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Interhemispheric differences of sleep EEG complexity

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Abstract. Complexity of EEG (Ω), a global measure reflecting degree of spatial synchronization, was computed for whole night recordings of sleep EEG of 10 healthy volunteers, 9 males and 1 female (age 21-53) and 6 depressive patients, 5 males and 1 female (age 23-64). Sleep was scored visually in 20 s epochs, Ω was calculated in 2.5 s segments and the median from 8 segments (20 s) was calculated. Ω was calculated for the whole field of 21 electrodes and for the left and right hemisphere separately (2 x 8 electrodes). Measure of global power (Σ) and generalized frequency (Φ) were also computed for the same data. In healthy subjects the complexity was higher over the right hemisphere during waking, and the difference shifted to higher complexity over the left hemisphere in slow wave sleep (F=5.15, df_1=4, df_2=6856, P<0.0005). The opposite trend was found in depressives (F=10.51, df_1=4, df_2=3960, P<0.0001).

Short communication

Key words: sleep, interhemispheric differences, EEG complexity, depression

Amplitude, frequency, and degree of synchronization constitute three basic parameters of background EEG activity. While the first two parameters are easy to quantify, synchronization only recently has become a subject of computerized EEG analysis. The opposite of synchronization is complexity. A few years ago, analysis of complexity of EEG was dominated by growing interest in the theory of deterministic chaos (for review, see Pritchard and Duke 1992). The most frequent measure of complexity was correlation exponent or correlation dimension (D_2). D_2 was shown to be higher in waking and to decrease to its lowest values in slow wave sleep (Achermann et al. 1994a,b,c, Ziller et al. 1995). The so-called global correlation dimension was proposed by Dvorak (1990) as a generalization of D_2 to multichannel EEG, and used in studies of EEG activity (Wackermann et al. 1993, Matousek et al. 1995).

Recently, yet another measure of complexity called Ω (Wackermann 1996) was proposed which was explicitly designed for global EEG analysis. For a multichannel signal from K electrodes, this measure is defined by the following formula:

$$\Omega = \exp\left\{ -\sum_{i=1}^{K} \lambda'_i \log \lambda'_i \right\}$$

where λ'_i (i=1,...,K) are normalized eigenvalues of the K x K covariance matrix of the signal. Thus, Ω-complexity is not directly related to D_2 or to the chaos theory; rather, it is based on linear methodology. Because λ'_i represent relative contributions of different spatial principal components of the signal, the distribution of eigenvalues reflects the covariance structure of spatially distant activities. Lower values of Ω correspond to a higher degree of synchronization and *vice versa*. Ω is a member of a wide family of "entropy measures" which apparently will play an increasing role in assessment of EEG dynamics, e.g., entropy of amplitude distribution (Fell et al. 1996) or "spectral entropy" (Inouye et al. 1991). Obviously, log Ω could be called "entropy" of the spectrum of eigenvalues of the covariance matrix.

In addition to Ω, the integral global power (Σ) and generalized frequency (Φ) were also computed. These two measures assess the properties of EEG in

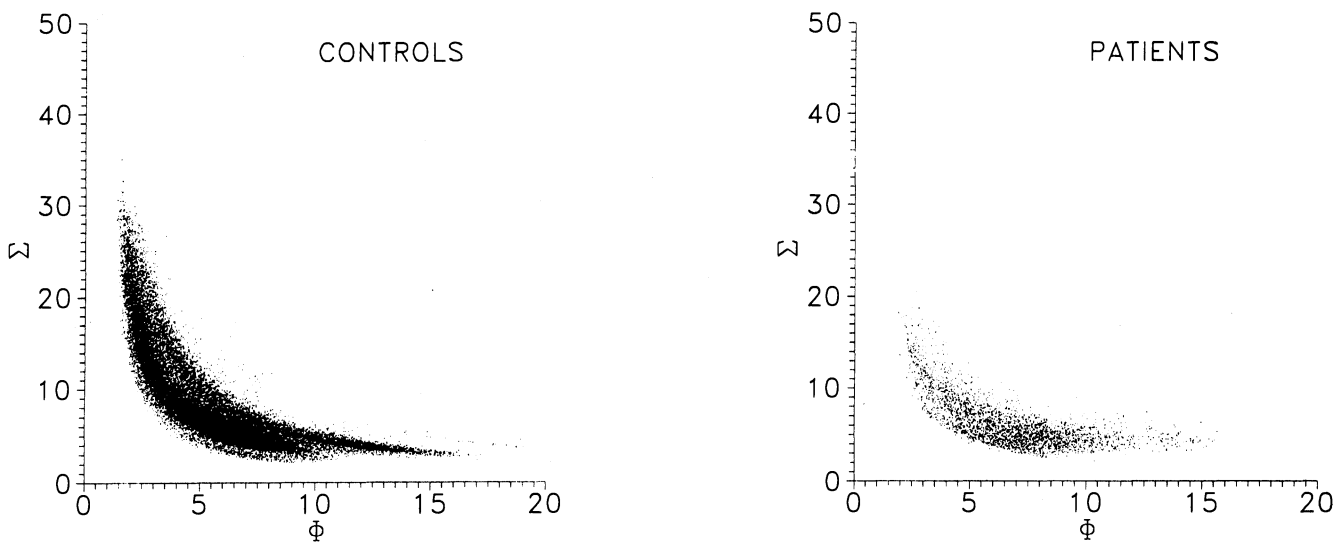

Fig. 1. Two-dimensional distributions of integral global power (Σ) vs. generalized frequency (Φ) in the group of controls (left) and patients (right). Each point represents one 2.5 s segment of 21-channel data.

traditional dimensions; they are multichannel analogs of Hjorth's descriptors of activity and mobility, respectively. Summary plots of Σ *vs.* Φ provide a comprehensive information on spectral characteristics of the data (Fig. 1).

We used Ω as a simple measure of global EEG complexity or desynchronization. In whole night EEG records Ω decreased systematically from waking to slow wave sleep, and increased systematically in consecutive sleep cycles (Szelenberger et al. 1996).

The aim of the present study was to compare Ω from left and right hemispheres during whole night sleep in healthy subjects and depressive patients.

Ten healthy subjects, 9 males and 1 female (age 21-53) and six depressive patients, 5 males and 1 female (age 23-64) participated in the study. Three subjects had a diagnosis of major depressive disorder, two had dysthymic disorder, and one had a personality disorder, according to DSM-IV (American Psychiatric Association 1994). The range of Hamilton Depression Rating score was 18-32. Five patients were on tricyclic antidepressive drugs. All subjects were right-handed. EEG was recorded from 21 standard derivations against average reference. In addition, 6 standard polysomnographic channels were used, so the total number of polysomnographic channels was 27. Analog data were filtered to the band of 0.53 Hz - 35 Hz (3 dB/octave) and an additional anti-aliasing low-pass filter (12 dB/octave) was used. The sampling frequency was 102.4 Hz, and the digital conversion resolution was 12 bit. Data were collected on the hard disk and archived on CD-ROMs. Sleep stages were scored on a computer screen in 20 s epochs (pages) from standard polysomnographic derivations. On a second run artifacts were visually inspected in all channels in 2.5 s segments (8 segments per page). The most frequent case was eye movement artifacts. Ω was computed in 2.5 s intervals for the entire array of electrodes and separately for each hemisphere (Fp1, F3, C3, P3, O1, F7, T3, T5 and Fp2, F4, C4, P4, O2, F8, T4, T6). Medians of Ω from 8 successive segments were computed to comply with the 20 s page, used in visual stage scoring. SPSS for OS/2 was used for statistical analysis (Norusis 1990). ANOVA was used for testing differences in Ω between sleep stages. Student *t*-test for paired data was used to test interhemispheric differences within sleep stages; Student *t*-test for independent data was used for comparisons of average Ω values between healthy and depressive subjects. In healthy subjects and patients entire array Ω decreased significantly from waking to slow wave sleep (F=609.14, df_1=4, df_2=6856, P<0.0001 for controls, F=332.43, df_1=4, df_2=3960, P<0.0001 for depressives).

Left-right differences of Ω significantly changed in both groups from waking to slow wave sleep (for healthy subjects F=5.15, df_1=4, df_2=6856, P<0.0005, for patients F=10.51, df_1=4, df_2=3960, P<0.0001) but the course of left-right differences in depressives showed almost a mirror image of those in healthy subjects (Fig. 2).

In healthy subjects the right side Ω was higher than the left during waking; in the depressives left side Ω was higher. During slow wave sleep, Ω was higher in the left hemisphere in healthy subjects and in the right hemisphere in depressive patients.

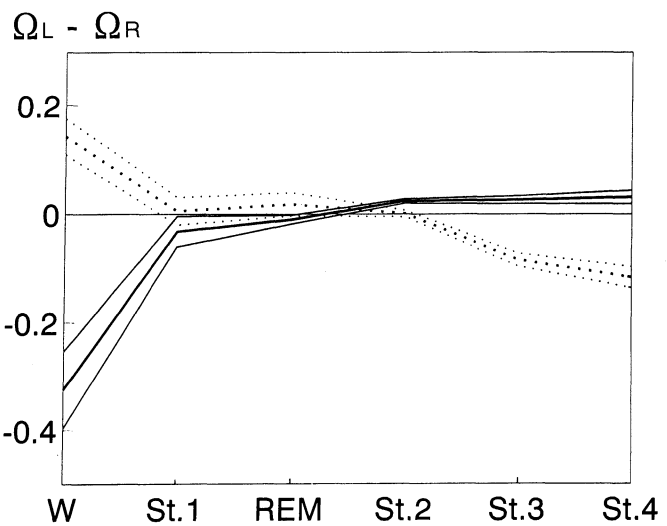

Fig. 2. Differences between left and right side Ω in healthy subjects and depressive patients in waking and stages of sleep. Abscissa, sleep stages; ordinate, average difference between left and right side Ω of all pages scored as a given stage and standard error. Solid line, healthy subjects; dotted line, depressive patients.

Generally, the depressives show quite the opposite trend of interhemispheric differences than the healthy subjects. Differences between the two groups were significant for waking (t=6.72, P<0.0005), stage 2 (t=3.27, P=0.001), stage 3 (t=7.94, P<0.0005) and stage 4 (t=5.93, P<0.0005).

Our data show that in healthy subjects during waking electric activity of the right hemisphere is less synchronized in comparison to the left. The opposite is true in depression. In slow wave sleep of healthy subjects the left hemisphere is less synchronized, and again the opposite is true in depressives.

Right hemisphere abnormalities in depression are well known from many fields of research (Matousek et al. 1981, Tucker et al. 1981, Bruder et al. 1992, Armitage 1995). Matousek et al. (1981) found lower EEG amplitudes over the left hemisphere than on the right in healthy subjects, but the opposite trend was found in patients with endogenous depression. This trend was resistant to medication and correlated with degree of anxiety. Armitage (1995) considered elevated fast frequency in depressives during sleep, especially in the right hemisphere, as a most consistent finding. While these findings concern mainly the differences or ratios of amplitudes, our results indicate that variables of higher order, reflecting degree of coordination or looseness of various functional centers, may also play a role in differentiating normal function from pathology.

The standard methods of chaos dynamics (D_2) need reevaluation, as shown recently by Theiler and Rapp (1996). In their opinion, the future of studies of EEG dynamics is in development of alternative measures and multichannel approach (ibid., p.220). In contrast to the mainstream of studies in EEG chaos dynamics which focused on single-channel measurements, the global strategy used in our study aims at assessment of quantitative characteristics of large brain areas, or even the brain as a whole. This approach involves a drastic data reduction and provides a straightforward method for evaluation of intrahemispheric dynamics as well as for interhemispheric comparisons.

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