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EVOLUTION OF ANTERIOR AND POSTERIOR SLEEP SPINDLES IN RATS

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INTRODUCTION

Sleep spindles are the EEG signature of non-REM sleep. They arise spontaneously from a desynchronized background EEG as sinusoidal oscillations¹. No studies have been reported on the modification of electrical brain activity that occurs just before the onset of sleep spindles. Some EEG studies use short pieces of EEG (a few seconds before spindle oscillations) as a control for sleep spindles², however, these periods might contain some precursory oscillatory activity. One could expect a rapid rearrangement of EEG pattern in the transition from 'pre-spindle' to spindle activity that requires short-term amplitude modulation and augmentation of 7-14 Hz frequencies. Here we explore quantitative changes of EEG parameters, i.e. EEG power in the most characteristic frequency (bands, delta, theta, alpha, beta) 1 sec prior to and during sleep spindles.

Spindle oscillations differ in frequency, in time-evolution, in their reaction to drugs and in circadian phase. Two types of spindle oscillations with distinctive topography and spectral features, anterior and posterior sleep spindles, have been described in humans^{3,4} and rats^{5,6,7}. It is hypothesized that different processes may be involved in the development of sleep spindles in anterior and posterior cortical areas, so that the genesis of each spindle type would correspond to specific shifts of EEG power over various frequency bands. Here we describe the dynamics of EEG power in the transition from pre-spindle into spindle activity for the two local types of sleep spindles.

METHODS

Nine male 11-12 month old WAG/Rij rats (body weight 320-360 g) were chronically implanted with two epidural electrodes (above the frontal [AP 2; L 2.5] and occipital [AP -7; L 6] areas). Experiments were conducted in accordance with the regulation of animal experimentation in the Netherlands and were approved by the Ethical Committee on Animal Experimentation of the Radboud University Nijmegen. The EEG was recorded in freely moving rats during 5-7 hours in the dark period of the light-dark cycle. EEG signals were band-pass filtered between 1-500 Hz, digitized with 1024 samples/second/channel and stored on hard disk (Data Acquisition Hardware and Software, DATAQ Instruments, Inc., Akron, OH).

Sleep spindles were identified during non-REM sleep using formal criteria^{1,3} and divided in anterior and posterior types⁵⁻⁷. 30-70 representatives of each spindle type were collected in each animal. Using Brain Vision Analyser (© BrainProducts GmbH) Hanning windowed Fast Fourier transformation was performed on 700 ms epochs (this roughly corresponds to mean duration of sleep spindles) with either anterior or posterior sleep spindles. Two successive 700-ms EEG epochs preceding spindle activity (pre-spindle EEG) were recorded

before the onset of selected spindles (40 per animal). Individual power spectra were averaged per channel, per spindle type and per animal. Quantitative analysis of EEG included computation of EEG power in total and in selected frequency bands – delta (1-4 Hz), theta (7-9 Hz), alpha (9.25-12 Hz) and beta (12.25-16 Hz). Paired t-tests were used for the statistical analysis.

RESULTS AND DISCUSSION

The EEG power spectrum of anterior sleep spindles showed a broad high power in 8-15 Hz (maximum 11 Hz) only in the frontal cortex (Fig. 1). Similarly, posterior sleep spindles were characterized by high power in 8-16 Hz band (maximum around 10 Hz) only in the occipital EEG. This suggests that anterior and posterior sleep spindles are area-specific oscillations (Fig. 1B). Anterior sleep spindles on the frontal EEG are regarded as ‘area-specific’ oscillations, while simultaneous activity on occipital EEG was called ‘area-non-specific’. And vice versa in case of posterior sleep spindles.

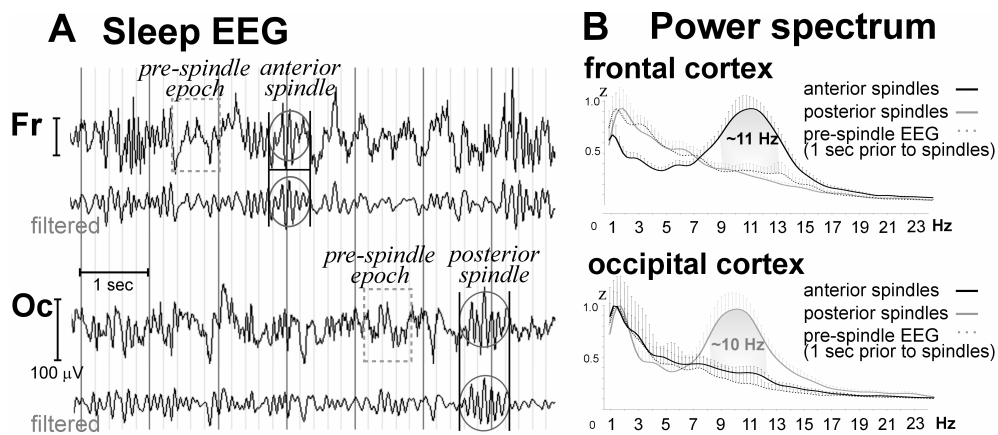


Figure 1. A. Raw and filtered sleep EEG with representative examples of anterior and posterior sleep spindles. B. Normalized power spectrum of sleep spindles and pre-spindle EEG (mean \pm s.e.m., n=9 rats).

The EEG power, which was measured in the specific cortical areas, was much higher during anterior sleep spindles as compared to the corresponding values of posterior sleep spindles for all characteristic frequency bands (asterisked in Table 1).

During non-spindle periods, total power in the frontal cortex was significantly higher than in the occipital cortex (marked with ‘s’ in Table 1). Compared to pre-spindle EEG, total power of the frontal EEG during anterior sleep spindles showed a strong tendency to be increased; the increase of power was significant in theta, alpha and beta diapasons, while delta activity was significantly decreased. Posterior spindles in the occipital cortex were characterized by the same total power for pre-spindle and spindle periods, while the amplitude of alpha and beta bands increased significantly during the genesis of occipital posterior spindles with a decrease in the delta band and no change in theta.

Table 1. EEG power of investigated transients (n=9 rats).

| type of activity frequency band | frontal EEG □ V ² , mean ± s.d | | occipital EEG □ V ² , mean ± s.d | |
|------------------------------------|--|-----------------------|--|-------------------------|
| | pre-spindle | anterior spindles | pre-spindle | posterior spindles |
| delta [1-4 Hz] | 203 ± 65 | 133 ± 53 ^S | 98 ± 52 | 48 ± 35 ^S * |
| theta [7-9 Hz] | 51 ± 20 | 83 ± 29 ^S | 19 ± 8 | 30 ± 22 ^{NS} * |
| alpha [9.25-12 Hz] | 74 ± 37 | 221 ± 83 ^S | 21 ± 10 | 56 ± 26 ^S * |
| beta [12.25-16 Hz] | 70 ± 61 | 151 ± 57 ^S | 13 ± 5 | 25 ± 14 ^S * |
| Total power | 593 ± 212 | 795 ± 189 | 211 ± 104 | 220 ± 101 * |

paired t-test, p<0.05: * - significant differences between anterior and posterior sleep spindles, ^S - significant and ^{NS} differences between sleep spindles and non-spindle EEG.

The constant amplitude difference between amplitude of frontal and occipital EEG (Table 1) is likely the result of local functional and structural features of these cortical areas.

We compared area-specific dynamics of EEG power during anterior and posterior sleep spindles after getting rid of constant amplitude difference between frontal and occipital EEG. For that purpose EEG power of delta, theta, alpha and beta was divided by the total EEG power (relative EEG power, Figure 2).

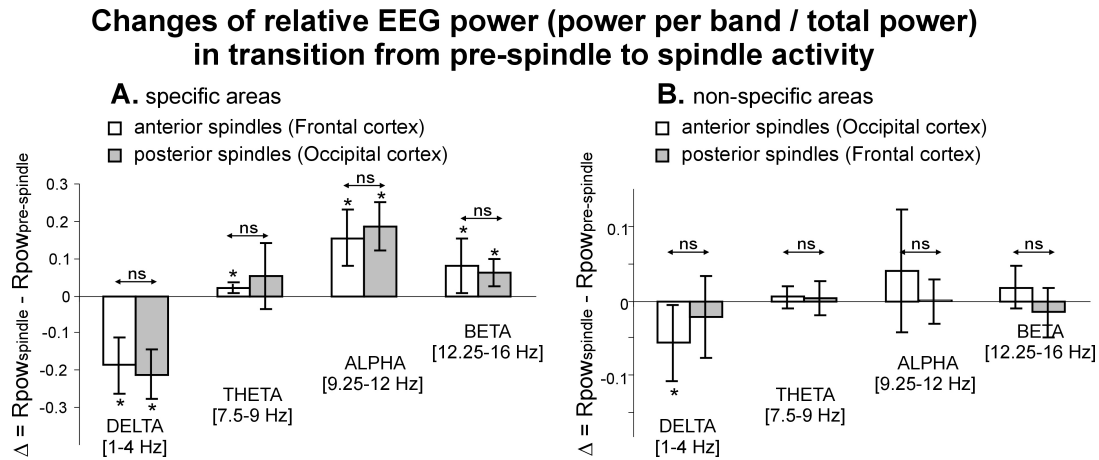


Figure 2. Distribution of spectral power in some frequency bands as a proportion to total power (relative EEG power). Anterior and posterior sleep spindles have the same relative power in the area-specific sites (columns filled up with uniform color - white and gray) and also in area-nonspecific sites (columns with patterns).
 * - significant difference, t-test for related samples, ns - non-significant difference

CONCLUSIONS

Our study describes local ('area-specific') sleep spindles, which are expressed in the frontal (anterior spindles) or in the occipital (posterior spindles) cortical areas. The genesis of the anterior and posterior sleep spindles is associated with a decrease in delta and an increase in alpha and beta. A tendency towards an increase was also found in the theta band. This allows us to suggest that the development of both types of spindle oscillations is the same for multiple cortical areas.

ACKNOWLEDGEMENTS

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