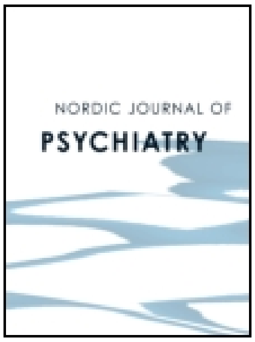

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Multifractal analysis as an aid in the diagnostics of mental disorders

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The digitalization of EEGs (electroencephalogram) has showed new possibilities for analyzing electrical activity of brain. This has offered new methods, e.g. multifractal analysis of $1/f^{\beta}$ EEG rhythms fluctuations. It is one of highly mathematical methods feasible in routine practice now that modern personal computers (PCs) have reached sufficient computing power. In this study, we applied the multifractal analysis of $1/f^{\beta}$ EEG rhythms fluctuations in 33 patients suffering from schizophrenia and schizophrenia-like syndromes, and we had 23 healthy controls. Our results indicated that the patients suffering from schizophrenia have statistically different values compared with the controls. This method is rather easy and quick to perform when using a standard PC. It may have the potential to become an important tool in the diagnostics and analysis of the patients with schizophrenia and schizophreniformic psychoses. It can help to understand the quasi-chaotic processes in neural processing and narrow the gap between the phenomenological psychiatry and bio-psychiatry.

• *Alpha rhythm, EEG, Multifractal dimensions, Schizophrenia, Theta rhythm.*

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It is known that the stable functional state of the brain arises from the "chaotic" processes in the brain tissue. These processes appear to have periodicity but also some stochastic variation.

Biological signals often demonstrate fractal, statistically self-similar temporal structure. The dependence of spectral density of power of such processes on frequency has the form of $1/f^{\beta}$, where f if frequency and β is a numerical parameter. Fractal fluctuations with a spectrum in the form of $1/f^{\beta}$ are characteristic attributes of the EEG signals registered in various areas of the cortex (1–3). $1/f^{\beta}$ fluctuations have been found also in a number of subcortical structures, for example, in hippocampus, reticular formation (2). Some parameters of basic EEG rhythms, such as the period (4) and the alpha rhythm amplitude (5), can fluctuate according to the law $1/f^{\beta}$. It is assumed that there exists a level of chaos and fluctuations optimal for electric activity of a healthy brain, and in the case of the development of pathology, it can change in this or that direction (3, 6).

In this study, we try to show that the multifractal analysis of $1/f^{\beta}$ EEG rhythms fluctuations may be a very effective and promising method for clinical evaluation of schizophrenia and schizophrenic disorders.

Material and Methods

Our normal material consisted of 23 healthy subjects (12 male and 11 female, mean age 32 ± 3.3 years). Our pathological material consisted of 11 patients suffering paranoidic schizophrenia F20.0 (seven male and four female, mean age 28 ± 4.8 years), 10 patients with schizoaffective disorder F25 (six male and four female, mean age 26 ± 3.5 years) and 12 patients with schizotypal disorder F21 (six male and six female, mean age 31 ± 4.3 years).

All, except the controls, had been inpatients at a psychiatric ward of Bekhterev Institute, and there an experienced psychiatrist had clinically diagnosed them according to the clinical descriptions and the diagnostic guidelines in the Russian version of ICD-10 manual. In the Russian Federation, the ICD-10 has been in official use since 1999, but since 1996 it was used also at the clinic of this study in the classification of mental and behavioral disorders. All the diagnoses had been made prior to any of multifractal analyses.

The EEG recording was performed using the digital encephalograph Telepath-104D (St Petersburg, Russia) based on an IBM-compatible personal computer. Electrodes were placed according to the international 10–20

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system. The multifractal analysis was performed in all the subjects in four EEG channels: the electrode sites F3, F4, O1 and O2. The sample rate was 250 Hz and the total epoch time for analysis 180 s.

Data processing was carried out using software package MATLAB 6.0. on the basis of which the multifractal analysis was made. From the general EEG signal allocated, the alpha and theta rhythms were singled out by the method of filtration. Peak values of the singled-out EEG rhythm were squared and the envelope of the power (squared amplitude) of the singled-out rhythm was calculated. The spectrum of the envelope power was calculated according to the Fast Fourier transformation (FFT) method.

Furthermore, fractal analysis proper was made. The graph of dependence of the power S spectral density from frequency was plotted in double logarithmic coordinates. The obtained spectrum of the envelope power in different frequency ranges assumed the form $1/f^{\beta}$ and was described by the following ratio:

$$\log(S) \sim -\beta \cdot \log(f)$$

where f is the frequency, β is the fractal index (factor of the inclination).

The fractal analysis was made in two frequency ranges of fluctuations of the rhythms' power with the spectrum in the form of $1/f^{\beta}$: 0.1–1.5 Hz (low-frequency fluctuations), 1.5–4 Hz (mid-frequency fluctuations). In the chosen ranges of frequencies, the approximation of fluctuations of the spectral density of power by the linear dependence according to the least squares method was performed. The fractal index β was determined according to the angle of inclination of the power spectrum to the abscissa (y-axis).

The basic numerical characteristics of the results of the fractal EEG analysis were $\beta 1$ and $\beta 2$ – fractal indexes of the low-frequency and mid-frequency fluctuations of the rhythm power, respectively.

Statistical processing of the results obtained was carried out in the standard package of statistical programs Excel 7.0. There the mean values of visual and fractal EEG characteristics and their standard deviations were calculated. The determination of the degree of reliability of distinctions of the mean indices was carried out using the Student's t-test.

Results

Table 1 shows the mean values and SDs in normal subjects and patients suffering from mental disorders. It can clearly be seen that the values of the patients with schizophrenia and corresponding disorders are clearly different when compared with those of normal cases.

The fractal indexes of alpha rhythm power fluctuations at the schizophrenic pathology compared with the indices of the healthy subjects have been registered:

- In the group with the paranoid schizophrenia, a decrease of $\beta 2$ mean values as well as a decrease of $\beta 1$ mean values in F4.
- In the group with the schizoaffective disorder, a decrease of $\beta 1$ mean values in F4, O2 and $\beta 2$ mean values in all the electrode sites.
- In the group with the schizotypal disorder, a decrease of $\beta 1$, $\beta 2$ mean values.

The fractal indexes of theta rhythm power fluctuations at the schizophrenia and corresponding disorders compared with the indices of the healthy subjects have been registered:

- In the group with the paranoid schizophrenia, an increase of $\beta 1$ mean values, mainly in the frontal sites (F3, F4) and $\beta 2$ mean values in F3, O2.
- In the group with the schizoaffective disorder, an increase of $\beta 1$ mean values in O1, O2, F3 and an increase in $\beta 2$ mean values.
- In the group with the schizotypal disorder, an increase of $\beta 1$ mean values in O1, O2, F3, $\beta 2$ mean values in F3, O2 and a decrease of $\beta 2$ mean values in F4, O1.

Discussion

In this study, we have presented one method for evaluation of EEG in patients suffering from schizophrenia or schizophreniform psychoses. We used multifractal analysis of $1/f^{\beta}$ alpha and theta rhythms fluctuations.

The presence of $1/f^{\beta}$ fluctuations has been pointed to in many studies, like Anderson & Mendell (3). Although the physiological role of these fluctuations has been poorly understood, it is known that they are closely related to the deep processes in the brain tissue and can reflect fine changes in its functional activity.

Our research has shown a change of $1/f^{\beta}$ fluctuations of alpha and a theta-rhythm power at the pathology of schizophrenia. On the basis of the received results, it is possible to speak about increase in instability, unpredictability, a randomness and complexity of alpha rhythm dynamics at the following psychopathological states: schizoaffective disorder, paranoid schizophrenia and schizotypal disorder. Dynamics of the theta rhythm in the schizoaffective disorders and the paranoid schizophrenia, on the contrary, is characterized by increase of stability, regularity and decrease of complexity concerning a normal EEG. Investigation demonstrated specific findings of the used criteria in schizotypal disorder. In case of this disorder, medium-frequency

Table 1. Fractal indexes of the alpha- and theta rhythm power fluctuations in the controls and patients with schizophrenic psychosis.

		Groups			
Fractal index	Derivations	Normal subjects	Paranoid schizophrenia	Schizoaffective disorder	Schizotypal disorder
Alpha rhythm					
β1[a]	F3	0.36[b]	0.36	0.36	0.27*
		0.05	0.05	0.08	0.06
	F4	0.49	0.37*	0.36*	0.32*
		0.06	0.09	0.12	0.03
	O1	0.40	0.41	0.40	0.28*
		0.12	0.06	0.08	0.14
	O2	0.44	0.40	0.34*	0.34*
		0.11	0.02	0.09	0.08
β2	F3	2.98	2.50*	2.73*	2.84
		0.09	0.11	0.13	0.22
	F4	3.04	2.53*	2.78*	2.76*
		0.12	0.15	0.12	0.18
	O1	3.76	2.83*	2.90*	2.76*
		0.12	0.19	0.20	0.23
	O2	3.87	2.71*	2.85*	2.79*
		0.16	0.20	0.20	0.23
Theta rhythm					
β1	F3	0.25	0.38*	0.26	0.31*
		0.04	0.07	0.07	0.07
	F4	0.30	0.39*	0.39*	0.29
		0.09	0.10	0.04	0.10
	O1	0.21	0.24	0.23	0.42*
		0.04	0.05	0.13	0.13
	O2	0.24	0.26	0.34*	0.36*
		0.03	0.06	0.15	0.05
β2	F3	2.66	2.82*	3.05*	2.88*
		0.10	0.13	0.16	0.15
	F4	2.74	2.73	2.93*	2.57*
		0.15	0.15	0.17	0.14
	O1	2.62	2.56	2.72	2.40*
		0.13	0.14	0.20	0.12
	O2	2.36	2.59*	2.62*	2.51*
		0.13	0.11	0.16	0.13

[a]β1 and β2 are fractal indexes of the low-frequency and medium-frequency fluctuations of the rhythm power, respectively.
[b]Mean value, with its standard deviation below.
*Degree of reliability of distinctions of the mean value of the groups with schizophrenic pathology and the group of normal subjects = $P < 0.05$.

fluctuations of theta rhythm power dynamics have atypical, opposite dynamics in some cortex areas. We suppose that the schizotypal disorder is a specific form of psychosis.

The group of mental disturbances classified by the ICD-10 as schizotypal disorder differs in their clinical manifestations and inner dynamics both from various forms of schizophrenia and "personality disorders" proper.

Schizotypal disorders differ from the personality group by having a deeper register of psychotic disturbances, stability of the clinical and an impediment to the social adaptation. A peculiarity characteristic of schizotypal psychology consists of pronounced linguistic polysemantics (including a so-called "plural logic"), the reflection of the phenomena of objective reality being in such a case formally not disturbed (7–13). Based on our analysis, we conclude that the schizotypal disorder is a specific form of psychosis. However, this issue needs further investigation.

Conclusion

In this study, we have tried to find some new way to analyze the EEG examination of both normal subjects and patients suffering from schizophrenia or schizoaffective or schizotypal disorder.

The multifractal analysis of our normal material when compared with that of our clinical material suffering from psychotic disorder seems to show that the β-values of $1/f^{\beta}$ fluctuations of the alpha and theta rhythms of this analysis are statistically different, which means that multifractal analysis may be of value in evaluation of routine EEG recordings.

In summary, it is possible to say that the non-linear dynamic analysis of bioelectric activity of the brain in psychosis opens new prospects in understanding of the developmental mechanisms of the psyche, and perhaps allows to describe more subtly the various phases of psychotic changes and transitions between them. The possibility of discovering psychotic phenomena, even masked with other activity, by the fractal structure of bioelectric activity of the brain can make a valuable contribution to the further investigation of mechanisms of generation and extension of psychotic activity.

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