Estimating the relationship between sleep EEG spectral peaks and general intelligence from the whitened Fourier spectrum

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Introduction

Although it was shown that sleep EEG spindle amplitude, density and intensity correlate positively with intelligence (e.g. Bódizs et al., 2005), and that this relationship is primarily seen in women (e.g. Ujma et al., 2014), yet, several potetntial biases could emerge from the authors' "freedom" in defining sleep spindles. Here we propose a more straightforward method to analyse the Fourier spectrum and the intelligence-sleep spindle relationship. This method was inspired by studies aiming to whiten the spectral power in the sleep spindle frequency (Gottselig et al., 2002; Geiger et al., 2011).

We suggest that the Fourier spectrum can be reliably described by an approximation of the parameters of the following function:

$P(f) = Cf^{\alpha}P_{Peak}(f)$

P is power as a function of frequency

C is the constant (amplitude multiplier) expressing the overall, frequency-independent EEG amplitude

α is the spectral exponent indicating the decay rate of power as a function of frequency

$P_{Peak}(f)$ is the peak power at frequency f

Methods

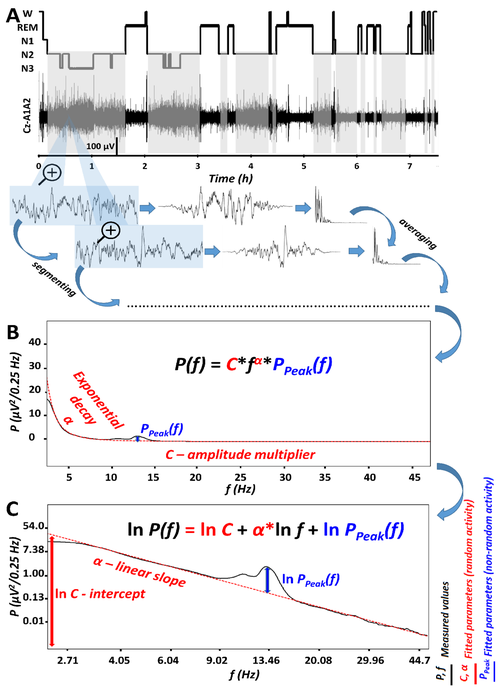
Subjects and tests:

- Previously recorded database
- 149 healthy adult
- Age range: 17-60, average:29.08 years
- Intelligence tests: Raven Advanced Progressive Matrices and Culture Fair Test
- IQ range: 88.66-155.5, average IQ:116.99

EEG recordings:

- recorded on the second night
- standard 10-20 EEG system: Fp1, Fp2, F3, F4, Fz, F7, F8, C3, C4, Cz, P3, P4, T3, T4, T5, T6, O1, O2 and left and right mastoids
- standard AASM criteria on a 20-sec basis by an expert.
- Artefactual segments were marked on a 4-sec basis and excluded from further analyses.

Fig.1. The parametrization of non-rapid eye movement (NREM) sleep electroencephalogram (EEG) spectra.



A. Hypnogram and steps of the spectral EEG analyses as exemplified in a representative record of a young male volunteer. Grey shaded areas represent NREM sleep, which is analyzed in the present report. Blue-shaded EEG segments are magnified 4 seconds long epochs, with 2 seconds overlap and modified with a Hanning window before power spectral analysis via mixed-radix Fast Fourier Transformation (FFT).

B. Average spectral power (P) is characterized by a frequency (f)-dependent exponential decay (α), as well as by an overall, frequency-independent amplitude multiplier (C) and a peak power multiplier at critical frequencies [$P_{Peak}(f)$].

C. The natural logarithm of spectral power (P) is a linear function of the natural logarithm of frequency (f), characterized by a linear slope α (which is equal with α in panel B) and an intercept (the latter being the natural logarithm of the amplitude multiplier, C in panel B). In addition, this linear function must be summed with the natural logarithm of the peak power multiplier [$P_{Peak}(f)$, equal to the same frequency-dependent function in panel B]. Please note that "no peak regions" can be compressed in series of all ones, resulting in reduced number of variables as compared to the bins in the original spectra.

Estimation of the spectral peak amplitudes:

Spectral power at peak frequencies were estimated by spline interpolation of the double logarithmic plots of the power spectra. The spectral peak amplitude was then whitened by subtracting the estimated power based on the fitted linear function from the colored peak power:

$$\ln P_{Peak}(f) = \ln P(f) - (\ln C + \alpha \ln f)$$

In order to avoid negative amplitudes due to the logarithmic scale, the power values were shifted for being all positive before this subtraction by adding a constant

Results

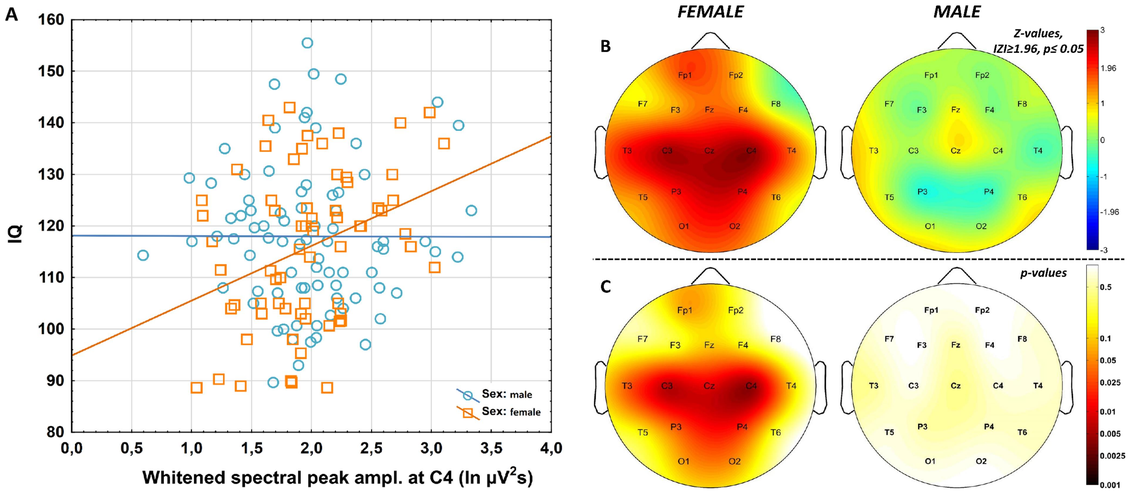


Fig 3. Correlations between NREM sleep EEG spindle frequency whitened spectral peak amplitudes and IQ in females and males.

Conclusion

Pearson correlations revealed significant associations of whitened maximal spectral peak amplitudes pertaining to NREM sleep EEG spindle activity with IQ in women but not in men. This result is in line with earlier findings providing convergent reliability for our approach of parametrizing the NREM sleep EEG spectra. In addition, our method provides a reliable tool to overcome the issues raised by the largely inconsistent time-domain sleep spindle features by using the peak attributes of the NREM sleep EEG in humans.

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