Medical Xpress

Team reports on multifractal detection of the early stages of multiple sclerosis

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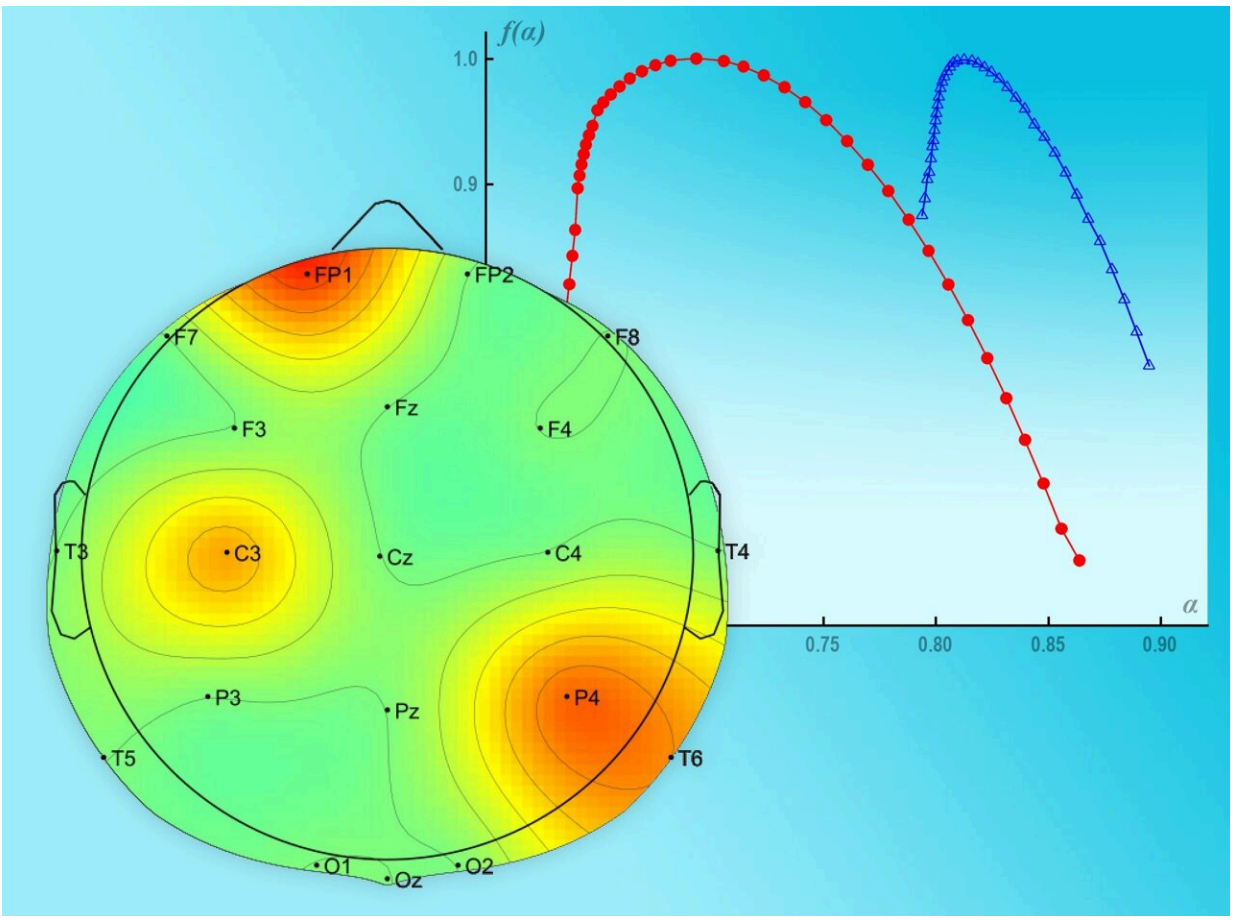

Differences in the complexity of the EEG signal (yellow and red colors) in a specific brain area between the group with advanced multiple sclerosis and the control group, and multifractal spectra calculated for the group of patients (red line) and for the control group (blue line). Credit:IFJ PAN

Multiple sclerosis is a disease mainly associated with the slowing down of information processing and a lack of motor coordination. It is an incurable disease that leads to degeneration of the central nervous system, manifesting as motor and sensory disturbances.

The earlier the disease is detected, the more effectively its course can be mitigated. A promising tool for early detection of the severity of this neurological disease appears to be multifractal analyses of electrical signals flowing from the brain, as has just been demonstrated by researchers carrying out the "Biologically inspired neural networks" project of the Foundation for Polish Science.

The paper is published in the journal *Biomedical Signal Processing and Control*.

The achievement is the result of collaboration among researchers from four scientific institutions: the Jagiellonian University (UJ), Cracow University of Technology, SWPS University (USWPS) in Katowice, and the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Cracow, where the multifractal analyses were carried out.

"The search for multifractal relationships is computationally demanding and has only started to become more widespread in the last decade or so, together with the increase in computing power of computers and the development of software. As a result, in many areas of scientific activity, multifractals are only at the stage of 'taking their first steps.' One such area is the analysis of the complexity of electrical signals emitted by the human brain, especially in the context of degenerative changes taking place in it," says Dr. Pawel Oswiecimka from the Department of Complex Systems Theory at the Institute of Computer Science, Polish Academy of Sciences.

The patients for the studies that formed the basis of the project were strictly selected by researchers and doctors from the Department of Neurology at the UJ Medical College and the Department of Neurology at the UJ Hospital. The group with diagnosed early-stage multiple sclerosis was eventually reduced to 38 subjects—and the control group to 27.

Electroencephalographic (EEG) data were collected several times over a two-year period, each time involving the subjects in different tasks. The electrical activity of the brain was measured using 256 electrodes, each sampled one thousand times per second. Before the actual analysis, the signals were cleaned--removing, for example, artifacts caused by eye blinks--and according to the generally accepted convention, were combined into groups corresponding to 20 brain areas.

"The total amount of data collected is so large that it will take our team years to complete a full set of multifractal analyses. Therefore, the paper we have just published in *Biomedical Signal Processing and Control* discusses only the readings collected during the earliest phase of the measurements concerning the situation when the subjects taking one of the two prescribed pharmaceuticals did not perform any activity during the measurements," explains Dr. Oswiecimka.

The basic feature of "ordinary" fractals is their self-similarity: by enlarging them, sooner or later, we see a structure very similar to the initial one, or even identical. What happens when we combine several fractals in a simple manner? The result is generally noise. However, there are mathematical operations that weave fractals into complex structures that retain the capacity for self-similarity.

In ordinary fractals, self-similarity appears when we scale any fragment by a factor that is always constant for that fractal, whereas different fragments of multifractals must be scaled in different ways. This feature means that while analyses using ordinary fractals allow linear correlations such as trends to be picked up, multifractals can reveal the existence of less obvious, non-linear correlations.

At the fractal analysis stage, the IFJ PAN specialists noticed that the electrical signals emanating from the brains of healthy people showed the presence of certain long-range trends, which made the graphs of their electrical activity visually smoother than in patients with multiple sclerosis, whose brains send out more "jagged" signals. But when multifractals are involved, the situation changes: The electrical signals emitted by the brains of healthy people have less structural complexity than in patients.

"It seems that in people with early-stage multiple sclerosis, the communication between neurons is more complex. However, the neurons are not fully independent of each other, as they are still jointly responsible for the formation of the EEG signal, and therefore, we observe a tangle of fractals, i.e., multifractals," says Dr. Oswiecimka, and adds, "In contrast, in the control, healthy group the individual fractal components are more regular, fit together better and the multifractal structure becomes more difficult to see."

The interpretation of the obtained results is presented by Prof. Tadeusz Marek, from the USWPS Department of Psychology: "The existence of complex signal organization in multiple sclerosis sufferers may indicate compensatory processes in the brain's neural networks. The brain attempts to compensate for the deficit created by the disease and seeks ways around damaged areas, leading to a reorganization of the network. The functions of these areas try to be taken over by other, still efficiently working groups of neurons, which manifests itself in an increase in the complexity of electrical activity."

In summarizing the results of the analysis of multifractal EEG recordings, Prof. Marek emphasizes that they are proving to be a highly sensitive tool for detecting compensatory processes occurring in the neural networks of the brain in the early phase of multiple sclerosis development.

The results of the work of the team of physicists from the IFJ PAN are the first step towards developing more accurate techniques for assessing the progression of multiple sclerosis in patients. Currently, a questionnaire survey, which is highly subjective by nature, is used for this purpose, while more objective examinations require the use of magnetic resonance imaging and are therefore not only invasive but also highly cost-intensive.

Discovering the relationship between a patient's condition and the multifractal complexity of their brain's electrical activity would allow for an objective assessment using an easy-to-use measurement technique that is non-invasive and not too troublesome for the patient.

The reported results are the first phase of analyses of the EEG signals collected during this project, with the remaining electroencephalographic data currently being processed. However, the scope of the research was broader and also included brain imaging using structural and functional magnetic resonance techniques.

These resulted in a series of images showing cross-sections from which the structure of the brain and changes in the blood supply and oxygenation of its various areas can be reconstructed. The search for multifractal heralds of multiple sclerosis will therefore continue, no longer in one, but in four dimensions.

More information: Marcin Wątorek et al, Multifractal organization of EEG signals in multiple sclerosis, *Biomedical Signal Processing and*

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