as do insomnia patients even if objectively sleep could be seen between arousals. The human brain seems to need continuous sleep episodes of longer durations without arousals to perceive sleep.

2.7.4 Polysomnography (PSG) in Patients with Periodic Limb Movements in Sleep and Patients with Restless Leg Syndrome

Periodic limb movements in sleep (PLMS) and restless legs syndrome (RLS) are two indepen-

dent, delayed, or even simultaneously emerging disorders with suspected central nervous system genesis.

According to the AASM recommendations [10], PSG is considered as the essential technical examination to confirm PLMS. RLS, in contrast, is primarily a clinical diagnosis. In the following cases, PSG is also indicated in this context:

- Cases with unclear diagnosis
- Children and adolescents with RLS
- Therapy-refractory RLS
- Persisting daytime sleepiness or sleep disorders under therapy
- Necessity of complex pharmaceutical strategies with opiates, anticonvulsants, or other atypical pharmaceutical treatment approaches

Furthermore, PSG is the most important criterion for verification of the effectiveness of therapeutic approaches to frequently associated nocturnal periodic arm and leg movements, especially for patients with persisting insomnia or daytime sleepiness under therapy (evidence level 1).

PLMS are characterized by episodes of periodic leg or, rarely, arm movements in sleep. They may be unilateral, bilateral symmetrical, or alternating (Figs. 2.15, 2.16, and 2.17).

PLMS in combination with RLS are predominantly observed in the sleep stages N1 and N2: these occur less frequently in REM sleep. PLMS also emerge in wakefulness and at the transition between wake and sleep. PLMS increase with increased age. In healthy subjects aged between 30 and 50 years, the incidence amounts to about 5%; in 50-year-old individuals, PLMS is suspected in about 30% of the examined population.

Regarding diagnosis, PLMS must be differentiated from these events:

- Hypnagogic foot tremor
- Alternating leg muscle activation (ALMA)
- Excessive fragmentary myoclonus in non-REM sleep
- Phasic REM twitches
- Leg cramps
- PLMS associated with or terminating apnea

The last-mentioned symptoms are no longer observed in the context of sufficient ventilation therapy.

PLMS are often accompanied by other sleep disorders, frequently appearing in insomnia disorders, sleep apnea, narcolepsy, some psychiatric diseases, and REM behavior disorder.

The typical sleep profile with PLMS is significantly different from that of healthy sleepers. The sleep efficiency is relevantly reduced, more phases of light sleep (N1 and N2) are observed, and deep sleep and REM sleep are often reduced. The periodicity of the sleep cycles is significantly impaired or even disappears with the frequent arousals and the increased wake phases (Fig. 2.14). In 1993, the Atlas Task Force of the American Sleep Disorders Association (ASDA) defined the duration, periodicity, and arousal reactions of rhythmic movements in sleep. In 2007, these criteria were substituted by those of the American Academy of Sleep Medicine (AASM). The original classification criteria, however, will probably be applied for a certain time until the computer-assisted analysis systems are able to implement the AASM criteria that are based on absolute signal properties.

AASM Criteria for the Classification of PLMS (2020)

- At least four consecutive contractions must be observed within an interval between 5 and 90 s (Fig. 2.17). They are measured in all sleep stages and in wakefulness.
- The basic EMG signal should be measured with a relaxed anterior tibialis muscle and should not amount to more than 10 µV (between positive and negative amplitude, −5 µV to +5 µV). The application of 60 Hz (notch) filters should be avoided if possible. The impedances must be below 10,000 Ω; below 5,000 Ω is recommended. The measurement range should be between −100 and +100 µV.
- The duration of one leg movement (LM) is between (minimum) 0.5 s and (maximum) 10 s.
- The onset of LM is defined when the increase of the EMG is higher than 8 µV compared to the signal at rest. The end of LM is defined by a reduction of the EMG signal to <2 µV above the signal at rest for at least 0.5 s.

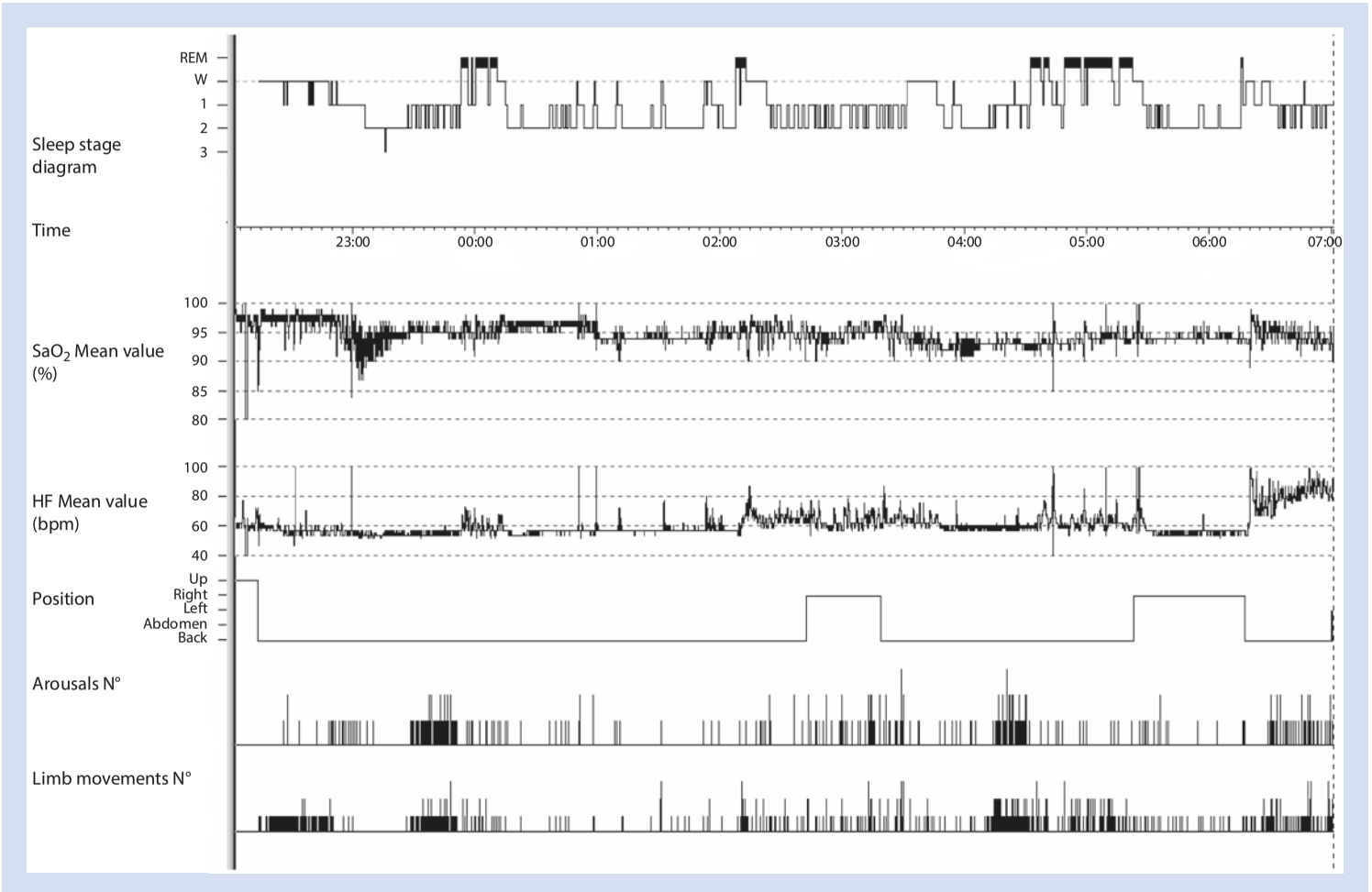


Fig. 2.15 Typical hypnogram in case of PLMS. The hypnogram shows the characteristic deep sleep suppression (stage N3) and the increased sleep stage change caused by repetitive arousals (arousal N0) in cases of periodic limb movements (limb movements N0). The increased sleep-onset latency is also striking. The increased number of arousals (arousal N0) is also seen in the increased heart rate variation (HF mean value, bpm) (N0 = number). The SaO_2 decrease at the beginning of the sleep period is still physiological and expresses the partially realized deep sleep. Note the scale of the *y*-axis, which shows a high resolution and suggests O_2 desaturation

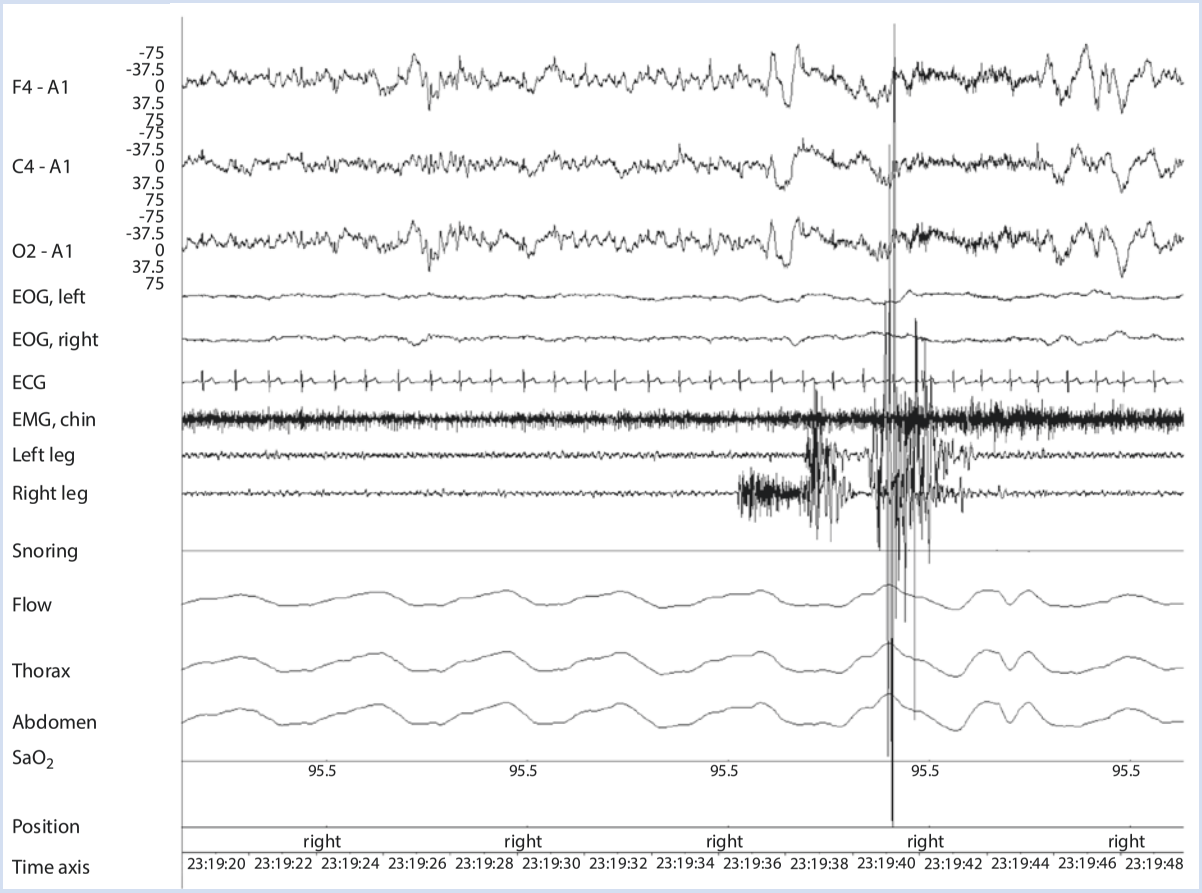


Fig. 2.16 Bilateral PLMS with arousal during a 30-s epoch of polysomnography. Arousals are classified as associated with leg movements if the interval between the end of the first event and the beginning of the second event is less than 0.5 s (independent from the order of the events). Leg movements of both legs are classified as one movement (LM) if less than 5 s is measured between the onsets of both movements

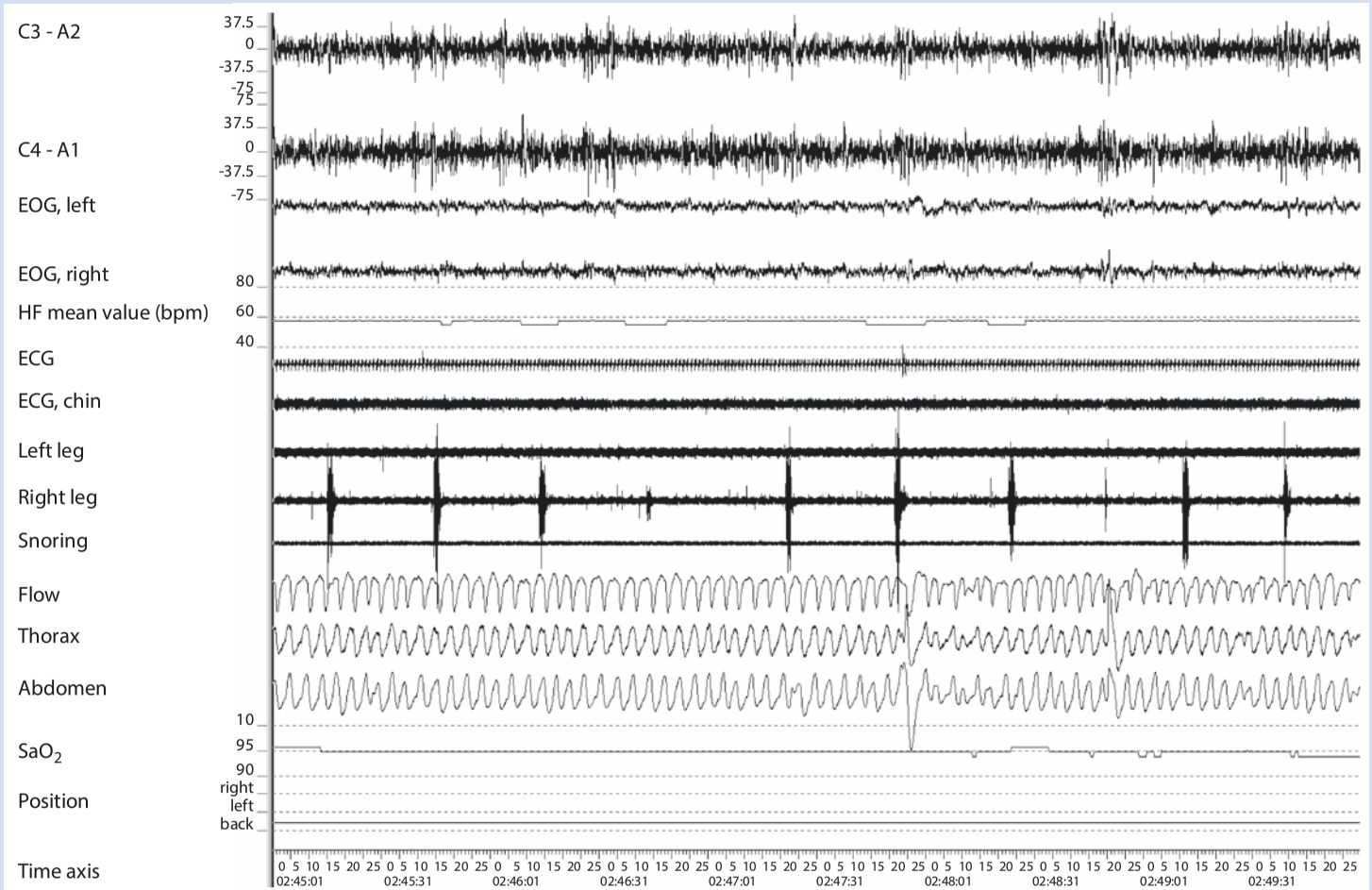


Fig. 2.17 PLMS of the right anterior tibialis muscle with arousals in the 5-min depiction of polysomnography. The associated arousals are no longer visible because of the time compression in the EEG. Amplitude increases in the EEG suggest the possible presence of an arousal

- Leg movements of both legs are classified as one leg movement (LM) if less than 5 s is measured between the onsets of both movements.
- According to the ASDA, leg movements at the end of an apnea or hypopnea that emerge together with an onset of hyperventilation are classified separately as breathing related. Today, they are no longer assessed based on the AASM criteria when they emerge in an interval that starts 0.5 s before the onset of apnea or hypopnea and ends 0.5 s after the end of apnea/hypopnea.
- Arousals are classified as associated with leg movements when the time interval between the end of the first event and the onset of the second event is less than 0.5 s (independent from the order of the events).

If a wake phase of less than 90 s separates a series of leg movements, the leg movements during the wake phase are not counted. However, the series of leg movements is assessed as such.

The AASM recommends the following parameters for analysis:

- Definition of the total number of PLMS during measurement and definition of the total number of PLMS with arousals.
- Assessment of a PLMS index (PLMSI) that is calculated by the following formula: total number of PLMS during TST × 60/TST (minutes).
- Definition of a PLMS arousal index (PLMSArl) calculated based on the formula: number of PLMS with arousal × 60/TST (minutes).
- Furthermore, it is recommended to differentiate between PLM in sleep and in wakefulness.

Practical Tip

PLMS index:

- Up to 5/h: inconspicuous
- Between 5/h and ≤20/h: mild disorder
- Between 20/h and 60/h: moderate disorder
- More than 60/h: severe disease

Besides the more exact specification, the advantage of the AASM criteria is the possibility to perform computer-based evaluation by an automated analysis systems. The AASM has also described the first criteria for other motor phenomena and disorders during sleep.

The AASM defines *hypnagogic foot tremor* (HFT) as EMG potentials occurring at the sleep–wake transition in a group of at least four events or as movements with lengths between 250 and 1000 ms and an incidence between 0.3 and 4 Hz without amplitude criteria. HFT is considered as a benign symptom without clinical relevance.

Alternating leg muscle activation (ALMA) emerges during sleep independently from sleep stages and is associated with arousals, and it is also described as a benign phenomenon with an increased probability of occurrence in the context of RLS, sleep apnea, and antidepressant medication. For identification, at least four side-alternating muscle activations are required, emerging with a minimum frequency of 0.5 Hz and a maximum frequency of 3 Hz. The duration of the single events amounts to 100–500 ms.

Excessive fragmentary myoclonus (EFM) in non-REM is characterized by EMG interferences, discharge of single motor neurons, with a maximum length of 150 ms. According to the AASM criteria, these must appear over at least 20 min in total with a frequency of at least 5/min. They are not associated with movements, and they have no clinical relevance even if they are more frequently observed in radiculopathies.

2.7.5 Polysomnography (PSG) in Cases of Bruxism

For the first time, the AASM formulated criteria for polysomnographic registration and evaluation of bruxism (▶ Chap. 8). Hereby, the criteria for analysis are applied to the submental EMG. However, additional measurements of the masseter muscle may also be performed. To confirm the diagnosis, an accompanying audiometric measurement may be performed in the PSG.

Phasic as well as tonic increases of the EMG activity of the submental EMG or the masseter muscle are measured that show at least twice the amplitude of the background EMG activity. Short (phasic) increases of the EMG activity are considered as bruxism episodes if their duration amounts to

0.25–2 s and at least three of such increases occur in regular intervals. Tonic increases of the chin activity are considered as bruxism at a length of more than 2 s. After a bruxism episode, a new episode may only be defined when the EMG has returned to the level of the background activity for at least 3 s. A second type of bruxism activity must not be forgotten. It is characterized by tonic increases that originate from the permanent clenching of the teeth.

The AASM does not give recommendations regarding the indication of PSG in the context of bruxism.

2.7.6 Polysomnography (PSG) in Cases of REM Behavior Disorders

For diagnosis of REM behavior disorder (RBD), one or both of the following phenomena have to be observed in the PSG.

- Tonic muscle activation in REM characterized by EMG activity emerging in at least 50% of the epoch that is above the lowest amplitude in non-REM.
- Excessive transient (phasic) muscle activation (ETM) during REM in the submental and tibialis EMG. Hereby, it is necessary that at least 5 mini-epochs occur with ETM in 5 of 10 mini-epochs (3 s) of the respective epoch (30 s). In the context of REM behavior disorders, ETMs have a length between 0.1 and 5 s, and their amplitude is at least four times higher than the background activity.

The AASM has not published any recommendations regarding the indication for PSG in cases of REM behavior disorders.

2.7.7 Polysomnography (PSG) in Cases of Rhythmic Movement Disorders in Sleep

Rhythmic movement disorders in sleep (jactatio capitis nocturna) are defined as movements of large muscle groups with a frequency between 0.5 and 2 Hz. It is recommended to summarize at least four movements to one episode or one cluster. For assessment, the EMG should show at least the double amplitude of the background activity. Accompanying videometry, as well as additional application of EMG surface electrodes on the muscle groups involved, is recommended to find an exact diagnosis.

The AASM has not published any recommendations regarding the indication for PSG in cases of rhythmic movement disorders in sleep.

2.7.8 Polysomnography (PSG) in Cases of Sleep-Related Breathing Disorders

Sleep-related breathing disorders (▶ Chap. 4) include:

- Obstructive sleep apnea syndrome
- Central sleep apnea syndrome
- Sleep-related hypoventilation syndromes
- Sleep-related hypoxemia

It is characteristic for these kinds of disorders that apnea or reduced breathing (hypopnea) or hypoventilations or hypoxemia occur during sleep. In association, O_2 desaturations and respiratory arousals may develop.

PSG is performed for diagnosis, differential diagnosis, assessment of the severity, and therapy monitoring of sleep-related breathing disorders. The S3 guideline on "Non-restorative sleep/sleep disorders" [chapter entitled "Sleep-Related Breathing Disorders" published by the German Society for Sleep Research and Medicine (Deutsche Gesellschaft für Schlafforschung und Schlafmedizin, DGSM] as well as the criteria for the indication of polysomnography for sleep-related breathing disorders of the AASM revised in 2017 [6] recommend polysomnography as the diagnostic standard for all sleep-related breathing disorders with comorbidities that are suitable to reduce the significance of unattended polygraphy systems. Only in clinically clear cases with suspected SRBD without relevant comorbidities may the diagnosis be performed by means of polygraphy. Follow-up assessments are generally based on medical consultation with device-related examinations by means of polygraphy. Polysomnographic follow-up may be indicated in patients with relevant comorbidities (▶ Sect. 2.6). If an unattended polygraphic examination has already been performed with unclear results or technical problems, polysomnography is recommended.

Based on the recommendations of the AASM, oronasal thermistors may be applied to detect

apneas. Regarding hypopneas, the application of nasal pressure transducer sensors is required. More recently, combination electrodes have been developed allowing the simultaneous application of dynamic pressure and thermistor measurements.

Assessment of the respiratory effort should be performed by means of esophageal pressure sensors or induction plethysmography. Elastic belts with piezoceramic sensors are not recommended because measurements are only punctual (missing circumference measurement) (▶ Sect. 2.7.1). Because in practice two different sensors cannot always be applied for the assessment of apneas and hypopneas, nasal pressure transducer is also accepted to evaluate apneas. The registration of hypopneas can also be performed by means of oronasal thermistors. If these methods are not successful or no reliable signal can be registered, the AASM criteria alternatively allow assessing apneas by means of the sum signal of thoracic and abdominal induction plethysmography (estimation of the breathing volume) or the time-related sum signal of thoracic and abdominal induction plethysmography (estimation of the airflow). As an alternative for nasal pressure transducers or oronasal thermistors, the sum signal of thoracic and abdominal induction plethysmography, the time-related sum signal of thoracic and abdominal induction plethysmography, or the separate registration of induction plethysmography of thorax and abdomen is recommended for identification of hypopneas. It is also accepted to refer to the sum signal of thoracic and abdominal polyvinylidene fluoride sensors (belts) for identification of apneas or hypopneas. In nights when positive pressure ventilation should be titrated, the use of the flow signal of the ventilation device is recommended to identify apneas or hypopneas.

According to the AASM criteria, an event is considered as *apnea* when:

- The reduction of the thermistor signal (or the dynamic pressure measurement) is ≥90%.
- The amplitude criterion (reduction ≥90%) applies for at least 10 s of the duration of the event.

An apnea is considered as being:

- Obstructive when the respiratory effort persists unrelievedly
- Central when the respiratory effort is absent
- Mixed when the respiratory effort is first absent and in a second part of the event restarts with still absent airflow (◘ Figs. 2.18, 2.19, 2.20)

After revision of the AASM criteria from 2007, the version of 2020 summarizes the alternative hypopnea aspects to one single definition:

Hypopnea is confirmed when:

- The flow signal (dynamic pressure measurement, thermistor) decreases by at least 30% compared to the original value.
- This reduction lasts for at least 10 s.
- The oxygen saturation decreases by at least 3% compared to the original value or the result is arousal correlated (see ◘ Fig. 2.21).

An event is considered as apnea when the criterion of apnea is temporarily fulfilled in the course of hypopnea.

Following the AASM again obstructive and central types of hypopneas may be differentiated.

The advantage of the new AASM criteria is, among others, the exact definition of the beginning and the end of a respiratory event.

- The beginning of an apnea or hypopnea is defined from the nadir preceding the first breath that is clearly reduced.
- The end of a respiratory event is defined as the beginning of the first breath whose amplitude approaches the baseline amplitude. In cases of unclear original amplitude, such as when breathing is highly variable, the end is set at the point where a clear increase of the oronasal breathing amplitude is observed.

  Alternatively, it is recommended in cases of accompanying desaturation to define the end at that point where resaturation of 2% or more occurs.

However, this last-mentioned criterion is supposed to be a relevant prolongation of the respiratory event because of the time shift between apnea and associated desaturation from the cardiovascular time and thus it should be declined.

Also, the consideration of respiratory events that do not meet the criterion of apnea or hypopnea but that nonetheless impair the quality of sleep and have to be rated as pathological is a merit of the AASM. The respiratory effort-related arousals (RERAs) are defined by an increase of the respiratory effort or a flattening of the dynamic

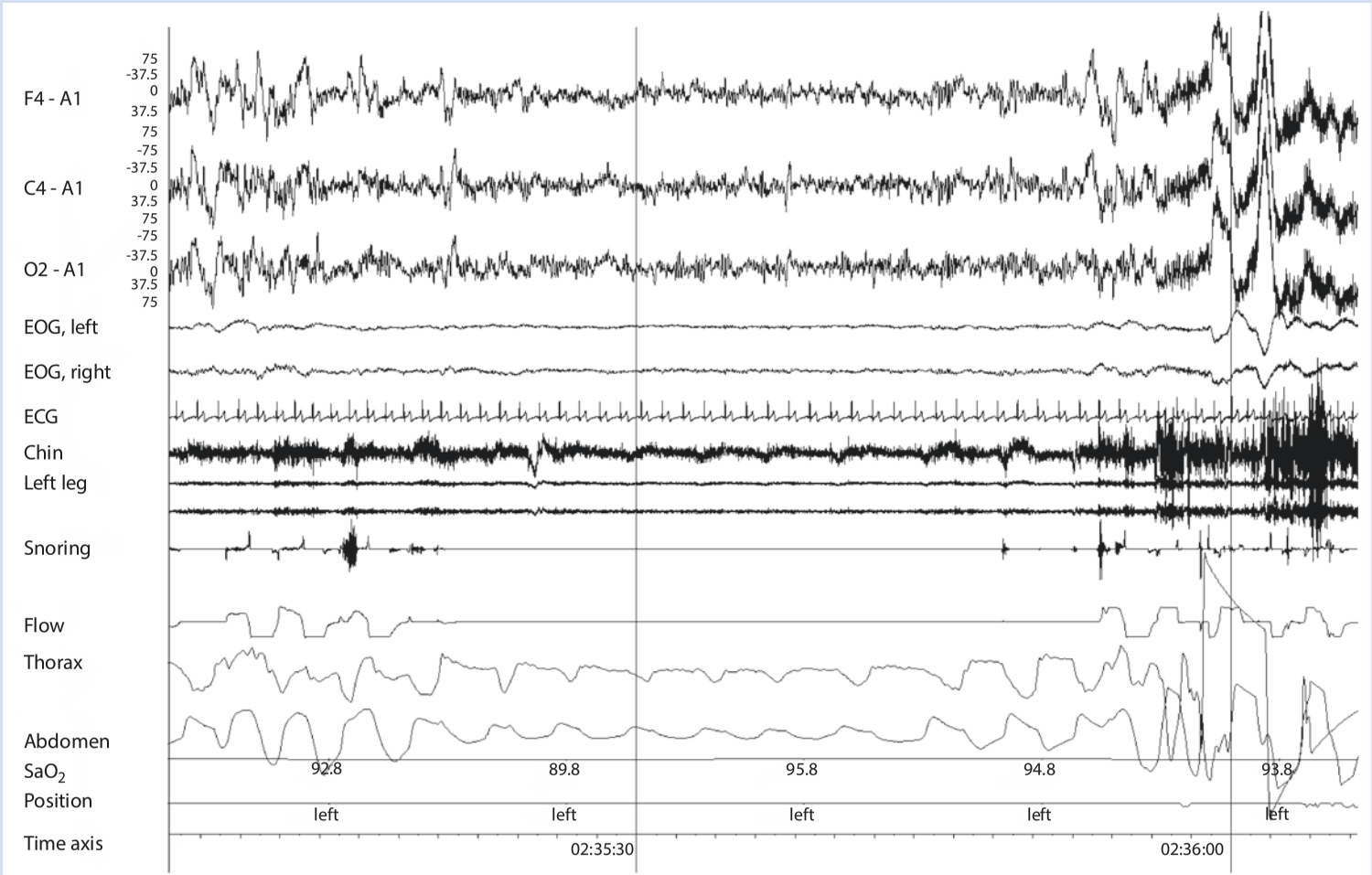


Fig. 2.18 Obstructive apnea of about 20 s with paradox thoracic and abdominal respiratory excursions. At the end of the apnea, an apnea-terminating arousal is found (increased frequency in the EEG and movement artifacts) and gradual HbO_2 decrease that continues in the consecutive epoch (not visible). The HbO_2 decrease at the beginning of the apnea as well as the previous arousal is the result of a previous apnea

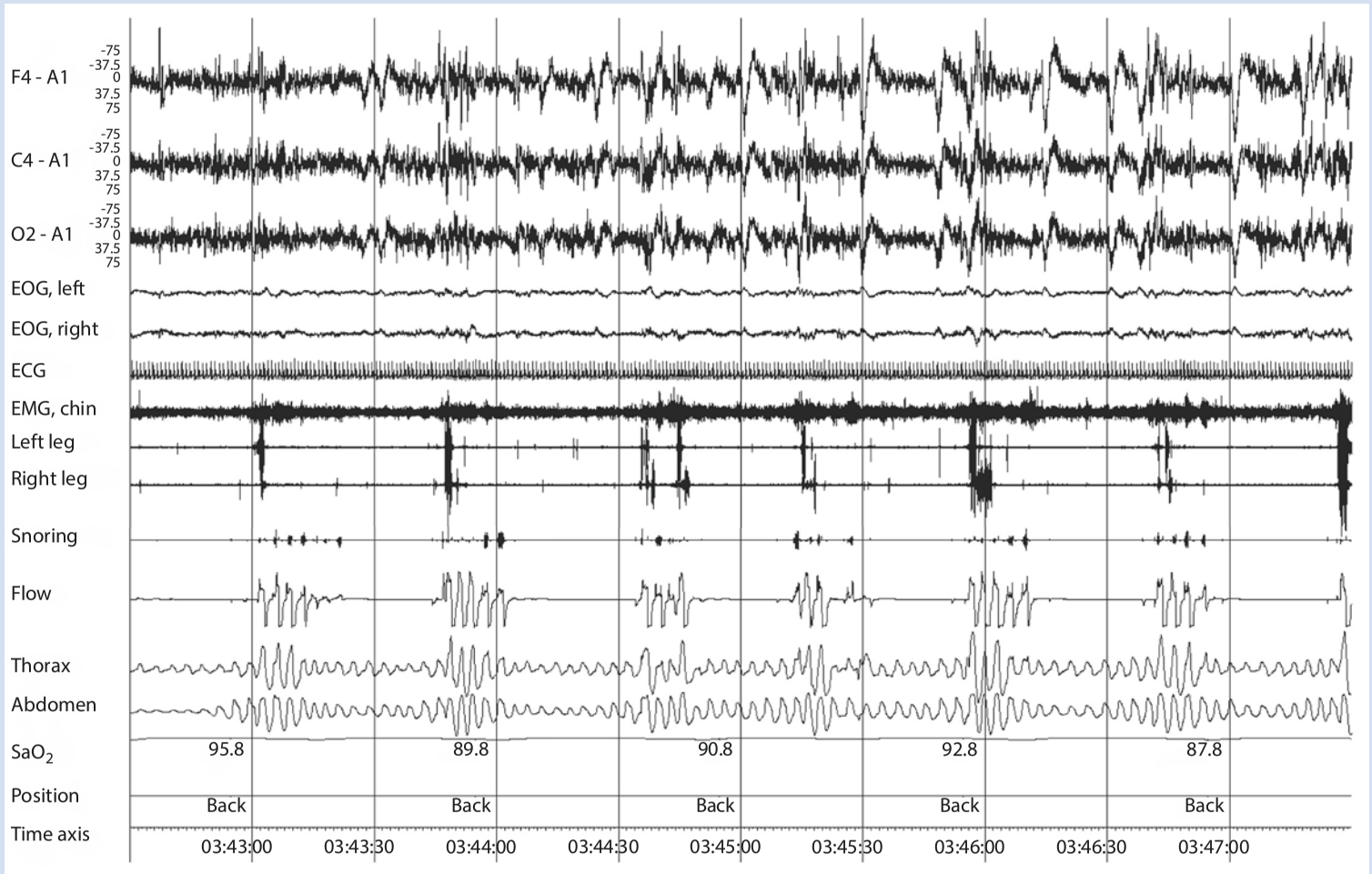


Fig. 2.19 Repeated obstructive apnea on the 5-min scale. Because of the concise presentation, the apnea-terminating arousals in the EEG can only be recognized based on the intermittent amplitude increases at the respective end of the apnea

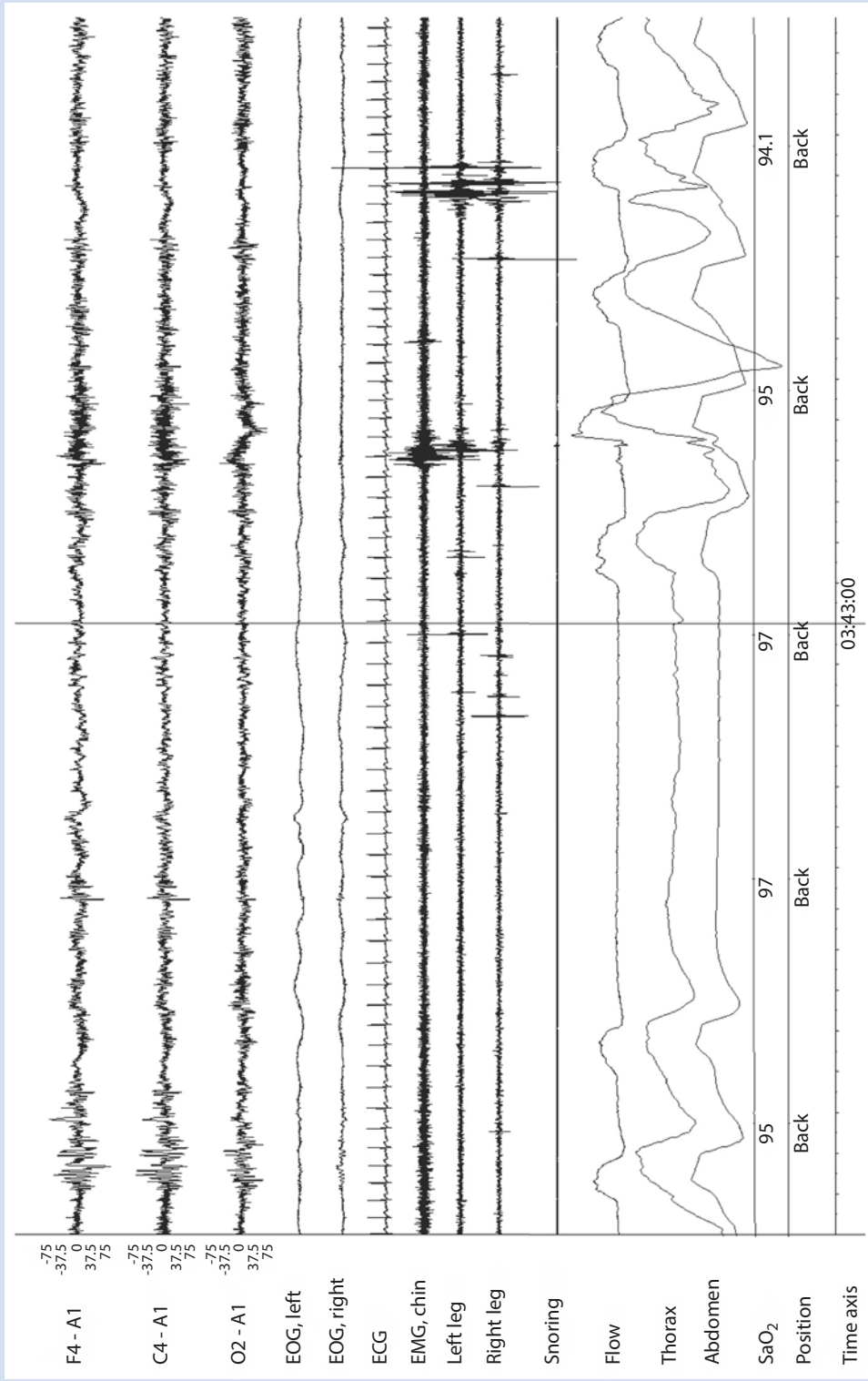


Fig. 2.20 Central apnea of 10 s with subsequent arousal reaction (accelerated frequency in the EEG and movement artifacts)

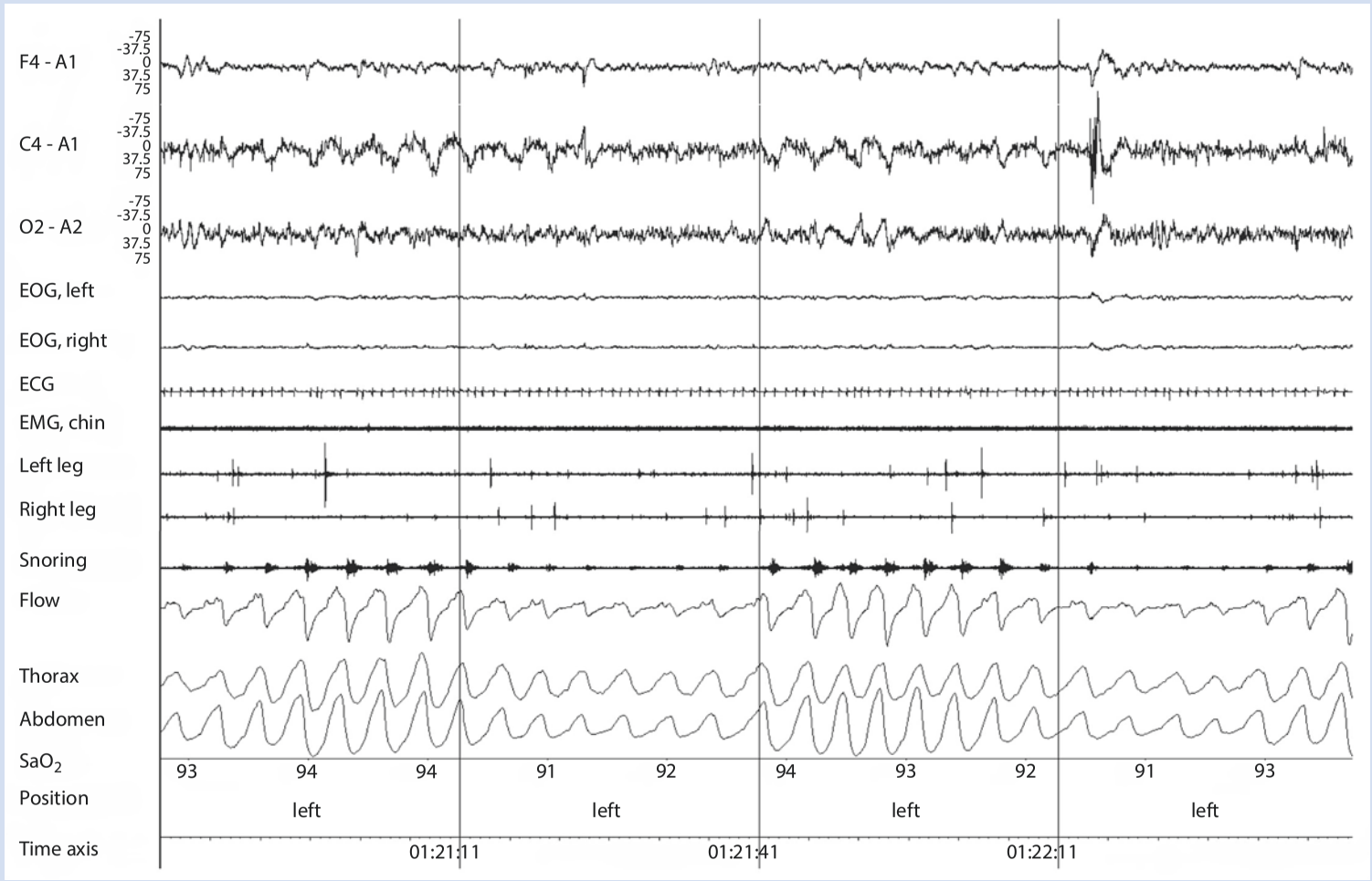


Fig. 2.21 Hypopneas in 2-min depiction. Reduction of the amplitude in the oronasal thermistor >30% and in the thoracic and abdominal respiratory excursions. Further, decrease of the HbO_2 saturation >4%

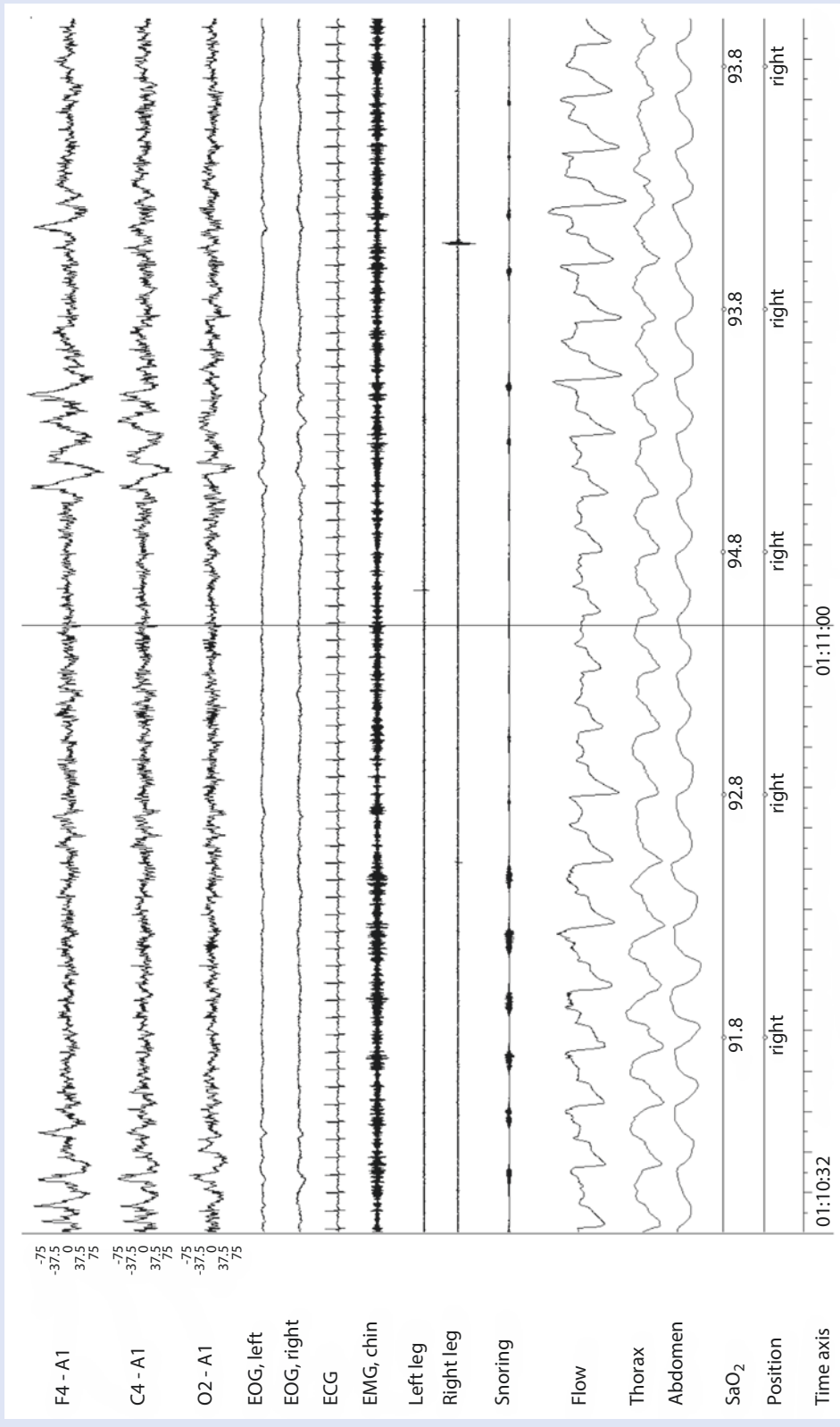


Fig. 2.22 RERA (respiratory effort-related arousal). Flattening of the curve and amplitude reduction in the oronasal thermistor by less than 30% with accompanying EEG frequency acceleration is introduced by waves with higher amplitudes (delta waves) including a K complex

pressure signal over an interval of 10 s or more. It is required that the respective event leads to arousal and the criteria of apnea or hypopnea are not met (Fig. 2.22).

In cases of primary or secondary alveolar hypoventilation and central apnea, a gradual or complete loss of the airflow can be observed with open airways and reduced or absent thoracic and abdominal respiratory efforts.

The event is confirmed as *hypoventilation* when:

- The $PaCO_2$ value is at least 55 mmHg for a duration of at least 10 min.
- An increase of at least 10 mmHg of $PaCO_2$ is observed for at least 10 min over a value of 50 mmHg.

Persisting O_2 desaturation does not suffice for documenting hypoventilation (▶ Sect. 4.1.1). An increased $PaCO_2$ immediately after awakening is a clear hint to the presence of sleep-related hypoventilation. Transcutaneous as well as end-tidal (end-expiratory) measurements may be used to determine $PaCO_2$.

In the context of central sleep apnea syndromes (▶ Chap. 4), often typical airflow patterns occur that are identified as Cheyne-Stokes respiration. The AASM criteria define Cheyne-Stokes respiration as follows:

- At least three consecutive apneas and/or hypopneas emerge, in between crescendo–decrescendo breathing is observed, and the cycle length of this breathing pattern is at least 40 s.
- At least five or more central apneas or hypopneas per hour are observed within a measurement period of at least 2 h that are associated with Cheyne-Stokes respiration (Fig. 2.23).

An overview of respiratory events in sleep is given in Table 2.5.

Depending on the severity of the disease, a fragmentary sleep profile with deep and REM sleep suppression is found based on apnea-terminating arousals with simultaneous increase of the superficial sleep stages. Coinciding with the apnea or hypoventilation phases, phasic HbO_2 desaturations occur that appear phase shifted because of the physiological HbO_2 saturation curve (Fig. 2.24).

The AASM suggests statistically descriptive parameters for description of sleep-related breathing disorders (Table 2.6). For identification of severity, the following parameters are typically measured:

- The apnea-hypopnea index (AHI)
- The desaturation index (number of HbO2 desaturations >3% per hour of night sleep)
- The respiratory effort-related arousal index (RERA-I)
- Respiratory disturbances iIndex (RDI): Number of apneas, hypopneas and RERAs per hour of night sleep.

In cases of unattended polygraphy, the assessment of sleep and RERAs is not possible because of the missing EEG. Thus, alternative calculation formulas and reference parameters are identified for description of the respiratory severity, and another classification of the severity is used compared to PSG. The respiratory event index (REI) is used instead of the RDI that considers apneas, hypopneas, and RERAs. The ODI replaces the EI.

- The REI describes the number of apneas and hypopneas with reference to the measurement time.
- The ODI describes the number of all O_2 desaturations (typically >3%) with reference to the measurement time.

For further details, see Tables 2.3 and 2.6.

In the past, the classification of the severity of sleep-related breathing disorders was only based on the extent of occurring nocturnal apneas and hypopneas. Currently, the occurrence of respiratory arousals and the daytime condition, in particular daytime sleepiness, are also considered (Table 2.7).

Based on this classification of the severity, also cases with a low RDI (respiratory events per hour of sleep) and relevant daytime sleepiness with severe attentiveness disorders and proneness to fall asleep are considered as cases of severe sleep apnea.

The main criticism of the classification of the severity is that age effects and also methodical effects are not taken into account. For example, in older healthy subjects, often an RDI of more than 5/h is found. It would be desirable that the severity also includes the individual cardiopulmonary risk. Furthermore, the sensitivity of the measurement methods of the oronasal airflow is very different. Numerous studies could reveal that oronasal thermistors lead to a lower RDI compared to nocturnal pressure transducers.

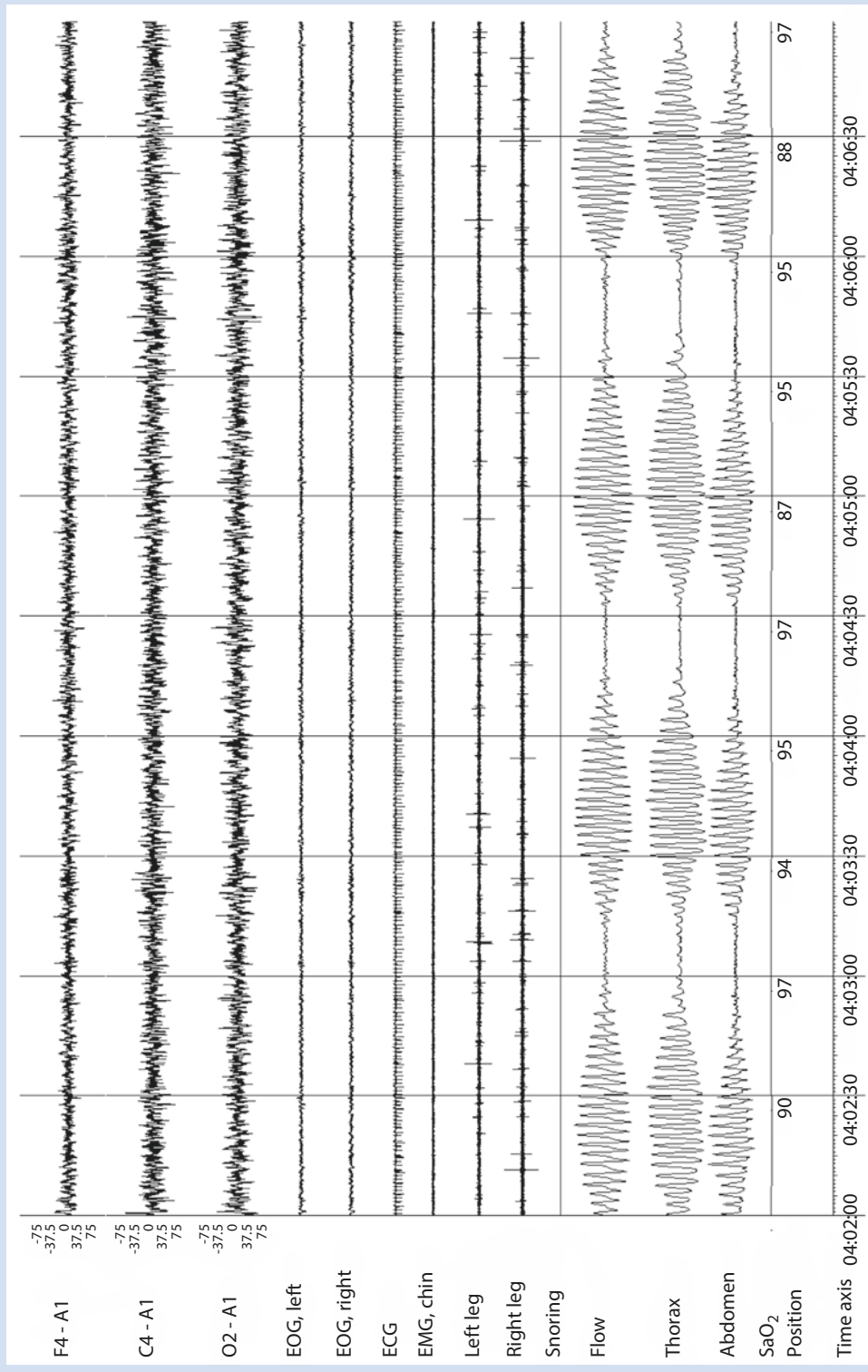


Fig. 2.23 Cheyne-Stokes respiration in the 5-min depiction of polysomnography. Crescendo–decrescendo phases of breathing follow each other. Central apneas between the events and arousals at the time of amplitude maximum. The arousal reactions are only seen because of the increased amplitude of the EEG (occipital)

Table 2.5 Systematic overview of respiratory events in sleep

Respiratory event	Oronasal airflow	Respiratory effort
Obstructive apnea	None (≥90%)	Maintained
Central apnea	None (≥90%)	None
Mixed apnea	None (≥90%)	First none, then onset
Hypopnea	≥30% (and 3% HbO_2 desaturation or arousal)	Maintained
Respiratory effort-related arousal (RERA)	Discrete reduction (<30%), not obligatory	Maintained
Cheyne-Stokes respiration	Crescendo–decrescendo-like course	Crescendo–decrescendo-like course

2.8 Examination of Sleepiness- and Fatigue-Related Daytime Impairments

Daytime sleepiness and resulting impairments at work, when driving a car, or in other socially demanding situations are a significant symptom of many diseases and in particular of many sleep disorders. A relevant percentage of 31% of the population older than 16 years report nonspecifically to suffer sometimes or frequently from sleepiness (Falkenstetter et al. 2011). A well-known, nearly legendary study of an important insurance company in Germany (HUK) reveals that about 25% of all accidents with fatal outcome on Bavarian highways are caused by driver weariness. Traffic statistics confirm that on German streets, about twice as many fatal accidents occur because of microsleeps rather than drinking/driving. About 20% of all critical events in aviation are explained by sleepiness of the safety staff, pilots, and tower staff. Numerous catastrophes, for example, the sinking of the tanker *Exxon Valdez*, the crash of the shuttle *Challenger*, or industrial accidents such as Chernobyl, Three Mile Island, and Bhopal, are supposed to be caused by, among other factors, faults because of daytime sleepiness.

The scientific interest in daytime sleepiness has been increasing in past years; however, daytime sleepiness is a young research field still with little small knowledge. A standardized scientific definition of the term is currently not available. Furthermore, a differentiation to related phenomena of fatigue has not yet been established.

Considering the current scientific knowledge, daytime sleepiness may be understood as reduced wakefulness and a reduction of the central nervous system alertness. Variations of the central nervous system activation are a universal human experience and physiological in the circadian rhythm.

Characteristics of a reduced central nervous system activation or an increased daytime sleepiness include these:

- Attention deficits
- Monotony intolerance
- Tendency to fall asleep
- Micro-sleep
- Imperative sleep attacks

These events are directly correlated with the performance in socially demanding situations as seen, for example, at work or in traffic.

In sleep medicine, nonrestorative sleep as the origin of daytime sleepiness is in the focus of diagnostic and therapeutic efforts. From a differential diagnostic point of view, it is essential to identify sleep disorders, physical diseases, and situational factors as well as the circadian phase situation as potential origins of daytime sleepiness and to include these aspects in the diagnostic and therapeutic efforts.

A theoretical model regarding the correlation between nonrestorative sleep and attention-related processes based on performance ability is described next. This neuropsychological model is based on Posner and Rafal, regarding its attention-related

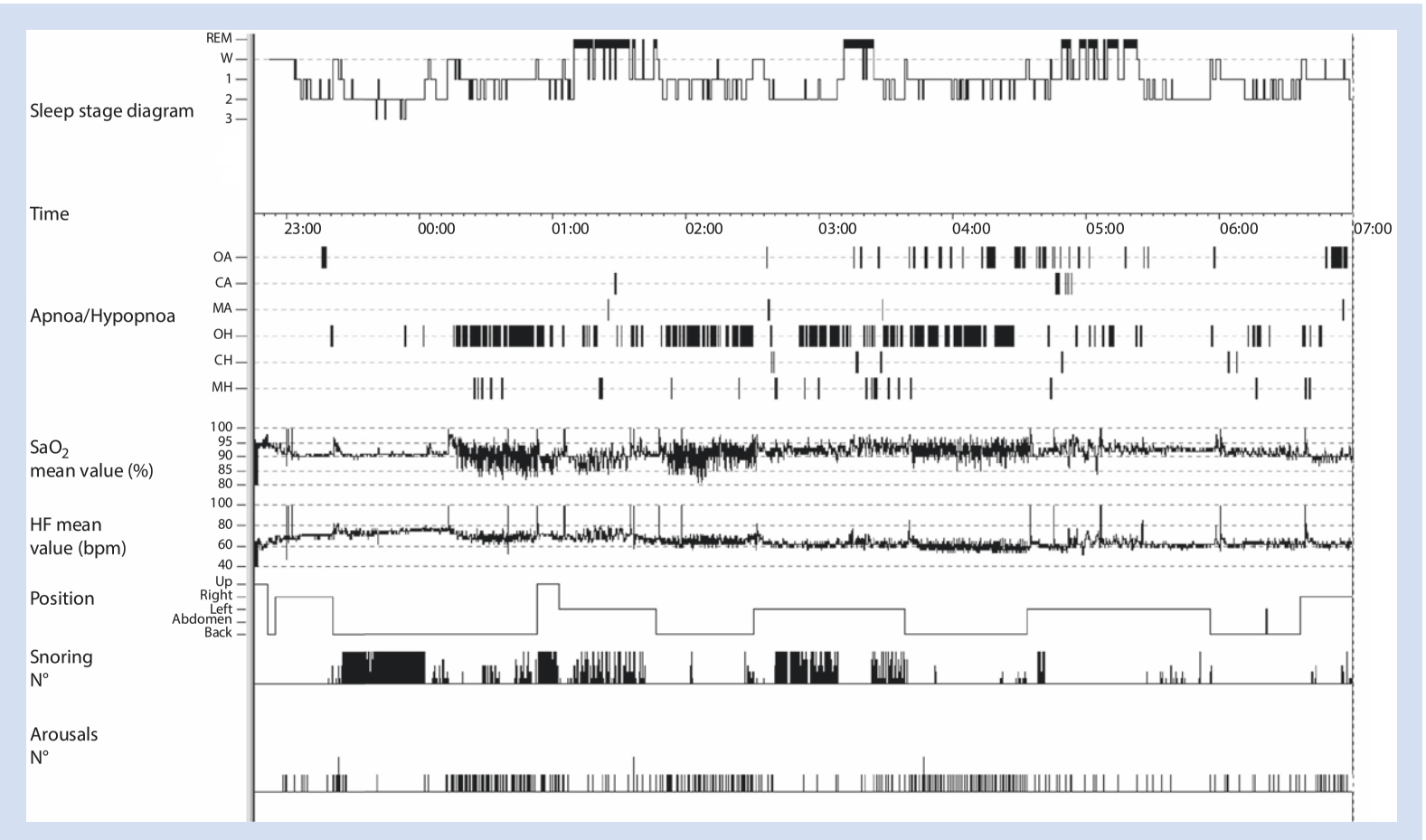


Fig. 2.24 Characteristic hypnogram of severe obstructive sleep apnea. The hypnogram shows the characteristic deep sleep suppression (Stage 3 is missing) and the increased change of sleep stages from repetitive apnea-terminating arousal reactions (*arousal N0 = number of arousals*). The increased number of arousals (*arousal N0*) is also expressed in the higher heart frequency variation (HF mean value, bpm). Predominantly obstructive hypoventilation phases (*OH*) and obstructive apneas (*OA*) emerge independently from the body position. As a consequence of respiratory disorders, intermittent HbO_2 decreases (*SaO_2 mean value, %*) as great as 80% may be measured. The channel entitled *Snoring* reflects the increased snoring activity

Table 2.6 Statistically descriptive parameters for description of sleep-related breathing disorders

Severity	Definition
Apneas	Total number of all apneas during TST
Apnea index (AI)	Average number of apneas per hour relating to the TST
Hypopneas	Total number of all hypopneas during TST
Hypopnea index (HI)	Average number of hypopneas per hour relating to the TST
Apneas + hypopneas	Total number of all apneas and hypopneas during TST
Apnea-hypopnea index (AHI)	Average number of apneas and hypopneas per hour relating to the TST
Respiratory effort-related arousal (RERA)	Total number of all events during TST
Respiratory effort-related arousal index (RERA-I)	Average number of events per hour of sleep relating to the TST
Respiratory disturbances index (RDI)	Average number of apneas and hypopneas and RERA per hour relating to the TST
For outpatient polygraphy: Respiratory events index (REI)	Number of all apneas and hypopneas relating to the measurement time
Oxygen desaturations >3%	Total number of all events
Oxygen desaturation index >3%	Total number of all events per hour relating to the TST
For outpatient polygraphies: Oxygen desaturation index	Number of all O_2 desaturations relating to the measurement time
Mean O_2 saturation	Mean value of the O_2 concentration without desaturations in percent during TST
Occurrence of hypoventilation	Yes/no
Occurrence of Cheyne-Stokes respiration	Yes/no

TST total sleep time including N1

Table 2.7 Severity of obstructive types of sleep-related breathing disorders (this classification of the severity includes the RERAs in the RDI)

Dimension	Mild	Moderate	Severe
Sleepiness or unintended sleep episodes during the day	During activities that do not require much attention, e.g., watching TV	During activities that require attention, e.g., meetings, conferences	During activities that require active attention, e.g., driving a car
Respiratory events per hour of sleep (RDI)	5–15	15–30	>30

RERA respiratory effort-related arousal

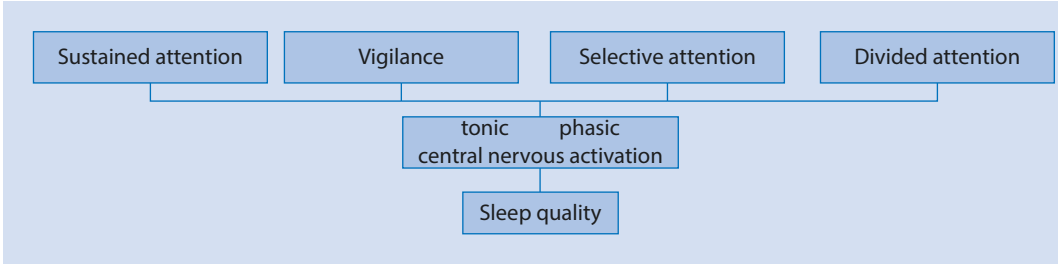


Fig. 2.25 Correlation between quality of sleep and sleepiness-related daytime impairment. The reduced quality of sleep seen in sleep disorders, for example, caused by slow-wave sleep (SWS) or REM suppression, leads to a reduction of the tonic and phasic central nervous system alertness (daytime sleepiness) that is not voluntarily controlled. In this way, also the voluntarily controlled vigilance, sustained attention, and divided and selective attention are reduced

elements, and it was confirmed in the context of numerous scientific investigations. The model differentiates five attention- and sleepiness-related aspects on which performance is based. More elaborate models are reserved for more scientific issues and are considered as too complex for the patient-oriented questions of sleep medicine.

For schematic depiction of the correlation between quality of sleep and sleepiness-related daytime impairment, see Fig. 2.25.

The model contains the tonic and phasic central nervous system alertness that is not under voluntary control.

- The tonic component is defined as the general degree of wakefulness that is influenced by circadian variations.
- The phasic component contains the ability to increase the tonic activity level triggered by requirements or a critical stimulus.

The neuronal substrate of wakefulness or also of the central nervous system arousal level is supposed to be located in the reticular formation of the brainstem. Its activity level is reflected, among others, in the frequency band of electric brain activity, heart rate, skin resistance, and pupil width (Table 2.8).

Alertness precedes the parts of attention, which are under voluntary control: vigilance, sustained attention, divided and selective attention.

In neuropsychology, *vigilance* is the ability to maintain the attention over a longer time on an increased or high level. An adequate reaction is required on rare or incidentally emerging stimuli. High requirements to vigilance are, for example, control and supervision tasks in power plants or

Table 2.8 Definition of sleepiness and associated attention processes

Attention component	Characteristics
Tonic alertness	Circadian aspect of the general arousal level, of wakefulness
	Independent of voluntary control
	Preceding vigilance, selective and divided attention
Phasic alertness	Capacity to increase the tonic activation level triggered by a critical stimulus
Selective attention	Ability to maintain the attentiveness over longer periods of time for a certain task
	Ability to suppress disturbing stimuli, interferences, and distractions
Divided attention	Speed of information processing
	Ability of divided and parallel information processing
	Ability of automated and controlled processing
Vigilance	Unspecific orgasmic readiness to react on rare and incidentally emerging stimuli over a longer time
	Under voluntary control
Sustained attention	Ability to react on incidentally emerging stimuli over a long time
	Under voluntary control

driving on a highway for a longer time. It is important to know that this definition of vigilance is not congruent with physiological definitions. In the physiological context, vigilance is used in the sense of central nervous system activation (degree of wakefulness) (Table 2.8).

As a neuropsychological term, *divided attention* describes the ability to process information in a rapid, automated, and controlled way including the ability to serial and parallel actions such as driving a car in confusing, busy situations. Hence, when approaching an intersection, the driver has to pay attention to moving and standing cars, has to observe indications, traffic lights, pedestrians, etc., and at the same time has to perform coordinated motor activities such as steering, setting signals, and pressing the clutch and brakes (Table 2.8).

Selective attention describes the ability of an individual to select relevant stimuli from the sum of all incoming stimuli. One classic example is a teacher who has to focus on his lesson despite a turbulent class and much disturbing noise. He has to focus (selectively) on his task to transmit knowledge and to suppress interferences that emerge because of discussions within the class (Table 2.8).

Sustained attention describes the ability to correctly react on incidentally emerging stimuli of high timely density over longer periods. The difference regarding vigilance is the significantly higher density of stimuli of the critical events.

Daytime sleepiness is influenced by numerous intrinsic and extrinsic conditions such as noise, temperature, activity, body position, time of the day, motivation, ability to fall asleep, psychophysiological arousal, or intake of sedating or activity-enhancing substances. All this has to be taken into account and controlled in the examination situation.

For better understanding, the preceding paragraphs depicted the basic definitions for the assessment of daytime sleepiness. In the following chapters, single diagnostic methods will be explained in detail. In Germany, some sleep centers and other healthcare institutions have specialized on exhaustive diagnostics of daytime sleepiness, ability to work, and fitness to drive in the context of sleep disorders. In cases of such questions, patients may be referred to these institutions.

However, from a legal point of view, also physicians or therapists who are not specialized in daytime sleepiness are required to estimate the risk of pathological daytime sleepiness and its negative impact on the patient's social life by taking adequate measures. They are supposed to inform the patients about the increased potential of endangerment of self and others, for example, in traffic. In cases of positive findings, it might be recommended to transfer the patient to a specialized sleep center or a physician specialized in occupational medicine for further diagnostics.

For assessment of the fitness to drive of driving license applicants or driving licensees with SRBD and daytime sleepiness, the EU published guidelines (2015) that had to be implemented in the national legislation of the member countries until December 31, 2016. The criteria developed for each member country of the EU are available from the respective national sleep societies.

2.8.1 Diagnostics of Daytime Sleepiness

If the data of a questionnaire or history taking (▶ Sects. 2.1 and 2.3) allow suspecting pathological daytime sleepiness, in particular high-risk patients have to undergo objective examination procedures (Table 2.9). In this context, sleepiness-related functions are checked:

- Central nervous system alertness
- Selective attention
- Divided attention
- Vigilance
- Sustained attention

If history taking justifies the suspicion of fatigue, no objective procedures are available (▶ Sects. 2.1 and 2.8). Moreover, the diagnosis of fatigue may be confirmed by applying respective standardized psychological questionnaires such as the Karolinska Exhaustion Disorder Scale, the Tiredness Symptoms Scale, the Fatigue Questionnaire, the Fatigue Severity Scale, and others.

For assessment of sleepiness-related impairments, numerous diagnostic methods are available (Table 2.9). The examination procedures register partial aspects of daytime sleepiness on different physiological, cognitive, and subjective levels of functioning. The extent of voluntary control is highly variable. It is characteristic that the results

Table 2.9 Diagnostic procedures for assessment of sleepiness-related impairments

Attention component	Suitable test procedures
Tonic activation	Tendency to fall asleep, e.g., multiple sleep latency test (MSLT)
	Ability to stay awake, e.g., maintenance of wakefulness test (MWT)
	Long-term EEG (with and without behavioral observations)
	Variations of the pupil diameter in darkness; pupillographic sleepiness test (PST)
	Measurement of the reaction time with omissions, e.g., psychomotor vigilance test (PVT), OSLER test (OT)
	EEG examinations, e.g., alpha attenuation test (ATT)
	Other measurements of the reaction time, e.g., test batteries for attentional performance (TAP), Vienna Test System (VTS)
Phasic activation	Measurements of the reaction time with cues, e.g., TAP
	ERP (event-related potentials), e.g., CNV, SN
Selective attention	For example, performance sequence, test of selective attention of TAP
Divided attention	Vienna determination unit
	Test of divided attention of TAP
Vigilance	For example, vigilance test of VTS or of TAP, Vigimar
Sustained attention	Tasks with high stimulus density over longer periods
	For example, permanent attention test of VTS, test set sleep of VTS
Self-assessment questionnaires	Epworth Sleepiness Scale (ESS)
	Stanford Sleepiness Scale (SSS)
	Pittsburgh Sleep Quality Index (PSQI)

ERP event-related potentials, *CNV* contingent negative variation, *SN* sharp negative variation, *FCRT* four-choice reaction time task, *TAP* test battery for attentional performance, *VTS* Vienna Test System

of the single examination methods have only few correlations when they assess different areas of functioning or performance. Because of these mentioned differences, it was not possible previously to establish one single procedure that could serve as standard for validation of other methods.

With regard to scientific standards, PC-supported neuropsychological procedures such as these applied, for example, in the Vienna Test System (test set sleep) seem to be generally superior to electrophysiological methods such as the multiple sleep latency test (MSLT) or the maintenance of wakefulness test (MWT). In single cases, even age- and intelligence-adjusted standard values are available. Furthermore, the ecological validity of these procedures is estimated higher compared to MSLT and MWT. Nonetheless, they are still laboratory testing procedures, and their transferability to specific everyday situations, such as checking the fitness to drive, seems to be limited.

The single aspects of daytime sleepiness (central nervous system alertness, selective and divided attention, vigilance, sustained attention) depend on numerous factors that have to be considered and controlled in the diagnostic procedure.

Preconditions for Examination with Regard to Diagnostics of Daytime Sleepiness

- The examination day should be preceded by an undisturbed and regular night's sleep of at least six hours (polysomnographic control). Irregular bedtimes and shift work should be avoided on the days before examination.
- The examination should not be performed on the day immediately after the adaptation night (first night effect) in the sleep lab.
- Medication and substance anamnesis should assess drugs and substances enhancing or reducing sleepiness. In particular, in the context of medical expert reports, urine screening may be indicated.
- It is not allowed to smoke in the examination situation. Smoking should be avoided at least 30 min before the respective examination.
- Generally, patients do not consume alcohol or other stimulating substances.

In contrast to other recommendations in the literature, caffeine need not be completely omitted on the examination day but rather consumed in the usual measure in cases of habitual regular consumption.

- The examination room should have a pleasant temperature, should be soundproof, and for examinations that include the sleep-onset latency as a target parameter it should be possible to darken the room.
- Excessive physical activities or emotional stress, in particular before the respective examination, should be avoided. In this context, it must also be mentioned that information about the medical findings or the daily visits may lead to emotional stress of the patient and in this way modify the examination results.
- An important condition that has to be controlled for examination is the appointed time of day, because in the course of the day, relevant circadian and homeostatic variations of sleepiness (central nervous system activation) may occur.

2.8.1.1 Diagnostic Procedures of Central Nervous System Alertness

For most procedures of central nervous system alertness, except the pupillographic sleepiness test (PST), either only insufficient standard values are available or in healthy individuals such a broad distribution of the results is found (e.g., in the context of MSLT) that diagnostic differentiation between normal and pathological values is only possible in extreme cases. For diagnostic assessment, generally a synopsis of several procedures is required that include different measurement levels. In most procedures, the motivation of the patient has to be taken into account.

The clinically diagnostic procedures of central nervous system alertness include these:

- The multiple sleep latency test (MSLT)
- The maintenance of wakefulness test (MWT)
- The pupillographic sleepiness test (PST)
- The psychomotor vigilance test (PVT)
- The OSLER test
- Other measurements of the reaction time, such as the test battery of attentional performance (TAP) and the Vienna Test System (VTS)

Further procedures such as evoked potentials, long-term EEG, and the alpha attenuation test are mostly applied for scientific questions.

Multiple Sleep Latency Test (MSLT)

The multiple sleep latency test (MSLT) is based on the assumption that the sleep-onset latency is reduced with increasing sleepiness.

In 1977, M. Carskadon and W.C. Dement were the first who presented the MSLT as a procedure to measure daytime sleepiness. For quite a long time, average sleep-onset latencies of 5 min or less were considered as a suggestion of pathological daytime sleepiness. According to Carskadon, healthy adult sleepers show sleep-onset latencies between 10 and 20 min. Sleep-onset latencies between 5 and 10 min are conspicuous but not actually pathological.

At the beginning of the 1990s, the American Sleep Disorders Association (ASDA) defined a questionable, not evidence-based, correlation between sleep-onset latencies in the MSLT and the severity of daytime sleepiness in light of the increasing relevance of daytime sleepiness and its sociomedical risks.

Based hereon, sleep-onset latencies:

- Between 10 and 15 min correspond to mild
- Between 5 and 10 min correspond to moderate
- Between 0 and 5 min correspond to severe daytime sleepiness

The mentioned limit values are not empirically gained, but they are based on experience knowledge and do not pass empirical testing.

Since its introduction until recent times, the MSLT was established as internationally acknowledged standard procedure to assess daytime sleepiness in sleep medicine (so-called experimental MSLT). A meta-analysis published by the Atlas Task Force of the AASM in 2005, however, revealed a very limited significance and validity of the MSLT with regard to the examination of daytime sleepiness. Based on this meta-analysis, the following recommendations were given for the clearly limited indication, standardized proce-

dure, and evaluation of the MSLT. The results of this meta-analysis have replaced it as the standard procedure for the assessment of daytime sleepiness. However, its high diagnostic validity for narcolepsy (clinical MSLT) remains undisputed.

Recommendations for the Performance and Evaluation of the MSLT According to the AASM

- The MSLT consists of five nap opportunities that are performed at 2-h intervals, starting 1.5 to 3 h after the end of nighttime PSG. Also, four nap opportunities are possible, but the MSLT is only reliable for the diagnosis of narcolepsy if in these four passes SOREM occurs twice together with nocturnal polysomnography.
- The MSLT is performed after polysomnography measurement that has occurred during the patient's major sleep period. The usefulness of the MSLT to confirm the diagnosis of narcolepsy is clearly limited if the total sleep time (TST) in the previous sleep period amounted to less than 6 h. An MSLT should not be performed after a split night sleep study (diagnostics and therapy in one night in the case of SRBD).
- A sleep diary should be kept for 1 week before the MSLT to assess the sleep–wake rhythm.
- The strict observation of the standardized conditions to perform an MSLT is crucial for obtaining valid results. The patient's sleep room has to be dark and quiet during testing; the temperature should be set at the patient's comfort level.
- Stimulants and stimulant-like medications as well as REM-suppressing medication should be ideally interrupted 2 weeks before examination. The intake of usual medications (e.g., antihypertensives, insulin) has to be critically planned before MSLT to control or minimize their stimulating and sedating side effects as well as their impact on the sleep-onset latency. Drug screening may be indicated to exclude the possibility that reduced sleep-onset latencies are not pharmacologically induced. Drug screening is typically performed in the morning before examination; sometimes it is also justified at other times. Smoking should be stopped 30 min before each nap opportunity. Vigorous physical activity should be avoided on the examination day, and the patient should end any stimulating activities at least 15 min before the MSLT. The patient should abstain from caffeine-containing beverages and avoid exposure to bright sunlight. A light breakfast 1 h before the first trial and a light lunch immediately after the second noon trial are recommended. It must be borne in mind that diagnostic-therapeutic discussions with the patient on the examination day may have a stimulating effect, such as when the patient is informed about the presence of sleep apnea or other diseases.
- The MSLT should only be performed by specifically trained and experienced specialists.
- The standard electrodes (C3-A2, C4-A1) are positioned according to the criteria of Rechtschaffen and Kales; in addition, occipital (O1-A2, O2-A1) derivations are performed for better identification of the sleep–wake transition. Furthermore, EOGs from the left and right orbita edge of the respective eye are measured as well as a mental/submental EMG and a single-channel ECG.
- Before each nap opportunity, the patients are asked if they need to use the bathroom or need other things for their comfort. The biosignal calibration before each trial comprises the following standardized instructions:
  1. Please lie quietly with your eyes open for 30 s.
  2. Close both eyes for 30 s.
  3. Without moving your head, look to the right, then to the left, then right, then left, right and left.

4. Blink eyes slowly for five times.
5. Clench your teeth tightly together.

- For each trial, the patient should be instructed as follows: "Please lie quietly, assume a comfortable position, keep your eyes closed and try to fall asleep." Immediately afterward, the lights are turned off, signaling the start of the test. Between the trials, the patient should leave the bed and be prevented from sleeping. This procedure requires continuous observation by the staff.
- Sleep onset for the clinical MSLT is determined by the time from lights out to the first epoch with sleep, including stage S1 (according to Rechtschaffen and Kales), defined as the first 30-s epoch with more than 15 s of cumulative sleep. In the so-called experimental MSLT, the sleeper is awakened after three consecutive sleep epochs. The absence of sleep during one nap opportunity is recorded as a sleep latency of 20 min. The latency is also included in the calculation of the mean sleep latency. For assessment of the REM sleep, the clinical MSLT is performed for a further 15 min after the first epoch of sleep, regardless of the occurrence of sleep. The REM latency is taken as the time of the first epoch of sleep to the beginning of the first epoch of REM sleep, regardless of the intervening stages of sleep or wakefulness.
- One MSLT trial is terminated after 20 min if sleep does not occur.
- The MSLT findings include the start and end times of each trial, the latency from lights out to the first epoch of sleep, the mean sleep latency (arithmetic mean of all naps or nap opportunities), and the number of SOREM periods. For the diagnosis of narcolepsy, at least two MSLTs with SOREM of a total of five MSLTs and two PSG are required.
- Events and conditions that require deviation from the standard protocol have to be documented thoroughly by the staff so that they may be included in the interpretation.

Table 2.10 Mean sleep-onset latencies of healthy individuals and narcolepsy patients for MSLT with four and five nap opportunities

Condition	Mean value	± SD (min)
MSLT with four nap opportunities	10.4	±4.3*
MSLT with five nap opportunities	11.6	±5.2*
MSLT for narcolepsy	3.1	±2.9

* = 4 vs. 5 nap MSL $p<0.01$

For interpretation of the mean sleep-onset latency, the mean sleep-onset latencies of healthy individuals were depicted for MSLT with four and five nap opportunities (Table 2.10).

Because the mean sleep-onset latency in MSLT is clearly age related, common age-dependent standards were determined for the clinical as well as experimental version (Table 2.11). The meta-analysis of the AASM did not reveal significant differences between the clinical and experimental version of the MSLT, except for the group of 30- to 39-year-old individuals, in contrast to the theoretical assumption. Thus, the values of both versions are pooled in Table 2.11.

Indications for MSLT According to AASM Criteria

- The MSLT is indicated in patients with suspected narcolepsy for confirmation of the diagnosis.
- The MSLT may be indicated as part of the diagnostic process to differentiate between idiopathic hypersomnia and narcolepsy.
- The MSLT is not indicated in the clinical routine for diagnosis or therapy evaluation of obstructive sleep apnea.
- The MSLT is not indicated in the clinical routine for the determination of sleepiness in cases of medical and neurological disorders (except narcolepsy), insomnia, and circadian rhythm disorders.

Table 2.11 Age dependency of experimental and clinical MSLT in healthy individuals

Age	Mean sleep-onset latency (min)	SD	Hours	Remarks
10–20 years	10.0	4.5	25	–
20–30 years	10.4	5.4	284	Sign diff to 50–80 years
30–40 years	10.8	3.9	192	Sign diff to 50–80 years
40–50 years	11.7	4.4	72	Sign diff to 80 years
50–60 years	12.1	1.1	11	Sign diff to 80 years
60–70 years	11.2	5.2	54	Sign diff to 80 years
70–80 years	n.i.	n.i.	n.i.	n.i.
80–90 years	15.2	6.0	22	Sign diff to all

Sign diff to significant difference to, *n.i.* no information

Practical Tip

The MSLT seems to be a procedure that assesses the ability to fall asleep. The sleep-onset ability is influenced by daytime sleepiness but also other factors such as the ability to relax and rest. The ability to fall asleep rapidly is not necessarily pathological, but it may also be an adaptive physiological behavior that allows switching quickly from activity to rest.

The MSLT should be included only as one of several procedures if daytime sleepiness has to be assessed. For statements in the context of individual cases, in particular with regard to fitness for work and driving, its significance is very limited.

For diagnostics of narcolepsy, the validity of the procedure is confirmed.

Maintenance of Wakefulness Test (MWT)

The maintenance of wakefulness test (MWT) was developed from the MSLT and represents a modification. Methodically, it is based on identical electrophysiological parameters as the MSLT: the EEG, EOG, and EMG.

The MWT is based on the assumption that it is more interesting in the field of sleep medicine to determine the ability to stay awake rather than the ability to fall asleep, especially in cases of hypersomnia. In comparison to the MSLT, the MWT has a higher face validity or ecological validity.

Thus, in modifying the MSLT, the examination is performed in a sitting position, such as in a comfortable armchair, and the patient is instructed to stay awake. Basically, the MWT has to contend with the same influencing factors as the MSLT.

The Atlas Task Force of the AASM gives the following recommendations for performing and evaluating the MWT. These recommendations are based on knowledge obtained from a trial performed by Doghramji and colleagues that was completed by expert opinions from a consensus process.

Recommendations of the Atlas Task Force of the AASM for Performance and Evaluation of the MWT

- The MWT consists of four trials of 40 min each performed at 2-h intervals, with the first trial beginning about 1.5–3 h after the patient's usual wakeup time. Thus, usually, the first trial starts at 9:00 or 10:00 in the morning.
- The examining physician decides if PSG is necessary in the night before MWT, based on the clinical conditions.

- The examination room should be maximally insulated from external light. A light source should be placed slightly behind the patient so that it is just out of the field of vision. It should deliver an illuminance of 0.10.0.13 lux at the corneal level. A 7.5 W nightlight may be used placed about 30 cm above the floor, and about 90 cm laterally removed from the patient's head. The room temperature should be set based on the patient's comfort level. During examination, the patient should be seated in a comfortable armchair or in bed with the back and head supported by a bedrest (alternatively, pillows may be used).
- Consumption of alcohol, caffeine, and other medications before and during MWT should be determined by the sleep clinician preceding the MWT. Drug screening may be indicated to clarify if the wakefulness or sleepiness is induced by other than the prescribed medication. Drug screening is usually performed on the morning of the MWT, but the timing may be modified according to the clinical conditions. A light breakfast is recommended at least 1 h before the first trial; a light lunch is recommended immediately after the termination of the second noon trial.
- The MWT should only be performed by specialized and experienced staff.
- The standard electrode montage for the MWT includes two central EEG (C3-A2, C4-A1) and occipital (O1-A1, O2-A1) derivations, left and right eye EOGs, mental/submental EMG, and a single-channel ECG.
- Preceding each trial, the patient is asked if he/she needs to use the bathroom or requires other things for comfort. Biosignal calibration before each trial encompasses the following standard instructions:
  - Please lie quietly with your eyes open for 30 s.
  - Close both eyes for 30 s.
  - Without moving your head, look to the right, then left, then right, then left, right and left.
  - Blink eyes slowly for five times.
  - Clench your teeth tightly together.
- Before each trial, the patient is instructed: "Please sit still and remain awake for as long as possible. Look directly ahead of you and do not look directly at the light." The same instructions are supposed to be given before each trial. Immediately afterward, the lights are turned off, signaling the beginning of the examination. The patient is not allowed to perform self-stimulations such as singing or slapping the face. Video surveillance during MWT may be helpful. Between the trials, the patient has to leave the bed or armchair and is prevented from sleeping. This procedure requires continuous surveillance by the staff.
- Sleep onset is defined as the first epoch of more than 15 s of cumulated sleep in the first 30-s epoch.
- Trials are terminated after 40 min if no sleep occurs or after unequivocal sleep, defined as three consecutive epochs of Stage 1 sleep or one epoch of any other stage of sleep.
- The following data are documented:
  - Start and stop times for each trial
  - Sleep-onset latency
  - Total sleep time (TST)
  - Stages of sleep achieved for each trial
  - The mean sleep latency (arithmetic mean of the four trials)
- Events and conditions that represent a deviation from the standard protocol have to be thoroughly documented by the sleep technologists so that they may be taken into account for interpretation.

Similar to the MSLT, the AASM does not present cut-offs for the presence of pathological sleep-onset latency in the MWT. Moreover, the unsatisfactory study situation regarding standard values and manifold influencing factors on the sleep-onset latency is mentioned. The mean sleep-onset latency (occurrence of the first epoch of sleep) in

the MWT (40-min protocol) was 30.4 ± 11.2 min in control persons. The upper limit of the 95% confidence interval (ceiling effect) was 40.0 min and the lower limit 12.9 min.

Sleep-onset latencies below a value of 13 min are classified as pathological. This type of limit value definition is based on statistical conventions and not on standardization studies with hypersomnia patients.

Indications for the MWT According to the Atlas Task Force of the AASM

- The MWT is an objective and valid examination procedure for assessment of the ability to stay awake for a certain period of time.
- The MWT is performed in combination with clinical history taking to assess the ability to stay awake.
- The 40-min protocol of the MWT is required for objective assessment of the individual ability to stay awake.

To ensure a valid assessment of the sleepiness/wakefulness, the MWT must be performed under suitable conditions (derivation techniques, acknowledged protocols, experienced and qualified staff).

The MWT is not suitable to assess sleepiness if it is the only method applied. Moreover, it is recommended to apply other test procedures and to consider the clinical symptoms of the patient.

Practical Tip

The MWT is an important element in the diagnostics of central nervous system activation. In contrast to the MSLT, it provides higher face validity because sleep medicine is more frequently interested in the patients' ability to stay awake than their ability to fall asleep. Similar to MSLT, MWT is a staff- and time-consuming procedure.

Cut-offs based on normative data are not available. Statements made in individual cases seem to be problematic, as also for MSLT, and require at least confirmation by other test procedures on daytime sleepiness.

Pupillographic Sleepiness Test

If a healthy awake person looks into the dark, his/her pupils widen immediately. In the wake stage, the pupil width remains stable for a long time under exclusion of light.

In cases of severe daytime sleepiness, however, relevant variations of the pupil width occur after just a few minutes. This wavelike phenomenon was defined as "fatigue waves" by Löwenstein, who was the first to describe this phenomenon. The low-frequency pupil oscillations increase with the extent of sleepiness; their amplitude increases to several millimeters.

The pupillographic sleepiness test (PST) is based on the measurement of the spontaneous pupil motor activity. A stable pupil width indicates a high alertness level; however, instability of the pupil width signals sleepiness.

During examination, the patient sits on a comfortable chair at the measurement table; the head is placed on a combined chin-forehead support. The eyes are protected against light by means of soft, light-insulated goggles (infrared). The typical sleepiness-related pattern of the pupil is assessed by means of an infrared-sensitive video camera and subsequent PC-assisted evaluation.

Target variables are the pupillary unrest index (PUI) in millimeters (mm)/minute as well as the amplitude spectrum of 0.8 Hz or less as measure for the oscillations of the pupil width; these describe pupillary variations of different amplitudes of less than 0.8 Hz as measure for the reduction of the central nervous system activation.

In a normal cohort of 349 subjects between 20 and 60 years of age, a mean value for the common logarithm (ln) of the PUI was 1.50 ± 0.39 mm/min (for standard values, see Table 2.12). Thus, values as of ln PUI >1.89 are conspicuous and as of ln PUI >2.28 they are pathological. This critical definition of the limit values corresponds to statistical conventions and results less from content-related reflections.

Compared to the classic procedures of sleep medicine such as the MSLT and the MWT, the PST is clearly more economical. Taking into account the short time of developing this procedure, an extensive verification of test-theoretical quality criteria is already available.

Table 2.12 Percentiles of the norm value range for ln PUI and PUI

Value range	MV−2SD	MV−SD	MV	MV+SD	MV+2SD
ln PUI/[mm/min]	0.73	1.11	1.50	1.89	2.28
Percentiles [%]	2.3	15.9	50	84.1	97.7
PUI [mm/min]	2.07	3.05	4.50	6.64	9.80

ln common logarithm

2.8.1.2 Diagnostic Procedures to Assess Vigilance

In neuropsychology, vigilance is defined as the ability to rapidly and adequately react to rare and incidentally emerging stimuli in long-lasting and monotonous situations.

Generally, it must be mentioned that some examination procedures that are available on the market have such a high stimulus density that they test less the vigilance but rather represent a task for sustained attention. The duration of the tasks has to be strictly observed. Methods with a duration of the tasks of less than 30 min frequently cannot differentiate between healthy individuals and sleep patients, probably because of motivational influences, or they mask vigilance impairments in patients.

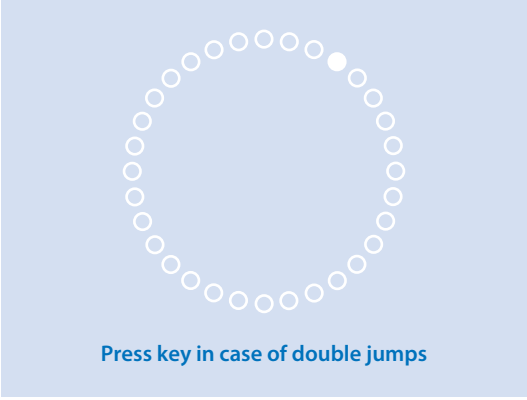


Fig. 2.26 Tasks of the vigilance test according to Quatember and Maly. Bildrechte: Stuck [Urheberrecht beim Autor]. Datei: Abb. 2.24

Vigilance Test According to Quatember and Maly

The computer-based test procedure regarding vigilance from the Vienna Test System (Fig. 2.26) is based on the clock test that had been developed in 1950 by Mackworth for measuring the vigilance of American soldiers. Based on this procedure, soldiers could be identified who showed good discovering abilities in the context of radar surveillance.

The patient is invited to follow a jumping light spot along the circumference of the circle shown on the computer screen. Each time the light spot makes jumps of double length, the patient has to rapidly press a button. Three different test versions vary with regard to the installation, the duration, the number of critical stimuli, the intervals, the number of times, and the steps and jumps.

If the vigilance is suspected to be impaired, as in cases of sleep-related breathing disorders, the test duration should be 60–90 min, at least 30 min. Test durations of less than 30 min often lead to a strong weighting of motivational effects and in this way to masking of vigilance impairments.

Standardization of the vigilance test is available; however, it is only limited in the version with a test duration of 66 minutes. One version of the vigilance test, according to Quatember and Maly, was standardized by the Siesta Group of Vienna in cooperation with the working group on vigilance of the DGSM based on the data of 200 healthy sleepers. The selected stimulus density, however, rather corresponds to a task of sustained attention.

Sub-test of Vigilance of the Test Battery for Attentional Performance

To work on a vigilance test, the patient sits in front of a computer screen. Four tasks with different stimuli (optic, acoustic, optic/acoustic) are available. All procedures can be performed with high or low stimulus density. The duration of the examination that has to be particularly taken into

account when assessing the vigilance can be varied up to 60 min. A sufficient standardization with good description of the norm sample is available.

Other procedures are available to assess the vigilance.

2.8.1.3 Diagnostic Procedures to Assess Selective Attention

Selective attention includes the ability of a subject to selectively differentiate relevant stimuli from the sum of all inflowing stimuli. The stimuli may come from different modalities. In the following, two of the most frequently applied computer-based procedures are described that are used in sleep medicine. They are also used in occupational medicine and for determination of the fitness to drive.

Achievement Motivation Test Series, Version 3.00 of the Vienna Test System

During the achievement motivation test series of the Vienna Test System, the subjects have to solve different arithmetical problems depending on the level of difficulty. According to the test version, they have 10–20 min at their disposal. The test is considered as being independent from the intelligence. Sufficient standardization is ensured.

Go/NoGo of the Test Battery for Attentional Performance

The selective attention can be verified by means of the sub-test Go/NoGo of the test battery for attentional performance (TAP). Two performance variants are available, and the second variant measures especially the selective attention. On a screen, five squares with different filling patterns are shown. The patient has to react when one of the five squares corresponds to the two given squares with the critical stimuli. Sufficient standardization is ensured.

2.8.1.4 Diagnostic Procedures to Assess Divided Attention

Situations requiring divided attention are usually the rule than the exception. The divided attention may be tested by means of so-called dual tasks where the subjects have to consider two simultaneous stimuli, sometimes of different modality. In the following, the examples of two computer-based procedures are described that are frequently applied in sleep medicine as well as in occupational medicine and for assessment of the fitness to drive a car.

Test of Divided Attention of the Test Battery for Attentional Performance

The subject sits in front of a computer screen and has to react whenever a series of crosses that are rapidly changing their positions form a square. At the same time, the verification of a monotonous sound sequence is performed as acoustic task. Four different stimulus sequences may be chosen to avoid learning effects during test repetitions. Sufficient standardization is ensured.

Vienna Determination Unit

The computer-based Vienna determination unit (Vienna Test System) provides a procedure to measure sensor-motor functions in the selective reaction behavior. Optic stimuli with lamps of five different colors have to be reacted on by pressing allocated keys. Two additional white lamps require a reaction with the left and right foot pedal. Two acoustic stimuli, high and low sound, require pressing of respectively assigned keys. Up to four stimuli may be offered at the same time. Sufficient standardization is ensured.

2.8.1.5 Subjective Diagnostic Questionnaires for Assessment of Sleepiness-Related Impairments

Self-assessment questionnaires are applied for qualitative and quantitative assessment of the patient's subjective level of suffering regarding sleepiness-related disorders.

Scientific investigations often reveal only few correlations between subjective and objective measurements, which is especially true for the MSLT and the MWT but also for neuropsychological examination procedures. The background might be that subjective procedures are applied unsystematically in cases of sleepiness as well as fatigue. Furthermore, objective procedures generally assess aspects of sleepiness, whereas subjective procedures rather aim at the subjectively stressing phenomenon of sleepiness in its entirety. In general, the results of subjective questionnaire data depend on the patient's ability of introspection.

Basically, subjective statements and complaints should not be neglected even if objective findings are inconspicuous, also because some

objective procedures applied in sleep medicine do not meet test-theoretical quality criteria. In the context of expert opinions, the possible falsification of the results of questionnaire data (simulation or dissimulation) must be taken into account.

In the following, questionnaire procedures for assessing the subjective sleepiness and one questionnaire for differential diagnostic assessment of sleepiness and fatigue are described. Both procedures are internationally applied in sleep medicine.

Stanford Sleepiness Scale (SSS)

The Stanford Sleepiness Scale (SSS) is applied in clinical routine and in particular in the context of scientific investigations in intra- and intergroup comparison.

In regular intervals, and also before each trial of the MSLT, patients estimate their degree of wakefulness based on a seven-step scale. To assess the circadian course of the subjective sleepiness, the evaluation of 1 h in 15-min intervals within a 3-h bloc over the day is recommended.

Investigations on the sensitivity reveal that already evaluations in 15-min intervals reflect discrete changes of the degree of wakefulness. From the scores of each time interval, a sum score is calculated.

Validity checks in the proper sense of the word are not known. The test correlates only weakly with the sleep-onset latency of the MSLT. Because of the doubtful validity of the MSLT, such low correlations must not be overstated.

Practical Tip

The SSS is a good, widely distributed questionnaire to assess the individual circadian rhythm of subjective daytime sleepiness. Because standardization is currently not performed, interindividual evaluation of the results is limited.

Regarding intraindividual comparison, such as in the context of therapy evaluations, it might be a suitable procedure.

Epworth Sleepiness Scale (ESS)

The Epworth Sleepiness Scale (ESS) is a simple procedure to quantify the tendency to fall asleep in everyday situations.

Because of behavior-related questions (items), a sufficient interindividual comparability may be assumed. The patients are interviewed with regard to the probability to fall asleep in eight typical everyday situations. The single results are summed up to a total score between 0 and 24. Based on some clinical trials, a score of more than 10 is considered as pathological.

However, the results have to be interpreted reluctantly when the patients never experience certain everyday situations that are mentioned, for example, theater visits, or passenger or driver in a car, because then the low values of the ESS mask the actual severity of the disorder. Validity checks and standardization studies are currently not available.

Practical Tip

ESS is the most frequently applied and best acknowledged procedure to assess the subjective sleepiness and tendency to fall asleep in monotonous everyday situation. It is operationalized by data on the probability to fall asleep in certain everyday situations. Sum scores greater than 10 are considered as pathological.

Practical Tip

The risk assessment of pathological daytime sleepiness includes these aspects:

- Intensive history taking regarding sleepiness with particular attention to risk factors in the past, supported by a procedure on self-assessment of daytime sleepiness, for example, ESS (► Sect. 11.2)
- If the patient's history and/or the questionnaire reveal an increased risk at work or in road traffic, the application of an objective procedure for examination of the central nervous system activation, such as MWT or PST, and a procedure to verify the vigilance with a test duration of at least 30 min are required.

If needed, information of the patient about potential endangerment of self and others in traffic or at work should follow. For the legal security of the treating physician, this information has to be documented in the files.

It must be taken into account that both procedures on central nervous system alertness and vigilance should be applied at two different times of a day, if possible (in the morning, peak performance; in the afternoon, performance slump).

2.9 Questions

1. Please list the rules for classification of respiratory events in sleep.
2. Which indications for performing an outpatient apnea screening do you know?
3. Which indications for polysomnography are given for RLS?
4. Which aspects of daytime sleepiness are differentiated?
5. Which types of history taking for sleep disorders are differentiated?

Further Reading

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