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WAVELET MAPPING OF SLEEP SPINDLES IN YOUNG PATIENTS WITH EPILEPSY

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Using the wavelet mapping of sleep spindles we investigated influence of focal epilepsy on spindle generation. We found that the maximum of sleep spindle intensity is usually localized away from the epileptic focus. We discuss the possibility of the application of wavelet mapping for localization of epileptic foci prior to epileptic neurosurgery.

Key words: *sleep spindles, focal epilepsy, wavelets*

INTRODUCTION

The sleep spindle, along with K-complex, is a defining property of light stage 2 sleep and one of a handful of transient electroencephalograhic (EEG) events unique to sleep (1). Spindles were identified as early as in 1932, but only recently the intricate neurophysiological mechanism of spindle generation was unraveled. Surprisingly enough, physiological significance of spindles remains to be elucidated. The recently formulated hypothesis that spindles are instrumental in sleep protection and processing of external sensory information during sleep has rekindled this research field (2).

Typical spindles are identified relatively easily by visual inspection of overnight EEG. However, identification may be hindered by superimposed background activity. Regardless of any technical difficulties the manual detection of as many as

1000 spindles is a very tedious and time consuming task. Consequently, considerable effort has been devoted to automation of spindle detection (3-6).

Agarwal and Gotman (1) while reviewing digital processing in polysomnography noted that "...of the many methods available, either as commercial products or from the literature, none have gained much popularity in clinical practice. Much of the failure is not the result of the limitation of the computing resources or the existing signal processing theory, but largely the translation of ambiguous standards to mathematical models". This remark succinctly reflects caveats of EEG analysis. In this work we use a novel wavelet mapping of sleep spindles to investigate influence of epileptic spikes on spindle generation. In particular we study the topography of sleep spindle intensity in children with focal epilepsy.

MATERIAL AND METHODS

The study comprised children who underwent routine epilepsy diagnostics at the Department of Child Neurology of the Marciniak Regional Medical Center in Wrocław, Poland. Nineteen channel digital monitoring of sleep EEG was performed according to the international 10-20 standard. Thirty minute recordings (sampled at 240 Hz) were processed by automatic spindle detection software. The software's output was verified by visual inspection. While the study involved 34 patients, the data analysis was confined only to 23 patients with more than 20 detected spindles (10 males and 13 females; aged 2-7 years, mean age 4.4 years). The maximum number of spindles was 147. The spindle detection was performed with a novel wavelet based software.

The wavelet transform is an integral transform that employs basis functions, known as wavelet, localized both in time and frequency (7). The wavelet basis can be constructed from a single function called the *mother function*. The description of numerical implementation may be found in a paper by Latka et al (8). The choice of *mother function* ultimately determines the outcome of wavelet analysis. The diversity of available wavelets allows for the selection of those which capture the salient features of an analyzed signal.

De Gennaro and Ferrara (2) give the following working definition of spindle: "It is commonly known as a group of rhythmic waves characterized by a progressively increasing, then gradually decreasing amplitude, and it may be present in low voltage background EEG, superimposed to delta activity, or temporally locked to a vertex sharp wave and to a K complex". These transient patterns can last from 0.5 to 3.0 s with Fourier frequency in the 12 to16 Hz range.

In *Fig.1a* we display an example of spindle extracted from the EEG recording of a child. *Fig.1b* shows the real part of a complex Morlet wavelet. It is apparent that the complex Morlet wavelet mimics wave-packet behavior of sleep spindle and provides a mathematical equivalent of the phenomenological description. In *Fig. 2a* we present the spindle from *Fig. 1b*, but this time embedded in a longer segment of background fluctuations of comparable amplitude. The distinct maximum in the density map of the modulus of the wavelet coefficients plotted as a function of time and wavelet scale (*cf. Fig. 2b*) unambiguously reflects the presence of the spindle.

To characterize the topography of sleep spindle intensity for each of 19 EEG channels we calculated the normalized wavelet power

$w(a_{max_x} t_{max})=W(a_{max_x} t_{max})/\delta^2$

for scale a_{max} and time t_{max} , which correspond to the maximum of the corresponding wavelet coefficient map of sleep spindle (*cf. Fig. 2b*). In the above equation, wavelet power $W(a_{max_x} t_{max})$ is normalized by the variance δ^2 of the EEG signal. We search for spindles in 5 s segments of EEG. Cubic spline interpolation was used to generate the continuous density plot from the values of the normalized wavelet power for each of 19 electrodes.

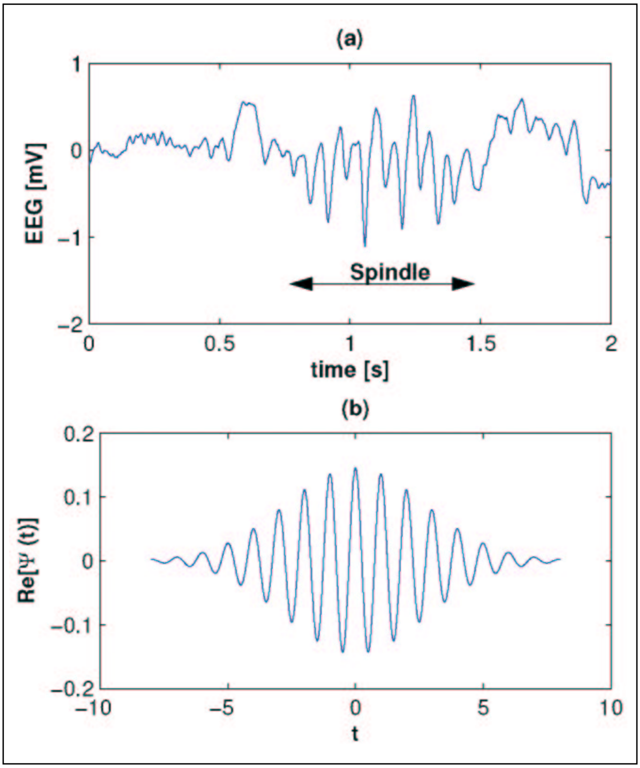

Fig. 1. (a) Arrow marks the sleep spindle. (b) The real part of the complex Morlet wavelet calculated for f_b=15 and f_c=1.

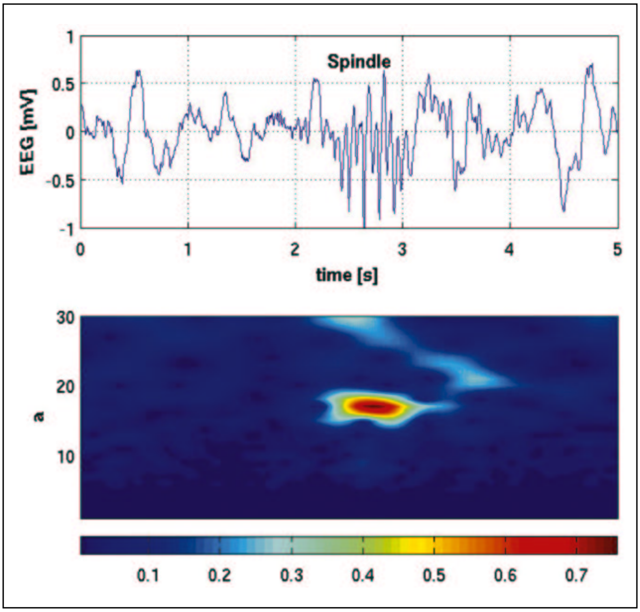

Fig. 2. Top panel: sleep spindle embedded in the background EEG fluctuations. Bottom panel: density map of the modulus of the complex Morlet wavelet coefficients calculated as a function of time (horizontal axis) and wavelet scale (vertical axis) for the EEG signal shown above.

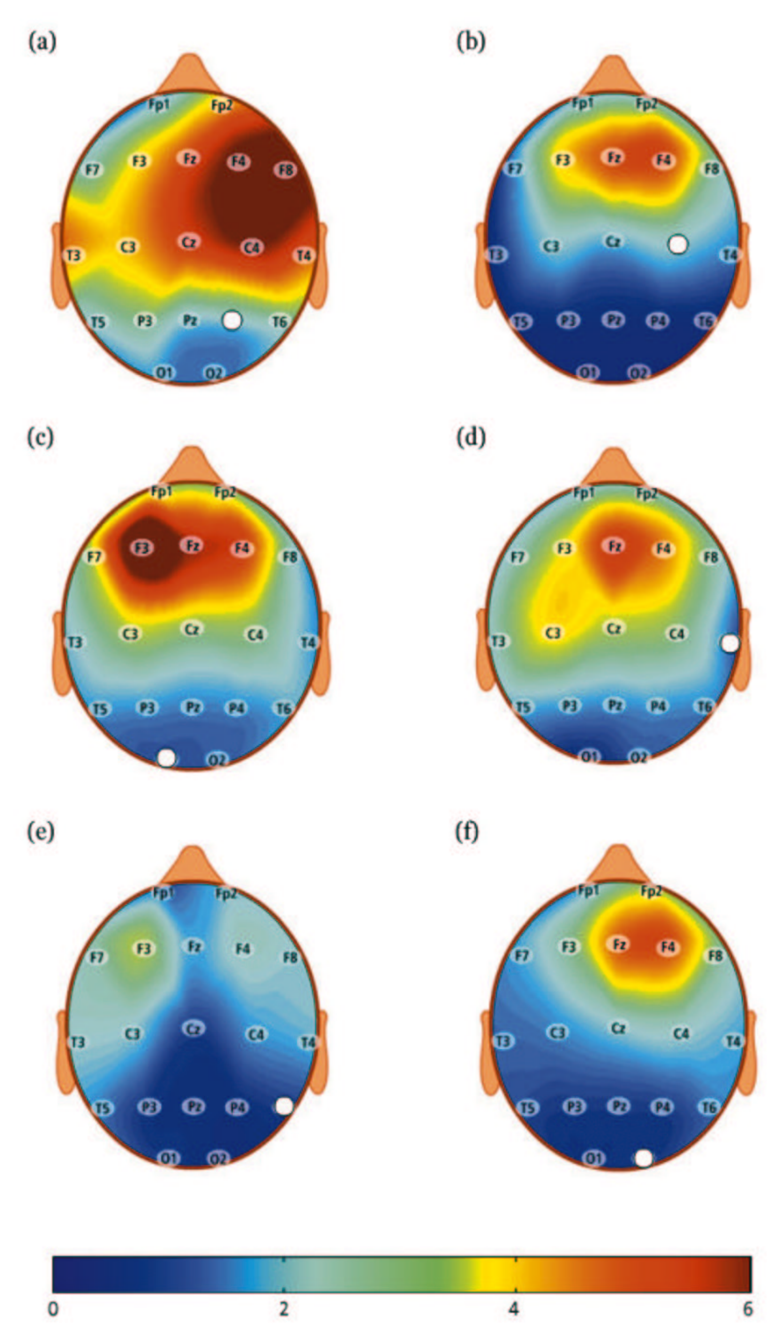

Fig. 3. The wavelet mapping of sleep spindles for six children with focal epilepsy. The normalized wavelet power was averaged over all spindles detected during monitoring. White circles mark the epileptic foci.

RESULTS

Fig. 3 shows the examples of sleep spindle wavelet mapping for patients with focal epilepsy. For each child, the distribution of the normalized wavelet power was *averaged* over all spindles detected during the monitoring. One can see that not only the displayed distribution is not uniform but also that its maximum is positioned away from the epileptic focus. The mean maximum normalized wavelet power for all 23 patients equaled 5.49 ±3.28 and was significantly larger that the mean power calculated at the epileptic foci 2.16 ±0.98 ($P=5x10^{-4}$).

DISCUSSION

NREM sleep increases the interictal epileptic discharges (IED) in the majority of children affected by partial epilepsy (both symptomatic or cryptogenetic). It has been argued that the neural mechanisms involved in the generation of sleep spindles facilitate the IED production in childhood partial epilepsies at least in those strongly activated by sleep (9). However, the previous studies relied exclusively on the traditional power spectral methods. The wavelet mapping of sleep spindles provides a unique opportunity for studying the influence of epileptic foci on the topography of sleep spindle intensity. Unlike spectral methods, wavelet transforms - backbone of the presented mapping are applicable to non-stationary and nonlinear signals such as EEG. Further studies should show to what extent the wavelet mapping may assist in localization of epileptic foci prior to epileptic neurosurgery.

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