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Do sleep-deprived EEG recordings reflect spike index as found in full-night EEG recordings?

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ABSTRACT

The sleep EEGs of many children with neurodevelopmental disorders reveal epileptiform activity. The aim of this study was to compare spike index (SI) in full-night recordings with SI in sleep-deprived EEGs in the morning; EEGs were obtained over 24 hours using ambulatory equipment. Sixteen children between the ages of 7 and 12 years were included in the study. They had to wake up at 3:00 AM and go to sleep again at 7:30 AM. Epileptiform activity was quantified, and SIs of full-night and morning recordings were compared. Two patients did not fall asleep. In one recording there was a technical problem that made calculations impossible. SIs calculated from EEGs obtained during a short nap in the morning were comparable to those calculated from full-night recordings. There seems to be a higher failure rate during morning recordings because of patients not falling asleep.

1. Introduction

It is well established that epileptiform activity during sleep in children affects cognitive functions and behavior [1–9]. Among the different cognitive disturbances reported are those in autism spectrum disorder (ASD) [3,10–13], attention deficit/hyperactivity disorder (ADHD) [5,14–19], language disturbances including Landau–Kleffner syndrome (LKS) [1,3,20–22], and learning disabilities [2,23–26].

Continuous epileptiform activity during sleep was first pointed out by Patry and co-workers [1], who called the activity "subclinical 'electric status epilepticus' induced by sleep in children." This was changed to *electric status epilepticus during sleep in children* (ESES) [27,28]. Later, this term was challenged [29], and in 1985 *continuous spike waves during slow sleep* (CSWS) was proposed [30]. The latter term has been confused with the syndrome *epilepsy with CSWS* [31] and also with the requirement for epileptiform activity over 85% of non-rapid eye movement sleep (NREM) sleep time [1,29]. Different use of the names and abbreviations has been suggested. It is now clear if epileptiform activity occurring during a smaller fraction of sleep time may disturb developmental functions in children. Because of the unclear meaning of CSWS, we have been using *focal nocturnal epileptiform activity* (FNEA) as a general term for all types of focal activity independent of syndrome and percentage of non-rapid eye movement (NREM) sleep affected.

Assessing the amount of epileptiform activity is an important part of the diagnostic workup. The treatment of epileptiform activity during sleep is not well established, but awareness of the need for treatment is increasing [19,32–35].

Semiautomatic estimation analysis of epileptiform activity in 24-hour EEG recordings in children is now a well established method [36]. However, most laboratories are still recording short sleep EEGs in the morning, after sleep deprivation. The aim of this study was to compare the yield and feasibility of full-night sleep recordings and short morning-sleep recordings after sleep deprivation, as used in most laboratories.

2. Material and methods

Spike indices were calculated according to the method described by Larsson and collaborators [36]. Spikes were detected by template matching. That is, a typical spike in the EEG was manually selected as the template. This spike was used for averaging about 50 spikes reducing artifacts, making an "averaged spike," which was then used

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as the template for automatic spike detection. If there were more foci or variability in spike morphology, more templates were selected, and automatic spike detection was performed for each template. Detections for all templates were combined to calculate a spike index (SI), which is defined as the proportion of time, in 10-minute epochs, during which there was less than 3 seconds to the next spike. SI during full-night sleep was calculated as the mean SI from the epochs within NREM sleep. In this context NREM sleep was defined as the 50% of the epochs having the highest SI values. SI during morning sleep was calculated as the mean SI for every 10-minute epoch within a manually marked sleep period.

Sleep stages were defined mainly by the SIs during night sleep [36]. During the day, arousal and eventual sleep were scored by an experienced sleep stager.

The patients and their parents were asked to complete a form eliciting information on the patients' experience with the procedures. We used a Likert-type scale [37] with five alternatives, except for the question on the comparison between sleep deprivation and full-night sleep, for which there were three alternatives (worse, indifferent, and better). Statistics were calculated by means of χ^2 testing of the tabulated results.

Patients admitted to the epilepsy center with known FNEA, and who were between 7 and 12 years of age, were eligible for inclusion. FNEA had earlier been diagnosed on the basis of at least one 24-hour ambulatory EEG recording with a SI above 30 [36] during NREM sleep.

Informed consent was required from both patients and their parents. The study was approved by the local medical ethics committee.

Primarily 105 patients were included. A total of 89 were excluded because they were unable to wake up at 3:00 AM, go to sleep in the morning, or cooperate in other ways during the test period. Sixteen patients underwent a full recording, fulfilling the inclusion criteria.

EEGs were recorded with TrackIt (Lifeline) ambulatory EEG recorders sampling at 256 Hz. The recordings were made with 25 channels according to the 10–20 system with added "low rows" (F9, F10, T9, T10, P9, P10).

The recordings were started in the afternoon. The patient went to bed in the ward as usual, but had to awaken at 3:00 AM, as this would fulfill the criteria for sleep deprivation for this age group. At 7:30 AM, the patient was asked to go to sleep, so that his or her EEG could be recorded until 10:00 AM. This mimics the routine sleep recordings used in the laboratory, except that those sleep periods usually end at 9:30 AM.

3. Results

Among the 16 patients who completed the test, 6 had symptoms of either ADHD or infantile autism. Five were diagnosed with rolandic epilepsy. Three had severe epilepsy, and were diagnosed with the syndrome of epilepsy with CSWS. One patient had generalized epilepsy with a brain lesion in the left parietal region. The last patient had a known genetic defect on chromosome 8.

Table 1
Data obtained from EEG recordings.[a]

Patient	Age	Mean SI	Max SI	SI morning	Comment
1	11	52	82	71	
2	11	11	30		No morning sleep
3	7	42	70		No morning sleep
4	9	94	100	99	
5	9	7	10	21	
6	12	42	60	56	
7	9	26	42	47	
8	11				Normalized EEG
9	11				Too small potentials
10	10	42	75	63	
11	9	39	58	34	
12	7				Artifacts
13	12	6	9	17	
14	7	35	56	50	
15	8	13	25	15	
16	10	19	30	23	

[a] Mean SI = mean SI during NREM sleep at night. Max SI = maximum value for any 10-minute period during NREM sleep. SI morning = mean calculated value during a manually marked sleep period in the morning.

Plotted in Fig. 1 are the SIs during a full recording of patient 1, who had a nap just after the start of the recording and another nap after sleep deprivation the next morning. The SI in the first nap was 66.8, and that in the second, 70.8. The mean SI during NREM sleep was 52, with a peak at 82. Hardly any spikes were detected during the morning and the SI was calculated to be 0.2.

Among the patients included, one did not have FNEA during the recording. Another patient had small, visible, detectable, epileptiform potentials not detected by the spike detection algorithm. Two patients did not fall asleep in the morning. In one recording there was a technical issue rendering it unusable for spike quantification (Table 1).

The mean SI during NREM sleep was 33. The maximum SI values during NREM sleep were higher, with a mean value of 50. Accordingly, the mean SI in the morning sleep recordings was 45. There is a good correlation between SIs calculated from a sleep-deprived recording in the morning and those from a full-night recording (Fig. 2). The SI during sleep in the morning was usually lower than the maximum SI during NREM sleep, with a mean difference of 5.2 ($p = 0.14$). Two patients (Nos. 5 and 13) had higher values in the day than at night, but both had NREM SIs below 10. Among patients who did fall asleep, the mean SI was 10.5 ($p = 0.002$) higher during sleep in the morning than during NREM sleep.

There was a minor difference between the parents and children in the experience of the full-night recording: eight children and four

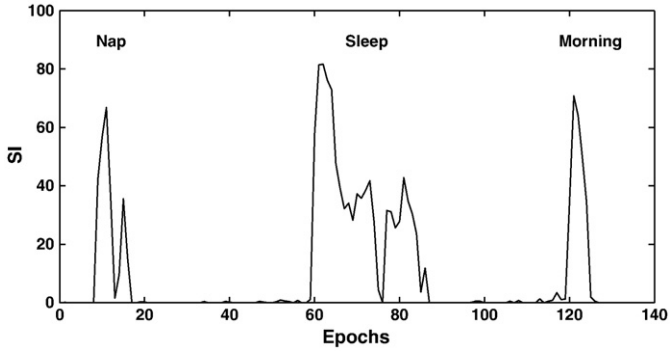

Fig. 1. Twenty-two-hour plot of SIs in patient 1. Epoch number is plotted against SI. There are three periods with spiking: (1) during a spontaneous nap in the morning after the start of the recording (Nap), (2) during the night (Sleep), and (3) in the morning when the patient was asked to go to sleep after sleep deprivation (Morning).

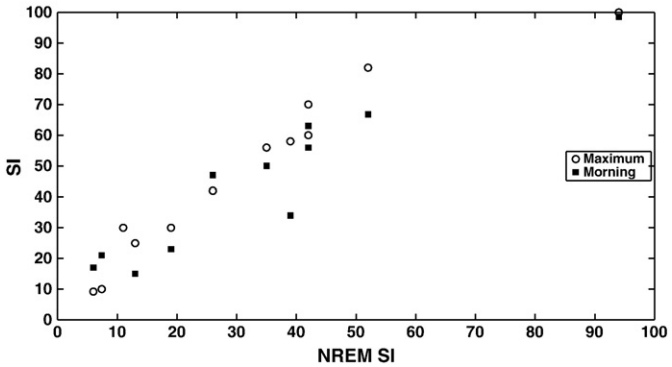

Fig. 2. Plots of maximum SI during the morning nap after sleep deprivation (■) and maximum SI during the night (○) against mean SI during NREM sleep.