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Routine and sleep EEG: Minimum recording standards of the International Federation of Clinical Neurophysiology and the International League Against Epilepsy ☆

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HIGHLIGHTS

- Minimum standards are needed to improve the accuracy, efficacy, and reliability of recording routine and sleep electroencephalography (EEG).
- The overall quality of research evidence was low, leading to conditional recommendations based on consensus.
- We formulated 16 recommendations for minimum standards for recording routine and sleep EEG.
- Implementation strategies need to be tailored by local organizations or chapters.

ABSTRACT

This article provides recommendations on the minimum standards for recording routine ("standard") and sleep electroencephalography (EEG). The joint working group of the International Federation of Clinical Neurophysiology (IFCN) and the International League Against Epilepsy (ILAE) developed the standards according to the methodology suggested for epilepsy-related clinical practice guidelines by the Epilepsy Guidelines Working Group. We reviewed the published evidence using the Preferred Reporting Items for Systematic Review and Meta-Analysis (PRISMA) statement. The quality of evidence for sleep induction methods was assessed by the Grading of Recommendations, Assessment, Development and Evaluations (GRADE) method. A tool for Quality Assessment of Diagnostic Accuracy Studies (QUADAS-2) was used to assess the risk of bias in technical and methodological studies. Where high-quality published evidence was lacking, we used modified Delphi technique to reach expert consensus. The GRADE system was used to formulate the recommendations. The quality of evidence was low or moderate. We formulated 16 consensus-based recommendations for minimum standards for recording routine and sleep EEG. The recommendations comprise the following aspects: indications, technical standards, recording duration, sleep induction, and provocative methods.

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Contents

1. Introduction

Non-invasive electroencephalography (EEG) remains an essential non-invasive method for analyzing electrophysiological brain activity in epilepsy and in selected disorders of brain dysfunction (Beniczky et al., 2017; Tatum et al., 2018). Although the practical definition of epilepsy is clinical (Fisher et al., 2014), scalp EEG has an important role not only in the diagnosis of epilepsy, but also in the follow-up if the disease evolves, and in the classification of the epilepsy syndromes (Tatum et al., 2018; Koutroumanidis et al., 2017a, 2017b).

The International League Against Epilepsy (ILAE) Neurophysiology Task Force has recently addressed the use of EEG as a clinical tool in the classification of the epilepsy syndromes (Koutroumanidis et al., 2017a, 2017b). Regarding the variable resources of EEG service worldwide, they distinguished two levels of EEG recording: basic and advanced. Routine EEG with activation procedures corresponds to the basic level and sleep induction is used at the advanced recording level. Epileptiform discharges are modulated by sleep and show higher frequency in non–rapid eye movement (NREM) sleep than in the awake state (Ng and Pavlova, 2013; Frauscher and Gotman, 2019; Nobili et al., 2021). Most clinical studies suggest an added diagnostic value of sleep EEG compared to standard EEG,(Carpay et al., 1997; Leach et al., 2006; Giorgi et al., 2013; Meritam et al., 2018) yet a few studies question the utility of sleep EEG (Gilbert et al., 2004; DeRoos et al., 2009). The sensitivity of EEG for epileptiform discharges increases with repeated recordings (Salinsky et al., 1987) and if one repeats the EEG, it is recommended to do a sleep EEG in the second round. In some patients (especially children) the routine wake recording can be so obscured by artifact that little undisturbed background is visible, in which case a sleep EEG is recommended.

In establishing and maintaining technical standards the aim is to ensure the high quality of laboratory investigations. The minimum standards represent a set of recommendations that can be readily adapted by countries and applied to laboratories at any level of the health care system (WHO, 2011).

In 2002 the Commission on European Affairs of the ILAE published recommendations for recording EEG across Europe (Flink et al., 2002), but this has not been updated since. A survey organized in 2017 within 28 members of the European Reference Network for rare and complex epilepsies (ERN EpiCARE) showed that almost all centers used local guidelines to record EEG (Beniczky, 2017). In addition, a lack of common standards for recording routine EEG impedes high-quality multicenter research projects, as was observed in the recently completed Human Epilepsy Project 1 (unpublished data).

Several societies—including the American Society of Clinical Neurophysiology, Canadian Society of Clinical Neurophysiology, French Society of Clinical Neurophysiology, and the French League Against Epilepsy—have recently published updated national recommendations for EEG recording standards (André-Obadia et al., 2014; Tsuchida et al., 2016; Dash et al., 2017). The lack of mini-

mum standards for recording EEG that are based on systematic review and unite the work of international experts impedes the development of global standards for good clinical practices (Gschwind et al., 2018).

The International Federation of Clinical Neurophysiology (IFCN) and the ILAE identified the need for a joint working group to define the minimum recording standards of EEG according to these standards. The ILAE Guidelines Task Force approved the Working Protocol that was based on the methodology recommended by the ILAE for developing a Clinical Practice Guideline (Sauro et al., 2015). The protocol followed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement as applicable (Appendix S1).

The objective of this joint IFCN-ILAE paper is to provide recommendations on the minimum standards for recording routine and sleep EEG. The target audience of the guideline is health care personnel who are referring patients to EEG, being responsible for EEG recordings, performing, analyzing, and reporting EEG.

2. Methods

2.1. Establishing a working group

The IFCN and the ILAE each appointed members to the joint working group. The IFCN-ILAE Working Group was composed of 10 experts who were adult and pediatric neurologists with subspecialty in epileptology and clinical neurophysiologists. Members represented four of six regions of the World Health Organization (WHO). The IFCN-ILAE Working Group has been approved by the ILAE Guidelines Task Force.

2.2. Developing clinical questions

To achieve the overall objective, the IFCN-ILAE Working Group defined five questions that were examined by five subgroups each containing two to three working group members (Table 1). Patient/population, Intervention, Comparison and Outcome (PICO) statements were used to organize the clinical questions when applicable.

2.3. Search strategy

The literature search was designed according to the PRISMA guidelines. We performed electronic search of PubMed and Embase databases for English literature between 1990 and September to December 2019. The full search strategies for PubMed and dates when the database was last accessed are presented in Appendix S2.

2.4. Study selection, data extraction, and synthesis of results

Specific inclusion criteria were defined for each of five clinical questions. Studies on neonatal EEG, emergency EEG, intensive care monitoring, and long-term epilepsy monitoring were excluded, as they were beyond the scope of this guideline. We included the following:

Studies that addressed the utility of non-emergent EEG in diagnostics or follow-up of patients; randomized control trials were searched for, but also studies evaluating the usefulness of EEG if a proper control group (no EEG) and follow-up measures (impact on the patient care) were used.
Studies that addressed recording electrode array and montages, electrode impedance, synchronized video, sampling rate and frequency band, ancillary equipment, display settings, data storage and EEG data format.
Studies that compared the yield of different length of EEG recordings and used the presence of EEG abnormalities as a primary outcome measure and cost–benefit as a secondary outcome.
Studies that compared EEG recordings with sleep deprivation (either 24 h or partial), studies with no sleep deprivation, studies that compared sleep deprivation to pharmacological sleep induction and studies that compared EEGs with different pharmacological sleep inductions, and studies with yield of sleep as outcome. Secondary outcomes included adverse effects and cost–benefit ratio of sleep induction.
Studies that addressed the utility of activations other than sleep and had the yield of epileptiform abnormalities, epileptic seizures, and psychogenic nonepileptic seizures as outcomes. Secondary outcomes included adverse effects.

At least two members of the subgroups independently reviewed the titles and abstracts to identify potentially eligible research articles. References of selected articles were screened for potentially eligible studies. Full-text articles were reviewed by two independent reviewers for inclusion. Data extraction was designed independently for each clinical question.

Table 1
Clinical questions and Patient/population, Intervention, Comparison and Outcome (PICO) statements.

Question	Population	Intervention	Comparison	Outcomes
1. What are the indications for routine and sleep EEG?	Patient in EEG	EEG recording	No EEG recording	Impact on diagnostics, management decisions or prognostication
2. What are the minimum technical standards for routine and sleep EEG?	Not practically applicable			
3. What provocation methods should be used in routine and sleep EEG and how?	Patient in EEG	Photic stimulation Hyperventilation Other provocation	No provocation	Epileptiform abnormality Seizure – Epileptic – Non-epilepticAdverse effects
4. What should be a minimum duration of routine and sleep EEG to be optimally diagnostic?	Patient in EEG	EEG duration 1	EEG duration 2	Abnormal EEG finding
5. Should sleep deprivation (partial or all night/24 h) used to obtain sleep?	Patient in EEG	Sleep deprivation	Natural sleep	Sleep Adverse effects Cost–benefit
6. Can melatonin or other drugs be used for sleep induction?	Patient in EEG	Melatonin Other sleep-inducing drug	Sleep deprivation Sleep inducing drug	Sleep Adverse effects Cost–benefit

Abbreviation: EEG, electroencephalography.

2.5. Quality rating of individual studies and synthesis of results

We used the Grading of Recommendations Assessment, Development and Evaluation (GRADE) method to assess the risk of bias of individual sleep induction studies that were pharmacological and non-pharmacological intervention studies (Sauro et al., 2015; Guyatt et al., 2011). In other (non-interventional) studies, the risk of bias was assessed by using a quality assessment tool for diagnostic accuracy studies (Quality Assessment of Diagnostic Studies [QUADAS-2]) developed for primary diagnostic accuracy studies that better targeted potential study limitations involved in technical and methodological EEG studies, although not being diagnostic accuracy studies (Whiting et al., 2011). The risk of bias assessment was carried out by two reviewers who solved possible disagreements by discussion.

In addition, we classified studies as meta-analysis, systematic reviews, randomized controlled trials (RCTs), and observational studies including diagnostic accuracy studies, case series, and guidelines. Observational studies were further categorized, using predefined criteria to evaluate the evidence reflecting risk of bias given the paucity of high-level evidence (Tatum et al., 2018; Gronseth et al., 2017). Category I observational studies included large (N > 50) prospective broad-spectrum studies and large blinded technical studies with an acceptable gold standard. Category II studies were large prospective narrow-spectrum studies, large retrospective broad-spectrum studies, and small (N = 10–50) blinded technical studies with an acceptable gold standard. Category III studies were large retrospective narrow-spectrum studies, small prospective and retrospective studies, or technical studies that were not blinded or without an acceptable reference standard. Category IV were mathematical simulation studies.

Due to the large heterogeneity of the studies, meta-analysis was not possible to conduct and our synthesis was qualitative.

2.6. Methods of recommendation

We assessed the overall quality of evidence for methods of sleep induction and yield of sleep during EEG recording using the GRADE approach and for outcomes of other clinical questions by the risk of bias and classification and category of individual studies. Due to the low overall quality of evidence, a modified Delphi process was used to formulate recommendations by each subgroup (Dalkey and Helmer, 1963). The modified Delphi process consisted of a series of written questionnaires that were answered anonymously (Appendix S3), followed by open consensus discussions concerning each clinical question. The iteration was continued until agreement of at least two thirds of the IFCN-ILAE Working Group members was achieved. One member of each subgroup designed the Delphi questions, provided supportive analysis of literature, did not answer to written questions but analyzed results and chaired the consensus discussion that was organized as a video conference. The strength of the recommendation was rated following the ILAE Guideline of developing clinical practice guidelines (Sauro et al., 2015).

3. Results

3.1. Indications of routine and sleep EEG

We found 121 articles through database search and six additional articles from other sources. After removing the duplicates, 99 articles remained for screening of abstracts. Fourteen full-text articles were assessed for eligibility. Three guidelines were included. None of the 11 research studies met the eligibility criteria. The reason for exclusion was lack of proper study design and methodology to study the indications for routine and sleep EEG. Screened studies described EEG findings on specific illnesses showing indirect evidence of the utility of EEG. However, expanding the systematic review to include specific diseases in search terms would have rendered the work exhaustive and less objective. A PRISMA chart is included in Appendix S4A.

Previous consensus-based guidelines on the best practice of the recording and reporting of EEG in adults and children include the general indications for EEG (Beniczky et al., 2017; Flink et al., 2002; Dash et al., 2017). They all emphasized that "clinical suspicion of epilepsy" was the main indication for EEG studies. Recently published clinical summaries determine the value of EEG for the diagnosis of seizures and epilepsy and monitoring of epilepsy (Tatum et al., 2018; Koutroumanidis et al., 2017a, 2017b; Benbadis et al., 2020). They discuss the sensitivity and specificity of interictal epileptiform discharges, the value of routine and sleep EEG in the diagnosis and classification of the epilepsy type, and the role of EEG in making decisions regarding antiseizure medication withdrawal.

3.1.1. Recommendation

We conclude that the quality of evidence on the indications of routine and sleep EEG is very low. Through a modified Delphi technique, we reached a consensus on the indications of routine and sleep EEG that justifies a weak (conditional) recommendation on the indications of EEG recorded by appointment in a nonemergent situation (Table 2).

3.2. Technical standards

Eighteen articles were found in the search and 14 additional articles were identified through other sources. After removal of duplicates, 30 abstracts were screened for eligibility and 10 full-text articles were included in the qualitative synthesis. A PRISMA chart is included in Appendix S4B. Four of the articles were guidelines(Flink et al., 2002; Dash et al., 2017; Sinha et al., 2016; Seeck et al., 2017) and six were Category III observational studies(Ferree et al., 2001; Rosenzweig et al., 2014; Koessler et al., 2015; Halford et al., 2016; Keller et al., 2018; Kappenman and Luck, 2010) (Table S1). Individual studies had a low risk of bias (Table S2). However, low observational study category and heterogeneity (variable outcomes) downgraded the quality of evidence. In the previous guidelines of recording EEG (Flink et al., 2002; Dash et al., 2017; Sinha et al., 2016), technical standards were based on expert opinion without systematic review or quality rating of scientific studies.

Table 2
Indications of non-emergent electroencephalography (EEG) recorded by appointment.

Epilepsy-related indications	Other indications for differential diagnosis
Clinical suspicion of seizure or epilepsy	Psychogenic nonepileptic seizures
Reconsideration of the initial diagnosis of epilepsy	Paroxysmal behavioral changes
Syndromic classification of epilepsy	Suspected encephalopathy
Changes in seizure pattern (seizure type or semiology)	Acute or subacute dementia
Etiological evaluation of epilepsy	
Prior to tapering of AED in seizure-free patients	
Systematic follow-up of specific epileptic syndromes (e.g., infantile epileptic spasms syndrome and epileptic encephalopathy with spike-and-wave activation in sleep)	

AED, anti-epileptic drug.

Table 3
Summary of minimum standards for recording routine and sleep electroencephalography (EEG).

Electrode types	Gold or silver/silver-chloride cup electrodes applied with electrode paste or gel, electrode caps, MRI-compatible electrodes, and needle electrodes in certain circumstances
Electrode array	The 25-electrode IFCN montage, when possible. Otherwise: 10–20 array
Polygraphic channels	One ECG At least two EMG channels if motor events of clinical interest are suspected At least one EOG channel if assistance is needed in differentiation between eye movement and slow EEG activity
Electrode impedances	<5 kΩ is recommended <10 kΩ is considered acceptable
Minimum sampling rate	256 Hz
Filtering for visualization:	
EEG	High pass 0.5 Hz; Low pass 70 Hz
EOG	High pass 0.3 Hz; Low pass 35 Hz
EMG	High pass 10 Hz; Low pass 100 Hz
Video	At least one camera when events of clinical interest are suspected
Display	Resolution 7 μV/mm for adults' EEG, 10 μV/mm for children's EEG Possibility to adjust viewing settings, gain of each channel, time resolution, filters, and annotations Possibility to display voltage maps
Data storage	The entire EEG and video from clinical events
Data export	Comma Separated Value (CSV) data format or European data format (EDF) or Digital Communication in Medicine (DICOM) format
Duration of recording	Routine EEG 20 min Sleep EEG 30 min Individualize the sleep EEG recording time and duration when increased benefit is expected. Postprandial period increases the chances of sleep in infants and children.
Sleep induction	Partial sleep deprivation for adults and children ≥ 12 years of age Melatonin or sleep deprivation in children < 12 years of age Dose of melatonin: 1–3 mg administered 30–60 min before EEG recording. If melatonin is not available, chloral hydrate may be used when partial sleep deprivation fails to attain sleep.
Hyperventilation (HV)	At the beginning of routine or sleep EEG ≥ 3 min after IPS. Exceptions: if EEG indication is genetic generalized epilepsy, perform HV at the end of recording. Record 2 min awake EEG after HV. Method: 15–30 deep breaths/min for ≥3 min In children, a pinwheel windmill is useful to enhance breathing. The EEG technologist should encourage the patient and rate breathing effort adequate or inadequate. Use a checklist for contraindications. Test the patient if a seizure occurs.
Intermittent photic stimulation (IPS)	Perform IPS at the beginning of routine or sleep EEG ≥ 3 min before HV.In children, perform IPS at the end of sleep EEG. Method: ILAE guideline on revisited methodology of photic stimulation[a] Stop the visual stimulus immediately as soon as generalized epileptiform discharges occur. Photomyogenic reaction must not be mistaken for a seizure. – Use flash frequencies: 1–2–8–10–15–18–20–25–40–50–60 Hz. If there is a generalized response at a certain Frequency (lower threshold): skip the remainder of the series and start again with 60 Hz and decrease frequencies (60–50–40–25 Hz–...) until again a generalized photoparoxysmal response occurs (upper threshold). – Determine IPS sensitivity with separate trains of flashes of 5 s duration each during eye closure, eyes closed, and eyes open. If limited in time, choose the closure of the eyes on command at the start of a flash train and stimulate for 7 s per flash frequency – observe clinical signs and test seizures.Contraindication: pregnancy
Asking the patient to blink, close, and open eyes for several seconds	At the beginning of routine EEG In wake period at the end of sleep EEG (assessment of posterior dominant rhythm) Assisted eye closure may be needed in children.

Abbreviations: ECG, electrocardiography; EMG, electromyography; EOG, electro-oculography; HV, hyperventilation; IFCN, International Federation of Clinical Neurophysiology; IPS, intermittent photic stimulation; MRI, magnetic resonance imaging.
[a] Kasteleijn-Nolst Trenité et al. (2012).

We conclude that the quality of evidence on technical EEG standards is low. Our recommendation is conditional and formulated by a consensus of modified Delphi discussions. Table 3 summarizes the conditional recommendation for technical standards. Skin safety was beyond the scope of our study, but we refer the reader to the previously published recommendations (ASET, 2016a, 2016b).

3.2.1. Electrodes and montages

For routine EEG, the use of either gold or silver/silver-chloride cup electrodes individually applied with electrode paste or gel are suggested. Head caps are becoming more commonly used and are also acceptable if electrode impedances are checked and meet standards. Dry electrode EEG systems are not recommended yet, because they are associated with increased movement and sweat artifacts, and the effectiveness of methods for mitigating this, such as automated artifact removal, have yet to be thoroughly studied (Halford et al., 2016). Magnetic resonance imaging (MRI)–compatible electrodes and needle electrodes are acceptable in certain circumstances. The use of the 25-electrode IFCN montage, which adds 6 additional subtemporal electrodes to the 10–20 array and uses 10–10 electrode nomenclature (Seeck et al., 2017), is suggested whenever feasible, because there is evidence that it improves the ability to detect both ictal (Rosenzweig et al., 2014) and interictal (Krauss and Lesser, 2018; Bach Justesen et al., 2018; Bach Justesen et al., 2019) epileptiform discharges. Otherwise, the 10–20 array is acceptable (Seeck et al., 2017; Rosenzweig et al., 2014; Koessler et al., 2015, 2018).

One electrocardiography (ECG) channel should be used. It is also suggested that at least two electromyography (EMG) channels be

recorded if motor events of clinical interest are suspected. Two EMG channels (if electrodes are placed on extremities bilaterally) provide an objective measurement of body movement that can be correlated with the EEG and can help in the identification of elementary motor seizure semiology (myoclonus, spasms, clonic, tonic, tonic-clonic seizures) and in the differentiation between tonic and atonic seizures (Mothersill et al., 2000; Beniczky et al., 2014, 2016, 2017).

Routine recording of the time-synchronized video to document seizure manifestations and possible sources of artifacts with at least one camera is strongly suggested. Video is essential in all patients with suspected epilepsy or clinical events.

Two electrooculography (EOG) leads may be placed in cases in which it is difficult to distinguish eye movement artifacts from slow EEG waves, and these leads should be placed according to the recommendations of the IFCN (Seeck et al., 2017) and the American Academy of Sleep Medicine (Berry et al., 2020)—1 cm lateral and above the outer canthus on the right and 1 cm lateral and below the outer canthus on the left.

3.2.2. Electrode impedances

In addition to visual signal quality control, it is advisable to check scalp-electrode impedance at the beginning of each EEG recording. Impedances below 100 Ω are unacceptable, as it often indicates shunting through a salt bridge on the scalp. To reduce the impact of disturbances and obtain a scalp-electrode impedance lower than 5 kΩ, skin abrasion is still required, but in a small subset of cases it is not proposed (Ferree et al., 2001). There is some evidence that a scalp-electrode impedance of 10 kΩ or higher is acceptable because modern EEG amplifiers have a relatively high input impedance (Ferree et al., 2001; Kappenman and Luck, 2010). These studies have measured only EEG signal amplitude, amplitude of 60 Hz artifact, and ability to resolve evoked potentials between electrodes with varying impedances. Studies of EEG signal quality as perceived by experts in electrodes of varying impedances are lacking. Electrodes with higher impedance can be more affected by sweat, movement, and electrode pop artifact. In addition, allowing impedance values up to 10 kΩ increases the chance that there will be a significant imbalance among the impedances of the array of electrodes. Unbalanced impedances can compromise the ability of an EEG amplifier to reject potentials that are the same at a pair of electrodes while amplifying those that are different (common mode rejection). Therefore, impedance values below 5 kΩ are suggested and an impedance value of <10 kΩ is considered acceptable.

3.2.3. Recording and review settings

For routine EEG in current clinical practice, frequencies of over 100 Hz are not currently considered of clinical interest. This may change in the future, with the increased use of commercial artifact reduction systems using blind signal source separation, which may work better if given EEG signals with higher signal frequency content. The Nyquist theorem specifies that the highest measurable frequency is half the sampling rate. For example, with a 256 Hz sampling rate, the highest frequency that can be resolved is 128 Hz. In actuality, because of phase alignment, it is necessary to discretely sample (digitize) the signal at a rate of at least 2.5 times the highest frequency component of the signal (Srinivasan and Tucker, 1993). Therefore, based on the experience of experts and the frequency content of clinically relevant EEG signals, the proposed minimum sampling rate is 256 Hz.

For visualization (display), the suggested low-pass (high-frequency) filter setting is 70 Hz, and the suggested high-pass (low-frequency) filter setting is 0.5 Hz. A value of 7 μV/mm is the proposed display resolution, except for children's recordings in which 10 μV/mm is suggested. It is recommended that EEG reviewers be allowed to change the gain of channels independently, adjust time resolution, display voltage maps at a time point, add and change annotations during review, apply notch filters, and adjust low-pass and high-pass filters if needed.

3.2.4. Data storage and export

We suggest archiving the entire EEG recording as well as the time-synchronized video either for the entire recording or video only from clinically relevant events, preferably with a backup copy. Good data security policy needs to be ensured. It is recommended that users be able to export EEG data for research in Comma Separated Values (CSV) or European Data Format (EDF). The IFCN is working with Digital Communication in Medicine (DICOM) to create a modern format for the storage and exchange of EEG data, which will become available within the next few years (Halford et al., 2021).

3.3. Duration of recording

The database searches generated 156 articles, and 19 additional articles were identified from other sources. After removing duplicates, 152 abstracts were screened. Forty-one of the full-text articles were assessed for eligibility. Twelve articles, three of them EEG-recording guidelines, were included in the qualitative analysis. A PRISMA chart is included in Appendix S4C.

We identified nine eligible original research papers, two of them Category I (Reardon et al., 1999; Burkholder et al., 2016) and seven Category II–III (Losey and Uber-Zak, 2008; Agbenu et al., 2012; Lee et al., 2013; Craciun et al., 2014; Miskin et al., 2015; Doudoux et al., 2018; Mahuwala et al., 2019) observational studies. Study characteristics are summarized in Table S3. Only two Category II studies evaluated the optimal duration of sleep EEG (Losey and Uber-Zak, 2008; Craciun et al., 2014). All studies included Quality Assessment for Diagnostic Accuracy Studies (QUADAS-2) domains with high risk of bias (Table S4). Most studies were at high risk of biased reference standard.

The previous consensus-based guidelines of the ILAE (Commission Report Commission on European Affairs: Subcommission on European Guidelines), American Clinical Neurophysiology Society, and Canadian Society of Clinical Neurophysiologists recommend at least 20 minutes of technically satisfactory recording for routine EEG (Flink et al., 2002; Dash et al., 2017; Sinha et al., 2016) and 30 min for sleep EEG (Dash et al., 2017).

A Category I study in children and adults found that the sensitivity of the 15-min routine EEG compared with the 25-min EEG for epileptiform or non-epileptiform abnormality was 94.1% (confidence interval [CI]: 88.7–97.4%), and the specificity 99.3% (CI: 97.5–99.9%) (Reardon et al., 1999). The sensitivity of the 15-minute EEG increased when only epileptiform abnormalities were considered (97.1%, CI: 92.6–99.2%). Authors estimated the 15-minute routine EEG to be cost effective, but the recording procedure had to be rigorous to include activations too. In agreement, a Category II study in children found that reducing the recording time of routine EEG from 20 to 15 min may miss epileptiform abnormalities in 2.36% (CI: 0.63–4.09%) of EEG studies (Agbenu et al., 2012). The largest Category II retrospective study conducted in a tertiary epilepsy center found a significant decrease in the diagnostic yield for recordings shorter than 20 min (Craciun et al., 2014). They did not find a significant difference between the yield of 20- and 30-min routine EEG studies or between the yield of 30- and 60-min sleep EEG studies in adult patients.

In a Category I study in children and adults, interictal epileptiform abnormalities became only apparent after the initial 30 min in 4.5% of patients (81/1803) (Burkholder et al., 2016). The relative increase in yield of interictal epileptiform abnormalities was 19.1% (CI: 15.6–23%). In addition, in a Category II study, the yield of

epileptiform abnormalities was increased by 11% (p =.001) by lengthening the recording from the standard 20 min to 40 min (Miskin et al., 2015). A category II study observed 51% of epileptiform abnormalities within 20 min of sleep-deprived EEG, 71% within 30 min, and 93% within 90 min (Losey and Uber-Zak, 2008).

3.3.1. Recommendation

The quality of evidence on the optimal duration of routine and sleep EEG is low. Therefore, our recommendations are conditional. Consensus after modified Delphi discussions is to suggest the duration of 20 min for the routine EEG and 30 min for the sleep EEG, excluding preparation (Table 3).

It is advisable to book the sleep recording of infants and children in the postprandial period, where there is a higher chance of falling asleep. Based on clinical expertise, we propose individualizing the recording time and duration when improved yield is expected (Koutroumanidis et al., 2017a, 2017b) Booking morning time for patients with suspected juvenile myoclonic epilepsy, prioritizing sleep recording in patients with suspected or diagnosed self-limited focal epilepsy of childhood or infantile epileptic spasms syndrome, and on suspicion of infantile epileptic spasms syndrome, extending recording at least 10 min after awakening to increase the probability of recording of epileptic spasms probably increases the yield of EEG.

3.4. Sleep-inducing methods

The database searches generated 360 articles, and 20 additional articles were identified from other sources. After removing duplicates, 259 records were screened. Sixty-nine full-text articles were assessed for eligibility. Seventeen studies fulfilled the eligibility criteria and three of them were guidelines. A PRISMA chart is shown in Appendix S4D.

All but one study evaluated the efficacy of sleep induction in children and young adults up to the age of 18 years (Milstein et al., 1998). The previous EEG recording guidelines (Flink et al., 2002; Dash et al., 2017; Sinha et al., 2016) do not recommend particular sleep-inducing method in adults, but recommend natural sleep in children (Flink et al., 2002; Dash et al., 2017), and if it fails, partial sleep deprivation or melatonin (Dash et al., 2017).

One randomized-controlled trial (RCT) with indirectness and three Category II observational studies without serious study limitations compared the yield of sleep in EEG studies with partial sleep deprivation to EEG studies without sleep deprivation in children and young adults (Tables S5–S8). The studies did not represent all WHO regions. The burden of sleep deprivation to patient, family, and society is very likely to be culturally biased. None of the studies used a stressful 24-hour sleep deprivation. Ten studies including six RCTs with high risk of bias and four observational studies with a high risk of bias explored the sleep-inducing efficacy of melatonin or another drug (Tables S6–S11). The studies showed inconsistency and imprecision because of heterogeneous methods, small numbers of studies, and small sample size in many studies. Publication bias was considered possible for 24-h sleep deprivation and the use of sedative drugs other than melatonin that have been used more commonly before 1990 but have been abandoned because of adverse effects.

Data on the adverse effects of sleep-inducing methods was assessed in nine studies using sleep-inducing drugs (Tables S9–S11). However, study limitations were serious (Tables S6–S7).

3.4.1. Efficacy of sleep induction

Partial sleep deprivation was shown to increase the probability of obtaining sleep during EEG (Carpay et al., 1997; Gilbert et al., 2004; DeRoos et al., 2009; Liamsuwan et al., 2000) (Table S3).

A Category I and a Category II study showed that melatonin and partial sleep deprivation are equally efficacious in inducing sleep (Wassmer et al., 2001; Gustafsson et al., 2015). A Category II study suggested that melatonin may be more efficacious in younger children 1–4 years of age in comparison to older children (Gustafsson et al., 2015).

A Category I multicenter study found combined intervention of sleep deprivation and melatonin to be significantly more effective to induce sleep than either method alone in pediatric patients (Alix et al., 2019). However, a smaller Category I study did find improved yield of sleep when melatonin was combined with partial sleep deprivation (Sander et al., 2012).

In a Category I study (Wassmer et al., 2001), sleep latency was significantly shorter with melatonin (mean latency 21 min) compared to partial sleep deprivation (mean latency 34 min), but the result was not confirmed by another Category I study (Sander et al., 2012). In addition, sleep latency was significantly reduced by combining melatonin with partial sleep deprivation in comparison to melatonin and partial sleep deprivation alone in a Category I study (Alix et al., 2019).

There was no difference in the yield of epileptiform abnormalities between the intervention groups in any of the included studies.

Significant adverse effects of melatonin were not found in Category I observational studies and randomized controlled trials that systematically assessed them in pediatric patients (Milstein et al., 1998; Wassmer et al., 2001; Sander et al., 2012; Fallah et al., 2014a). Disadvantages of sleep deprivation included difficulties in keeping children awake at night and in waking up in the morning in 50% of patients (Wassmer et al., 2001). In two studies, generalized tonic-clonic seizures occurred co-incidentally with sleep deprivation in one patient (Carpay et al., 1997; Liamsuwan et al., 2000).

We also collected data on the melatonin dose used in the studies, which varied from 2 mg to 10 mg. There are no trials on dose dependency for acute hypnotic or anxiolytic use of melatonin in children. In young healthy adults, increasing the dose from 1.0 to 10 mg did not significantly reduce the sleep-onset latency or the subjective sleepiness (Dollins et al., 1994). Clinical consensus recommendation by a group of European pediatric neurologists suggests a dose of 1–3 mg, 30 min before the examination (Bruni et al., 2015).

There is no evidence of an advantage of use of sleep-inducing drugs other than melatonin when the potential benefits and adverse effects are outweighed (Tables S10 and S11) (Milstein et al., 1998; Fallah et al., 2014a, 2014b; Sezer and Alehan, 2013; Bektas et al., 2014; Gumus et al., 2015).

3.4.2. Recommendation

We conclude that the quality of evidence on efficacy of partial sleep deprivation to induce sleep during EEG recording is moderate in children and young adults. However, it is very low for pharmacological sleep-inducing methods due to study limitations, imprecision caused by a small number of studies and small sample sizes, and adverse effects. We suggest partial sleep deprivation as a primary sleep-inducing method in adults and children 12 years of age or older who can cooperate with the sleep deprivation (Table 3). Sleep deprivation is a feasible method regardless of the availability of drugs and personnel needed for the administration of drugs. An example of a suggested partial sleep deprivation protocol is shown in Table 4. However, it is important to note that there are no studies evaluating the safety of partial or full sleep deprivation for any age group. Sleep deprivation may also cause significant distress to a child and family.

Melatonin or sleep deprivation are suggested as a primary sleep-induction method in children younger than 12 years of age

Table 4
Proposed partial sleep-deprivation protocol for sleep electroencephalography (EEG) in morning time.

Age group	Children aged <6 years	Children aged 6–12 years	Children aged >12 years	Adults
Instructions	Shorten the sleep by 1–3 h or an amount that you estimate is necessary for falling asleep at the time of EEG.	Go to sleep 2 h later than usual and wake up 2 h earlier than usual. Stay awake until the EEG.	Go to sleep 2 h later than usual, but at the latest at 00 a.m. Stay awake from 04 a.m. until the EEG.	Go to sleep at 00 a.m. Stay awake after 04 a.m. until the EEG.

(Table 3). If sleep deprivation or melatonin fails to induce sleep, the combination of both methods may be more effective. We also suggest melatonin as a primary sleep-induction method in children and adults who cannot cooperate with partial sleep deprivation. The proposed dose of melatonin is 1–3 mg administered 30–60 min before the start of the EEG recording. If melatonin is not available in the market, chloral hydrate may be used when partial sleep deprivation fails to attain sleep and patient safety is ensured.

3.5. Provocative methods

The database searches generated 3483 records, and 13 articles were identified from other sources. After removing duplicates, 3049 abstracts were screened. One hundred twenty-eight full-text articles were examined for eligibility. Forty-two original research studies and four guidelines (Flink et al., 2002; Dash et al., 2017; Sinha et al., 2016; Kasteleijn-Nolst Trenité et al., 2012) were included for review. A PRISMA chart is shown in Appendix S4E. Eighteen observational studies evaluated the use of hyperventilation (Table S12), 24 intermittent photic stimulation (IPS) (Table S13), and nine studies (Guaranha et al., 2009; Beniczky et al., 2012; Dhamija et al., 2018; Gelžiniene et al., 2015; De Marchi et al., 2017; El Shakankiry and Kader, 2012; Brinciotti et al., 1994; Lunardi et al., 2016; Sevgi et al., 2007) compared other provocation methods with IPS, hyperventilation, and/or sleep. A portion of the studies investigated several provocation methods. All studies were at high risk of bias because of limitations in both index and reference tests (Tables S14 and S15).

3.5.1. Hyperventilation

Protocol and technical standards

We found only two studies assessing hyperventilation protocol (Craciun et al., 2015; Watemberg et al., 2015). In a Category I study, 16% of seizures, 30.4% of interictal EEG abnormalities, and 30% of epileptiform discharges provoked by hyperventilation occurred during the last 2 min of the 5-min hyperventilation (Craciun et al., 2015). On the other hand, 85.5% of absence seizures were elicited within 1.5 min of hyperventilation in a Category III study (Watemberg et al., 2015).

Earlier EEG guidelines recommend a minimum of 3 min of hyperventilation that should be prolonged or repeated in a strong suspicion of typical absence seizures (Flink et al., 2002; Dash et al., 2017; Sinha et al., 2016).

Yield of hyperventilation

We found three, large Category I studies that showed an additional diagnostic value of hyperventilation (Craciun et al., 2015; Siddiqui et al., 2011; Kane et al., 2014). Hyperventilation precipitated epileptiform abnormalities that were not present on baseline EEG in 0.92% (3/326) (Siddiqui et al., 2011), 1.1% (10/877) (Craciun et al., 2015), or 3.0% (95/3170) (Kane et al., 2014) of adult and pediatric patients. These results were supported by two Category II studies reporting epileptiform abnormalities only during hyperventilation in 0.86% (5/580) (Angus-Leppan, 2007) and 5.7% (8/141) of patients (Ahdab and Riachi, 2014). In a Category III study in patients with newly diagnosed epilepsy, hyperventilation provoked epileptiform abnormalities not present at baseline in 7.7% (25/325) of patients (Baldin et al., 2017). The yield was greatest for patients 1 to 19 years of age (10.3%). In a study including the EEG studies of 100 healthy young men, no epileptiform activity was elicited by hyperventilation (Jabbari et al., 2000).

A significant increase in the frequency of epileptiform discharges compared with baseline was found in 23.7% (14/59) of patients with genetic generalized epilepsy in a Category III study (Gelžiniene et al., 2015).

Safety

In a Category I study assessing the safety of hyperventilation, no significant cerebrovascular, cardiovascular, or respiratory events were observed (Kane et al., 2014). Seizures during hyperventilation were relatively rare. Two Category I studies reported seizures that were provoked by hyperventilation in 2.2% (69/3170) and exclusively by hyperventilation in 2.9% (25/877) of patients referred to EEG on suspicion of epilepsy (Craciun et al., 2015; Kane et al., 2014). Only 1 of 3170 patients had a generalized tonic-clonic seizure (Kane et al., 2014). In a random sample of 580 reports of routine EEG with hyperventilation of Category II study, seizures provoked by hyperventilation were reported in 2.1% (12/580) of records (Angus-Leppan, 2007). Comparable or lower incidence of seizures during hyperventilation were reported in smaller Category II and Category III studies including narrow-spectrum studies on patients with genetic generalized epilepsy (De Marchi et al., 2017; Ahdab and Riachi, 2014; Raybarman, 2009).

Three Category I studies observed psychogenic non-epileptic seizures in 1.1% (10/877) and 0.9% (31/3475) of patients (Craciun et al., 2015; Kane et al., 2014), and in none (0/326) (Siddiqui et al., 2011) during hyperventilation. A Category III study showed increased frequency of psychogenic nonepileptic seizures when patients were informed about a potential seizure-inducing effect of hyperventilation (Hoepner et al., 2013).

3.5.2. Intermittent photic stimulation

Protocol and technical standards

We identified only two Category II (de Falco et al., 1992; Nagarajan et al., 2003) and one Category III (Leijten et al., 1998) studies assessing the IPS protocol. Of 45 patients with a photoparoxysmal response, this was elicited only on eye closure during IPS in 24.4% (de Falco et al., 1992). Photoparoxysmal response occurred in 8.0% (21/263) of children, and 45% of responses were found after 9 seconds of stimulation, which led to the recommendation for using 10 or more seconds for each stimulus frequency (Nagarajan et al., 2003). In photosensitive patients, the photosensitivity range for frequencies of 25–60 Hz was significantly higher (maximal) in the condition "eyes open with diffuser" compared with "eyes open," "eyes closed," and "eye closure" (p =.0002) (Leijten et al., 1998). Earlier EEG guidelines include the recommendation of a European expert panel on the methodology of photic stimulation (Kasteleijn-Nolst Trenité et al., 2012).

Yield of intermittent photic stimulation

We identified one Category I study that provided evidence for an additional diagnostic value of IPS (Whitehead et al., 2016).

Intermittent photic stimulation revealed generalized epileptiform discharges that were not present in the EEG before stimulation in 1.5% (79/5383) of patients, and the only useful information (epileptiform discharges, epileptic, or non-epileptic seizures) in 2.3% (122/5383) of patients (Whitehead et al., 2016).

In line with these results, in Category II studies, IPS elicited generalized epileptiform discharges (a type 4 photoparoxysmal reaction) (Waltz et al., 1992) as the only epileptiform activity in 0.68% (5/732) of EEG studies (Angus-Leppan, 2007) and epileptiform abnormalities occurring only on photic stimulation in 5.3% (12/226) of EEG studies (Ahdab and Riachi, 2014). In comparison, 0.32% (44/13658) of Air Force applicants showed epileptiform abnormalities induced only on photic stimulation (Gregory et al., 1993). On the other hand, IPS provoked the only epileptiform abnormalities in 30.5% of patients with genetic (idiopathic) generalized epilepsy (ages 14–17 years) in a Category III study (Gelžiniene et al., 2015).

A Category III study showed an additional yield of IPS in 3.7% (15/406) of patients with newly diagnosed epilepsy compared to baseline (Baldin et al., 2017). Repeated IPS in the second EEG after the first normal one, captured epileptiform activities in 3.0% (5/164) of patients. The yield was greatest for the patients younger than 20 years of age and for the patients with generalized seizures.

In a Category II study, a photoparoxysmal response was found in 2.3% of 2888 consecutive EEG recordings and in 10% of patients with epilepsy (de Falco et al., 1992).

A Category III study found photoparoxysmal response type 1–4 (Waltz et al., 1992), ranging from focal occipital spikes to generalized spikes and waves, in 74% of patients with epilepsy with generalized tonic-clonic seizures on awakening, in 56% in juvenile absence epilepsy, in 50% in juvenile myoclonic epilepsy, and in 44% in childhood absence epilepsy compared with 23% in childhood epilepsy with centrotemporal spikes and 16% in symptomatic/cryptogenic epilepsy (Lu et al., 2008). The relative frequency of the type 4 response among all photosensitivity reactions was significantly higher in genetic generalized epilepsy (59%) than in childhood epilepsy with centrotemporal spikes (38%). In a nationwide study in Great Britain, the annual incidence of patients with epilepsy and generalized spike-and-wave discharges on IPS on their first EEG was roughly 1.1 per 100 000, representing ~2% of all new cases of epilepsy (Quirk et al., 1995).

Safety

In a nationwide UK, Category I study, 0.72% (39/5383) of patients had seizures due to IPS including a generalized tonic-clonic seizure in 0.04% of patients (Whitehead et al., 2016). In 0.9% (49/5383) of patients, the IPS provoked a psychogenic nonepileptic seizure (Whitehead et al., 2016). In accordance, two Category II studies reported seizures exclusively during IPS in 0.53% (1/189) and 0.68% (5/732) of patients (Angus-Leppan, 2007; Ahdab and Riachi, 2014). The IPS caused epileptic seizures in 0.068% (4/5893) of Air Force applicants, of which three of four were generalized tonic-clonic seizures (Trojaborg, 1992). In a Category III study, the rate of psychogenic nonepileptic seizures rose significantly after informing the patients about the potential seizure-inducing effects of the activation method; this was seen both in patients with only psychogenic nonepileptic seizures and in patients with both psychogenic nonepileptic and epileptic seizures (Hoepner et al., 2013). Specifically, in the informed group, 17.6% (6/34) of patients showed psychogenic nonepileptic seizures due to the IPS, two thirds (4/6) of them exclusively during the IPS.

3.5.3. Other provocation methods

We did not find evidence for supporting the standard use of provocation methods other than hyperventilation and IPS in routine EEG recordings (Guaranha et al., 2009; Beniczky et al., 2012; Dhamija et al., 2018; Gelžiniene et al., 2015; De Marchi et al., 2017; El Shakankiry and Kader, 2012; Brinciotti et al., 1994; Lunardi et al., 2016; Sevgi et al., 2007). Two main indications of other provocation methods were recognized: genetic generalized epilepsies with reflex trait and focal-onset epilepsies with a specific seizure trigger. Three Category III observational studies compared the provocative effect of cognitive tasks to that of sleep deprivation, IPS, and hyperventilation on interictal epileptiform discharges in juvenile myoclonic epilepsy (Guaranha et al., 2009; Beniczky et al., 2012; Dhamija et al., 2018) and two in genetic generalized epilepsies (Gelžiniene et al., 2015; De Marchi et al., 2017). The duration of cognitive protocol was at least 15 min, and typically more than 30 min. The yield of cognitive tasks may exceed that of hyperventilation and IPS, but not sleep (Gelžiniene et al., 2015; De Marchi et al., 2017). Seizures during cognitive testing were not observed in two studies (Dhamija et al., 2018; Gelžiniene et al., 2015), whereas they occurred in three studies (Guaranha et al., 2009; Beniczky et al., 2012; De Marchi et al., 2017). In patients with juvenile myoclonic epilepsy, cognitive tasks were more provocative of myoclonia than conventional methods (Guaranha et al., 2009; Beniczky et al., 2012; De Marchi et al., 2017).

Other Category II–III studies investigated the provocative effect of visual pattern stimulation in unselected patients of 4–12 years of age (El Shakankiry and Kader, 2012) and in pediatric patients with visually induced seizures (Brinciotti et al., 1994) and olfactory stimuli in mesial temporal lobe epilepsy (Lunardi et al., 2016) that did not increase the diagnostic utility of routine EEG.

3.5.4. Recommendation

We conclude that the quality of the evidence for hyperventilation to provoke epileptiform discharges is moderate despite study limitations (three, consistent Category I observational studies), but low for photic stimulation and other types of stimulation. Our conditional recommendation was formulated by modified Delphi discussions. A summary of provocation methods is shown in Table 3. We suggest that hyperventilation, photic stimulation including baseline recording of eyes open, and eyes closed are part of routine or sleep EEG unless contraindicated. Asking the patient to blink, close, and open eyes for several seconds documents artifacts, permits evaluation of posterior dominant rhythm, and is a provocative method for eye-closure sensitivity (Wolf, 2017). We suggest tailoring the activation methods and using other simple stimulation methods, for example, touch, sudden noises, or reading aloud a difficult text, when they are known to provoke seizures (Koutroumanidis et al., 2017).

The patient and caregiver should be informed in advance about the potential benefits as well as adverse effects of activations, particularly seizures and potential loss of driving permission. Information may also increase the occurrence of nonepileptic seizures. The patient has the right to know about the possibility to refuse activations.

The EEG technologist is responsible for the safety of the patient and the quality of recording, which necessitates monitoring of one recording at a time. The patient should be under continuous surveillance during the recording. The EEG technologist should be able to call for help. During seizures it is advisable to test the patient with a standardized method. We advise the use of simplified versions of the ILAE Guideline and UK National Guideline for testing patients during seizures in long-term video EEG (Table 5) (Beniczky et al., 2016; Pressler et al., 2017). For testing of a potential absence seizure during generalized spike and wave discharge longer than 3–4 seconds, we propose the method proposed by the ILAE Neurophysiology Task Force: "The role of EEG in the diagnosis and classification of the epilepsy syndromes: a tool for clini-

Table 5
Proposed protocol for testing patients during seizures in routine and sleep electroencephalography (EEG).

Children < 6 years old	Children ≥ 6 years old and adults
1. Say the patient's first name 2. "Are you ok? 3. "Lift both arms up/like Superman or touch toy with right & left hand/clap." 1. First say only, 2. If not reacting show 4. Postictally ask: "Did you know what just happened?"	1. Say the patient's first name 1. If reacting, ask: "What do you feel?" 2. If not, touch arm 2. "Lift arms." 1. First say only, 2. If not reacting, show 3. "Please repeat and remember the following words: horse, table (*for example*) 4. Postictally ask:"Did you have a seizure?" "Can you describe what happened?" "What did you feel right before/at the beginning of the event?" "Can you recall the words I said to you/what I asked to do?"
For testing of a potential absence seizure during generalized spike-and-wave discharge longer than 3–4 s, we suggest giving commands or words when the generalized discharge starts and continues during the length of absence. Patients are monitored for a spontaneous response and after the offset of discharge, asked what they were told.	

Note: Modified from Beniczky et al. (2016) and Pressler et al. (2017).

cal practice."(Koutroumanidis et al., 2017). The EEG technologist gives simple commands or words when the generalized discharge starts and continues during the length of absence. Patients are monitored for a spontaneous response, and after the offset of discharge they are asked what they were told.

In adults, we propose that IPS is performed before hyperventilation at the beginning of EEG at least 3 minutes apart (Kasteleijn-Nolst Trenité et al., 2012). However, if the referral diagnosis is genetic generalized epilepsy, it is advisable that activations are done at the end of recording due to an increased probability of seizures. IPS often raises the level of vigilance and decreases the probability of sleep; hyperventilation has an opposite effect (Kaleyias et al., 2006). Therefore, in children, we advise performing hyperventilation at the beginning of sleep EEG and IPS at the end.

Hyperventilation protocol.

The patient is instructed to breathe deeply 15–30 times per minute for least 3 min. In children, a pinwheel is useful to enhance breathing. In some patients, numbness or tingling of perioral region and fingers may occur; if so, this is not a reason to discontinue hyperventilation. The EEG technologist should encourage the patient and rate breathing effort as adequate or inadequate. It is preferable to record 2 min of awake EEG after hyperventilation in all patient groups.

Contraindications for hyperventilation are sickle cell disease or trait; Moya-Moya disease and syndrome; cerebrovascular malformations including aneurysms, cerebrovascular events in the last 3 months, elevated intracranial pressure, myocardial infarction, cardiac arrhythmias, and other severe forms of cardiac disorders;

Table 6
Summary statements of the minimum standards for recording routine and sleep electroencephalography EEG.

Indications of non-emergent EEG recorded by appointment include indications related to epilepsy, seizures, brain dysfunction, and differential diagnosis as detailed in Table 2.

Technical standards are summarized in Table 3.

Duration of EEG: 20 min for the routine EEG and 30 min for the sleep EEG excluding preparation is suggested. It is advisable to schedule the sleep recording of infants and children in the postprandial period, where there is a greater chance of falling asleep.

We suggest individualizing the recording time and duration when increased benefit is expected. Scheduling morning time for patients with suspected juvenile myoclonic epilepsy, prioritizing sleep recording in patients with suspected or diagnosed self-limited focal epilepsy of childhood or infantile epileptic spasms syndrome, and on suspicion of infantile epileptic spasms syndrome, and extending recording at least 10 min after awakening to increase the probability of recording of epileptic spasms probably increase the yield of EEG.

Sleep-induction: Partial sleep deprivation is suggested as a primary method in adults and children 12 years of age or older who can cooperate with the sleep deprivation. An example of suggested partial sleep deprivation protocol is shown in Table 4. However, it is important to note that there are no studies evaluating the safety of partial or full sleep deprivation for any age group. Sleep deprivation may also cause significant distress to a child and family. Melatonin or sleep deprivation are suggested as a primary sleep induction method in children younger than 12 years of age. If sleep deprivation or melatonin fails to induce sleep, their combination may be more effective. Melatonin is proposed as a primary sleep induction method in children and adults who cannot cooperate with partial sleep deprivation. The suggested dose of melatonin is 1–3 mg administered 30–60 min before the start of the EEG recording. If melatonin is not available in the market, chloral hydrate may be used when partial sleep deprivation fails to attain sleep and patient safety is ensured.

Provocation methods: Hyperventilation, intermittent photic stimulation (IPS) including baseline recording of eyes open, and eyes closed are suggested unless contraindicated. Asking the patient to blink, close, and open eyes for several seconds documents artifacts, permits evaluation of posterior dominant rhythm, and is a provocative method for eye-closure sensitivity. It is proposed to use other simple stimulation methods, for example, touch, sudden noises, or reading aloud a difficult text, when they are known to provoke seizures.In

adults, it is suggested that IPS be performed before hyperventilation at the beginning of EEG, at least 3 min apart. However, if the referral diagnosis is genetic generalized epilepsy, it is advisable to do activations at the end of recording due to an increased probability of seizures. IPS often raises the level of vigilance and decreases the probability of sleep, and hyperventilation has an opposite effect. Therefore, in children, it is useful to perform hyperventilation at the beginning of sleep EEG and IPS at the end.

The patient and caregiver should be informed in advance about the potential benefits as well as adverse effects of activations, particularly seizures and potential loss of driving permission. Information may also increase the occurrence of nonepileptic seizures. The patient has the right to know about the option to refuse activations.

Hyperventilation and IPS protocols are detailed in Table 3.

Contraindication for IPS: pregnancy.

Contraindications for hyperventilation are sickle cell disease or trait; Moya-Moya disease and syndrome; cerebrovascular malformations including aneurysms, cerebrovascular events in the last 3 months, increased intracranial pressure, myocardial infarction, cardiac arrhythmias, and other severe forms of cardiac disorders; severe pulmonary disorders; and pregnancy. Preferably a list of contraindications is available for the referring physician to report existing contraindications. As a minimum and in cases of a time lag between referral and EEG, the EEG technologist should ask the patient about contraindications and document the answer.

Responsibility of EEG technologist is to guarantee the patient safety and the quality of recording that necessitates continuous monitoring of one recording at a time. The patient should be under continuous surveillance during the recording. The EEG technologist should be able to call for help. During seizures, it is advisable to test the patient with a standardized method (Table 5).

severe pulmonary disorders; and pregnancy. Preferably, a list of contraindications is available for the referring physician to report existing contraindications. At a minimum and in cases of a time lag between referral and EEG, the EEG technologist should ask the patient about contraindications and document the answer.

Intermittent photic stimulation protocol.

We suggest that IPS be performed in accordance with the ILAE guideline on revisited methodology of photic stimulation in EEG recording (Kasteleijn-Nolst Trenité et al., 2012). There is no need to repeat IPS during the same EEG recording if it remains unequivocal. Contraindication for the IPS is pregnancy due to the high risk of seizure.

3.6. Conclusions

Routine and sleep EEG have an established role in clinical diagnosis of epilepsy and provide real-time evidence of brain dysfunction. However, the overall quality of evidence for recording standards of routine and sleep EEG is low, which is an important limitation. This article is the second joint IFCN-ILAE EEG guideline in addition to recently published "Minimum standards for inpatient long-term video-electroencephalographic monitoring: A clinical practice guideline of the International League Against Epilepsy and International Federation of Clinical Neurophysiology (Tatum et al., 2022). The minimum standards summarize the available evidence based on systematic review and provides the first expert consensus-based global standards to record EEG (Table 6). Although the recommendations are conditional, they provide feasible international standards for new EEG laboratories and challenge established EEG laboratories to evaluate their protocols and to tailor implementation strategies of recommendations to the local context (Harrison et al., 2010). In the future, further research development and diagnostic accuracy studies are needed, as well as studies addressing cost-efficacy of routine and sleep EEG.

Conflicts of Interest

Sándor Beniczky has served as scientific consultant for Epihunter and received speaker honoraria from Natus. Jonathan J. Halford has served as a Board Advisor for CortiCare. Ronit M Pressler is an investigator for studies with UCB and does consultancy work for Kephala, Ireland. She served as a speaker and/or on advisory boards for Natus, GW Pharmaceuticals, Eisai, and UCB. The remaining authors have no conflicts of interest.

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Appendix A. Supplementary material

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