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Is sleep captured during a standard daytime EEG sufficient to diagnose Electrical Status Epilepticus in Sleep

Snehal Shah [a,c], Soumya Ghosh [a,b], Lakshmi Nagarajan [a,c,d,*]

[a] Dept of Neurology, Perth Children's Hospital, Nedlands, WA 6009, Australia
[b] Perron Institute for Neurological and Translational Science, QEII Medical Centre, Nedlands, WA 6009, Australia
[c] Faculty of Health and Medical Sciences, University of Western Australia, Nedlands, WA 6009, Australia
[d] Telethon Kids Institute, Perth Children's Hospital, Nedlands, WA 6009, Australia

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ABSTRACT

Electrical Status epilepticus of sleep (SES) is an EEG pattern where there is significant activation of epileptiform activity in NREM sleep. A spike wave index (SWI) of > 80–85% is often labelled as typical SES. We aimed to explore if sleep during a standard daytime-EEG, as compared an overnight-EEG, was adequate to diagnose ESES.

Ten children with daytime and overnight studies suggestive of SES were audited. SWI and Spike Wave Density (SWD) were calculated for 5-minute epochs of wake in the daytime and overnight study, as well daytime-EEG sleep and first and last NREM cycle in the overnight-EEG.

SWI in daytime NREM was not significantly different from SWI in the first sleep cycle of the overnight study. SWI in the last sleep cycle was significantly lower than the first sleep cycle in the overnight-EEG.

SWD was significantly higher in the first sleep cycle in the overnight-EEG than the daytime sleep and the last NREM cycle.

SES may be diagnosed in NREM sleep from a daytime-EEG study. Larger studies are needed to explore the significance of the disparity between SWI and SWD in the first and last NREM cycles in the overnight study.

Introduction

Electrical Status Epilepticus of Sleep (SES) is an EEG pattern in which there is significant activation of epileptiform activity in NREM sleep [1–5]. SES is also referred to as Status Epilepticus of Sleep, Continuous Spike and Wave during Slow Wave Sleep-CSSW [1,4–8]. Conventionally, a spike wave index-SWI of >80–85%, in an overnight sleep EEG, is labelled as typical SES [1,9,4–6]. The spectrum of EEG parametrics and criteria used to diagnose SES on EEG and assess response to interventions, is wide, with many variations in sampling, qualitative and quantitative methods [2,3,10–24].

SES is an important EEG phenomenon to diagnose. SES is the hallmark feature of developmental and epileptic encephalopathies with spike and wave activation in sleep: DEE-SWAS [9,25]. SES may occur on EEG in the evolution from typical to atypical benign childhood epilepsy syndromes such as self-limited epilepsy with autonomic features, self-limited epilepsy with centrotemporal spikes, childhood occipital visual epilepsy (SeLEAS, SeLECT, COVE). SES is seen in Landau Kleffner Syndrome, an age-related childhood clinical syndrome, presenting with regression of speech, auditory agnosia, behavioural problems and seizures. SES is a cardinal feature of epileptic syndromes associated with neuro-regression, such as epileptic encephalopathy with SES (EESES), epileptic encephalopathy with CSSW (ECSSW), pseudo-Lennox, opercular syndrome, DEE-SWAS [5,6,9,25–29].

It is well recognised that epilepsy and sleep have a bidirectional relationship. Interictal epileptiform discharges (IEDs) in NREM sleep are known to have an impact on cognition. The high SWI and SD in SES is thought to prevent the process of synaptic descaling, disrupt neuronal circuitry involved in information processing, and result in learning and memory impairments [6,30–32].

Early recognition and treatment with specific medications such as benzodiazepines, other antiseizure medications, immunomodulation, surgery, ketogenic diet, may impact on the neurodevelopmental outcomes in children when SES is associated with various combinations of seizures, cognitive, language, behavioural and motor impairments [6,9,13,16,26,28,29,33–42].

* Corresponding author at: Dept of Neurology, Perth Children's Hospital, Nedlands, WA 6009, Australia.
E-mail address: Lakshmi.Nagarajan@health.wa.gov.au (L. Nagarajan).

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The diagnosis of SES is based on overnight EEG recordings in most studies [1,7,9]. Repeated EEG studies are frequently required in both clinical management and research settings [14]. Overnight EEG recordings are labour and cost intensive, and not readily available, whereas standard daytime EEGs, with sleep, are much easier to obtain. The aim of this pilot study was to explore if sleep captured during a standard daytime EEG, as compared to sleep from an overnight study, was sufficient to diagnose SES.

Methodology

The pilot study was undertaken to see if sleep captured during a standard daytime EEG is adequate to diagnose Electrical Status Epilepticus during Sleep. This retrospective audit (GEKO32949) was approved by GEKO (governance, evidence, knowledge, outcomes), as required by the Hospital Ethics Committee.

Identification of subjects

The departmental database of EEG reports (undertaken in our institution), between 2000 and 2020 was searched for the terms suggestive of SES spectrum – SES, ESES, CSWS, CSSW, in the reports. We undertook 48,462 EEGs (neonates + children less than 18 years) during this period. Thirty-nine children had daytime EEGs reported as suggestive of SES spectrum, based on visual analysis. Of these 39 children, ten had overnight EEGs undertaken. The decision to undertake overnight EEGs was made by the treating paediatrician/neurologist. The median interval between the standard daytime EEG and the overnight study in these ten children was 2 months. The ten children's daytime and overnight EEGs were analysed. Their clinical details are outlined in Table 1.

EEGs

Standard practise for a daytime VEEG in our institution is to request partial sleep deprivation (tailored to the age of the child) in all children scheduled for an EEG. We capture both awake and sleep states in ~ 80% of our standard recordings.

Overnight studies are undertaken with the child admitted to the Epilepsy Monitoring Unit and most overnight studies are around 18–19 h' duration.

VEEGs were recorded using Compumedics (Australia) equipment, using PSG software. Electrode placement was in accordance with the International 10–20 system. No medication changes were undertaken for the EEG recordings.

EEG metrics

The SWI and SWD were calculated during 5 min of wake and 5 min of first NREM sleep in the standard daytime EEG. SWI and SWD were calculated in 5 min of awake in the overnight study. SWI and SWD were also calculated in 5 min of the first and last NREM cycles in the overnight study. NREM sleep was identified as initial onset of sleep spindles in the daytime or first and last NREM epochs in the overnight recordings.

SWI was defined as number of seconds with epileptiform activity in an epoch of 5 min (300 s) of sleep, expressed as a percentage. SWD was defined as number of spikes in 5 min (300sec) of sleep, expressed as a percentage. All one second bins with spikes were included in SWI analysis. Spikes were counted in the derivation with most spikes for SWD analysis. SES was defined as a SWI of > 80%. Fig. 1 illustrates epochs of wake, sleep during standard daytime study and sleep from first and last NREM cycle on overnight EEG.

Statistical analysis

Repeated measures ANOVA was performed to compare Spike Wave Index and Spike Wave Density at different times (standard and overnight EEGs) and states (wake and sleep recordings, and sleep recording at the first and last sleep cycles of the overnight recordings) during EEG recordings. Post hoc analysis with a Bonferroni adjustment was performed for pairwise comparisons. Significance was set to $p < 0.05$.

Results

The clinical characteristics of the ten children in this study are shown in Table 1. As can be seen, they span a spectrum of epilepsy syndromes from self-resolving to drug resistant epilepsy. Only one child carried a clinical diagnosis of EESES at the time of the overnight EEG study. This child had been on clobazam previously and was subsequently trialled on immunomodulation.

Table 1
Clinical details of study patients.

No	Age at EEG (years)	Sex	Epilepsy	Co-morbidity	ASM at STD EEG	ASM at ON EEG	No of ASMs trialled	MRI/CT
1	10	M	DRFE	ADHD	VPA, LTG	VPA LTG, TPM	4	Mild cerebral atrophy
2	8	M	FE	SLD, migraine	LTG	LTG	1	normal
3	3	F	DRFE	Coeliac disease, ADHD, SLD	CLN, TPM	CLN, TPM	8	FCD (R Parietal)
4	9	F	FE	SLD, ADHD	LTG	LTG	2	Features of NF1, with L optic glioma, multifocal myelin vacuolisation
5	7	F	DRFE	SLD, ASD	VPA, LTG	VPA, LTG	3	Rathke cleft cyst, PVL
6	7	F	FE	SLD, BD, ID	OXZ	OXZ	1	Mild PVL
7	7	M	DRFE	SLD	LEV, VPA	LEV, VPA	3	Normal (N)
8	10	M	Atypical BFEC	SLD	None	VPA, LTG	4	N
9	8	M	ESES	Coeliac disease	LTG	LTG	1	Small cystic gliosis in the R caudothalamic region, mild R periventricular volume loss, small L caudothalamic cyst
10	10	M	FE	ASD, SLD	CBZ	CBZ	1	Nonspecific bilateral deep white matter signal hyperintensity

Abbreviations. ADHD: Attention Deficit Hyperactive disorder, ASD: Autism Spectrum disorder, BD: Behaviour Disorder, BFEC: Benign Focal Epilepsy of Childhood, CBZ: Carbamazepine, CLN: Clonazepam, DRFE: Drug Resistant Focal Epilepsy, ESES: Epileptic encephalopathy with Status Epilepticus in sleep, F: Female, FCD: Focal Cortical Dysplasia, FE: Focal Epilepsy, ID: Intellectual Disability, LEV: Levetiracetam, LTG: Lamotrigine, M: Male, ON: Overnight, PVL: Periventricular Leukomalacia, SLD: Speech and Language Delay, STD: Standard, VPA: Valproate.

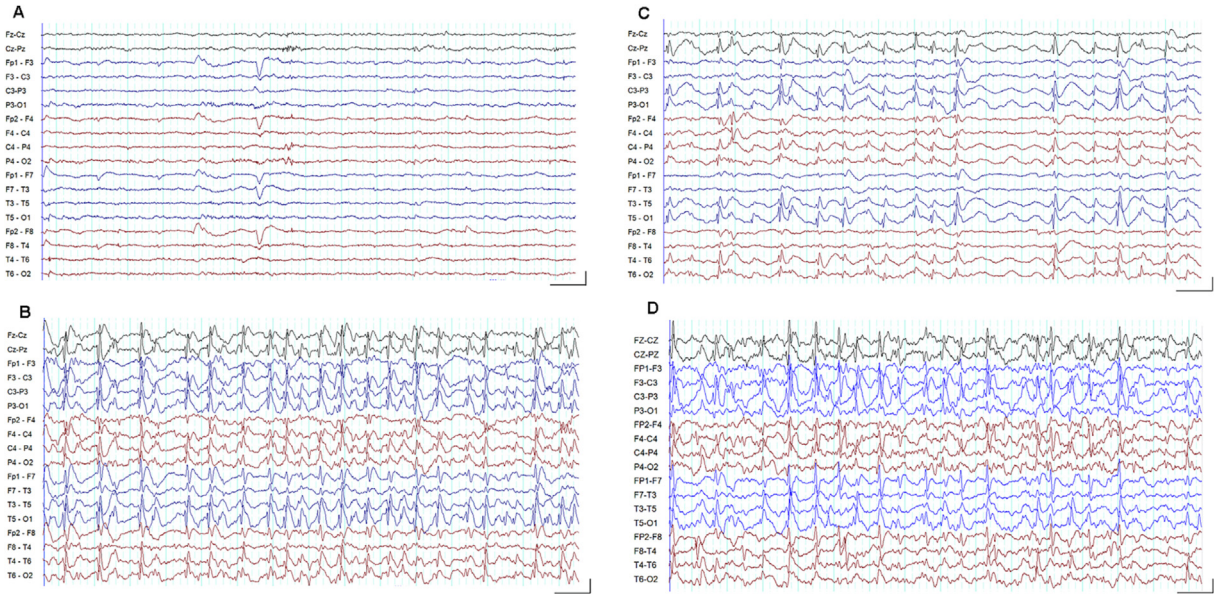

Fig. 1. Fifteen second epochs of EEG recording (bipolar montage) for one child taken from overnight study (A, B and C) and standard recording (D). In the overnight study A is from wake state, B is from first Non Rapid Eye Movement (NREM) sleep, and C is from last NREM sleep. D is from NREM sleep in the standard EEG. Calibration bars equal 0.2 mV vertical and 1 s horizontal for all epochs.

Statistical analysis of SWI and SWD in SES

The mean SWI and SWD (±SEM) are shown in Table 2. As expected, mean SWI and SWD were greater in sleep than in the wake state. All ten children with SWI of >80% in sleep on the standard daytime study also had SWI > 80% in the first sleep cycle of the overnight sleep.

SWI

The repeated measures ANOVA with a Greenhouse-Geisser correction determined that the mean SWI differed significantly between the different times and states recorded, F (2.419, 21.775) = 32.49, p = 0.000. Result of post hoc analysis (pairwise) with a Bonferroni adjustment is shown in Table 3. SWI was significantly different between wake and sleep states in the standard recording (p = 0.000) and wake and sleep states in the overnight recording (p = 0.000, p = 0.023). There was no significant difference between SWI in sleep on the standard recording compared to the first sleep cycle of the overnight recording (p = 1.000). However, SWI was significantly higher in the first sleep cycle compared to the last sleep cycle of the overnight recording (p = 0.026). Similarly, SWI was significantly higher in sleep in the standard recording than in sleep in the last sleep cycle of the overnight recording (p = 0.042).

Table 2
Mean ± Standard Error of the Mean (SEM) (range in brackets) Spike Wave Index (SWI) and Spike Wave Density (SWD) calculated from Electroencephalogram (EEGs) recorded at different times (standard and overnight) and different states (awake and sleep).

	SWI	SWD
awake standard	25.9 ± 9.4 (1–95)	34.1 ± 13.2 (1–133)
asleep standard	92.8 ± 2.2 (82–100)	116.8 ± 10.6 (89–207)
awake overnight	26.29 ± 9.4 (1–90)	38.06 ± 14.8 (2–141)
asleep overnight first cycle	96 ± 1.6 (86–100)	138.2 ± 11.1 (81–209)
asleep overnight last cycle	66.5 ± 9 (19–99)	95.7 ± 16.4 (30–186)

SWD

For the spike density measurements, the repeated measures ANOVA determined that the mean SWD differed significantly between the different times and states recorded, F (4, 36) = 18.456, p = 0.000. Result of post hoc analysis with a Bonferroni adjustment is shown in Table 4. SWD was significantly different between wake and sleep states in the standard recording (p = 0.013) and in the overnight recording (p = 0.002, p = 0.035). SWD was significantly lower in sleep in the standard recording than in the first sleep cycle of the overnight recording (p = 0.042). SWD was significantly higher in the first than the last sleep cycle of the overnight study (p = 0.046). SWD was not significantly different between sleep in the standard recording and in the last sleep cycle of the overnight recording (p = 1.000).

Discussion

The standard day time EEGs were reported as SES or suggestive of SES, based on visual analysis, by the child neurologist reporting on the EEG. The SWI was > 80% on SWI analysis in all ten children, suggesting SES based on visual analysis is reliable as a screening tool.

The SWI in sleep, captured on a standard daytime EEG, was not statistically different from SWI in the first NREM cycle of the overnight study in these ten subjects. As SWI is the parameter most often used to diagnose SES, this pilot retrospective study indicates that if daytime sleep is suggestive of SES, the overnight sleep also shows SES. In children with SES a standard daytime study which includes sleep may be specific and sufficient, along with the clinical profile, to make the diagnosis of EESES. A larger study with a different paradigm is required to confirm if all SES diagnosed in an overnight study will be captured in a standard daytime recording.

The SWI in the last sleep cycle was less than in daytime sleep and in the first sleep cycle of the overnight study. Interestingly the SWD was highest in the first sleep cycle of the overnight study

Table 3
Repeated measures Analysis of Variance (ANOVA) Post Hoc analysis (pairwise, with a Bonferonni adjustment) and p-values comparing SWI calculated from EEGs recorded at different times (standard and overnight) and different states (awake and sleep). Statistically significant comparisons in bold.

	SWI awake standard	SWI sleep standard	SWI awake overnight	SWI sleep overnight first cycle	SWI sleep overnight last cycle
SWI awake standard		**0.000**	1.000	**0.000**	**0.01**
SWI sleep standard	**0.000**		**0.000**	1.000	**0.042**
SWI awake overnight	1.000	**0.000**		**0.000**	**0.023**
SWI sleep overnight first cycle	**0.000**	1.000	**0.000**		**0.026**
SWI sleep overnight last cycle	**0.01**	**0.042**	**0.023**	**0.026**	

Table 4
Repeated measures ANOVA Post Hoc analysis (pairwise, with a Bonferonni adjustment) and p-values comparing SWD calculated from EEGs recorded at different times (standard and overnight) and different states (awake and sleep). Statistically significant comparisons in bold.

	SWD awake standard	SWD asleep standard	SWD awake overnight	SWD asleep overnight first cycle	SWD asleep overnight last cycle
SWD awake standard		**0.013**	1.000	**0.001**	**0.023**
SWD asleep standard	**0.013**		**0.027**	**0.042**	1.000
SWD awake overnight	1.000	**0.027**		**0.002**	**0.035**
SWD asleep overnight first cycle	**0.001**	**0.042**	**0.002**		**0.046**
SWD asleep overnight last cycle	**0.023**	1.000	**0.035**	**0.046**	

(compared to both daytime sleep and last sleep cycle). The clinical significance of these findings is unclear, at present [2,21,31,43–45].

There are several limitations to this study. We chose 5-minute epochs to calculate SWI and SWD as a practical approach, falling within the wide spectrum of EEG parametrics and criteria used to diagnose SWI, SWD and SES [2,3,10–24]. The number of EEGs reported as suggestive of SES, is smaller than expected, considering the number of EEGs undertaken during that period. It is possible that neurologists used the clinical information on the EEG request and did not report SES, if the clinical profile was typical of a benign or self-limiting epilepsy. In addition, of 39 EEG reports of SES only 10 had overnight studies. Overnight sleep recordings were not undertaken on twenty-nine children with SES, as the treating clinician did not initiate a referral for an overnight study, presumably based on the absence of features suggestive of an epileptic encephalopathy as they were not treated as EESES. There was a time lag between the daytime study and overnight EEG study. This was due to time for clinical review after standard EEG, waitlists for overnight V-EEG monitoring.

The relationships between SWI, SWD, duration of SES and cognitive profile, as well as neurodevelopmental outcome is not always tight [2,3,7,8,10,13,14,16,26,31,35,40,43]. However, it is essential to make an early diagnosis of an encephalopathy associated with SES. This will facilitate targeted therapeutic interventions. Repeated EEG studies are often necessary to evaluate efficacy of interventions and progress. Our audit suggests that SES on a standard daytime EEG, with sleep, may be specific and sufficient in making a diagnosis of SES. Daytime recordings with sleep would be easier to undertake, less costly, and more widely available. Larger studies are required prior to definitive conclusions regarding the validity and reliability of sleep in a standard daytime EEG, compared to an overnight study, in the diagnosis of SES.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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