Statistically significant decrease of the quantity of beta wave packets in de novo Parkinson’s disease

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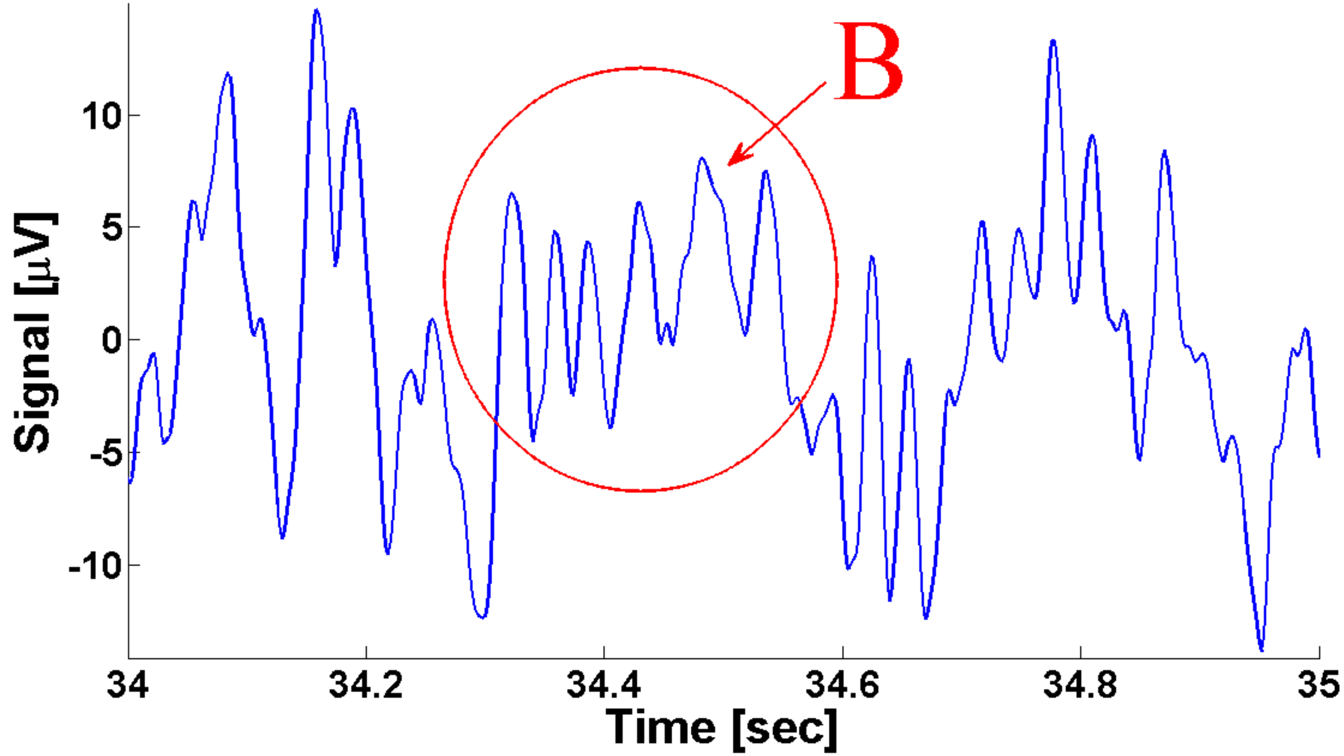
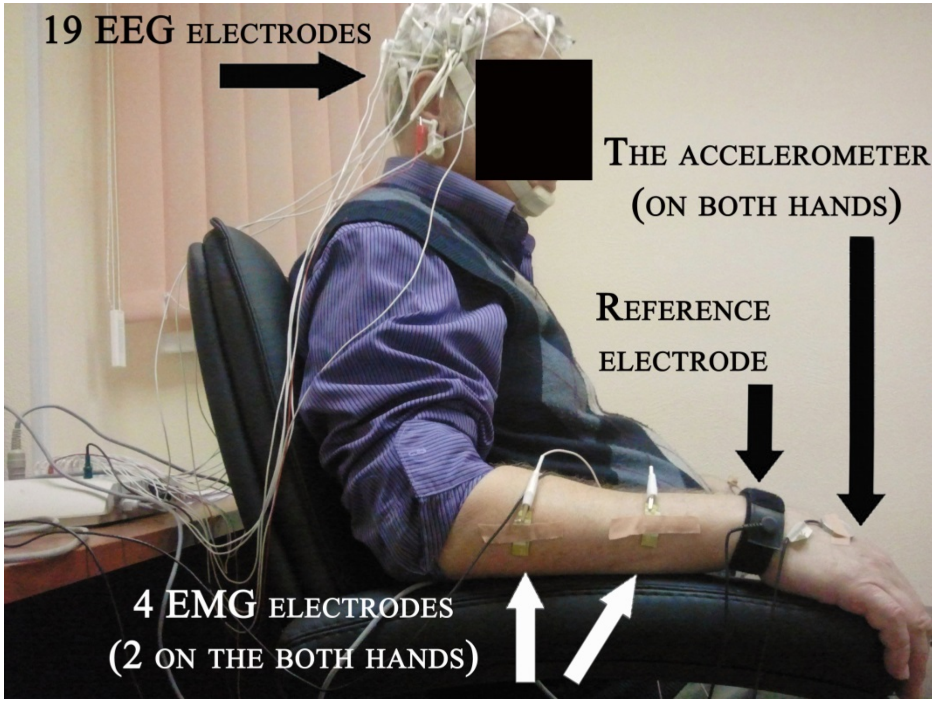
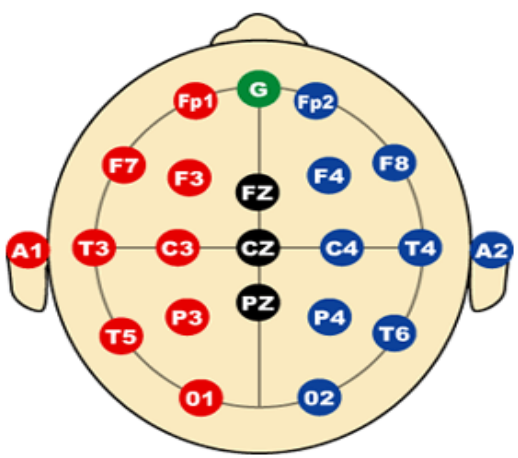
What is a wave train?



In physics, a wave train (or wave packet) is a short "burst" or "envelope" of localized wave action that travels as a unit. In this paper, we use a term "wave train" to denote a signal localized in time, frequency, and space.

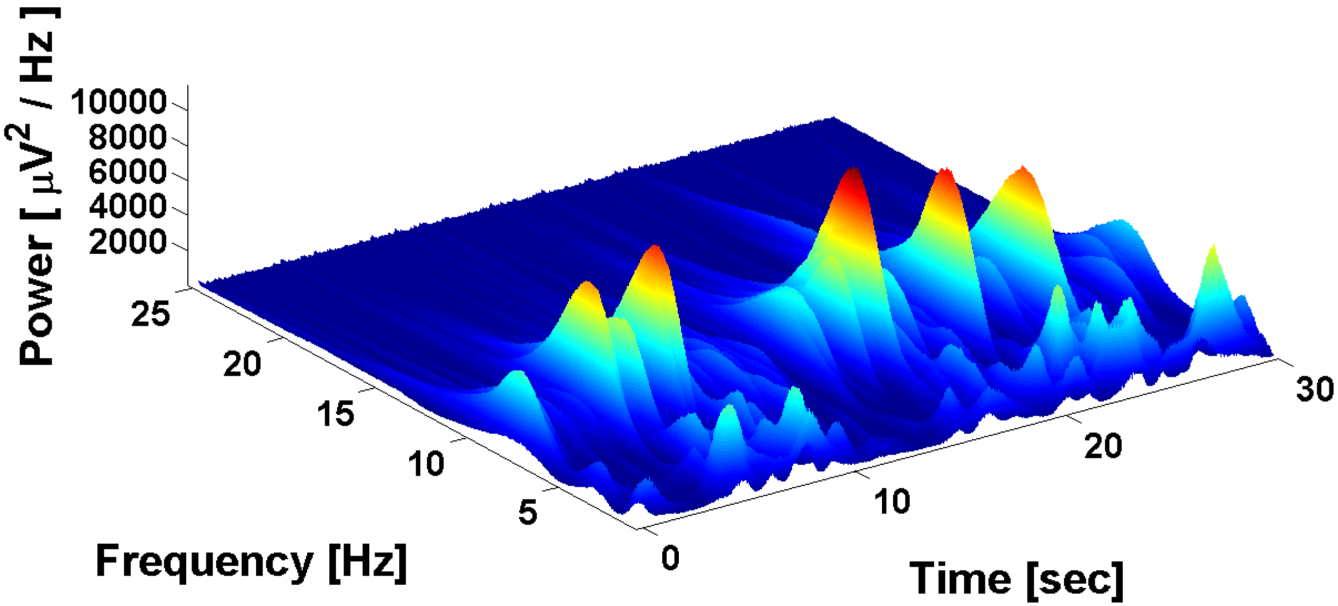
Introduction





- Conventional clinical analysis methods for study the electrical activity of the brain cortex is based on the calculations of power and frequency characteristics of EEG signals.
- The research and development of methods of quantitative analysis of other EEG characteristics that describe the time-frequency dynamics of brain electrical activity is also of great interest.

A case of the wave train analysis of Parkinson’s disease experimental data



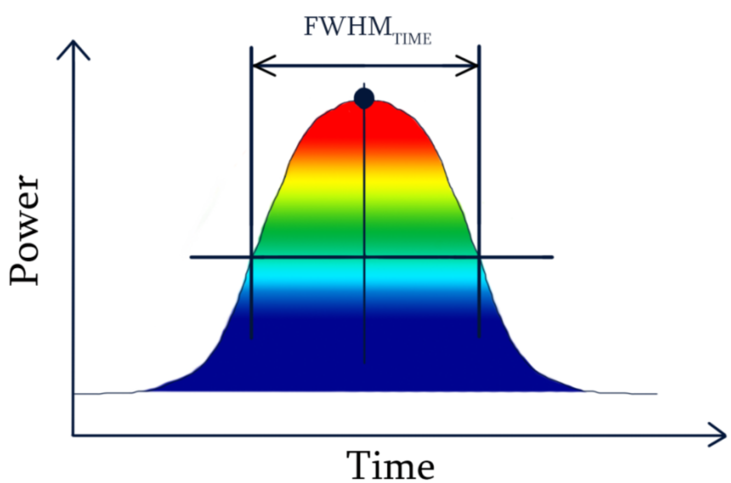
A wavelet spectrogram of the background EEG of an early stage Parkinson’s disease patient.

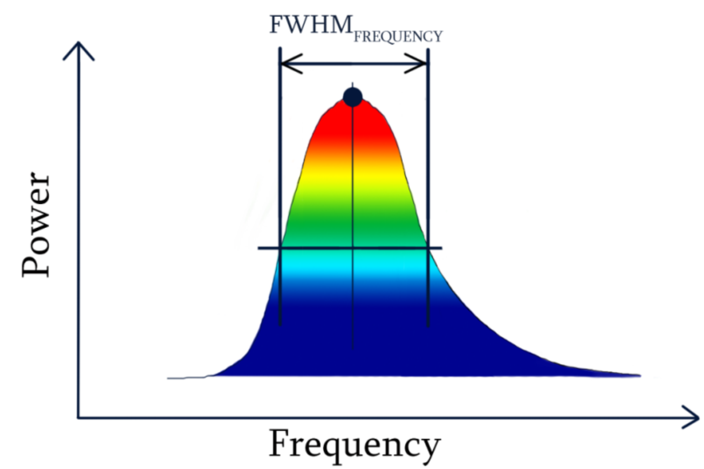
One can easily observe wave trains in the alpha frequency range (8-12 Hz), but wave trains in the beta frequency range (12-25 Hz) are hardly noticeable, because they are much smaller than the alpha wave trains.

A method of analysis of EEG wave trains

- Detection of wave trains in wavelet spectrograms.
- Estimation of wave train characteristics:
  - Counting of quantity of wave trains.
  - Calculation of central frequency and amplitude of wave trains.
  - Calculation of duration and bandwidth of wave trains.
- Visualising of wave train characteristics.

Cross-sections of a local maximum of a wavelet spectrogram



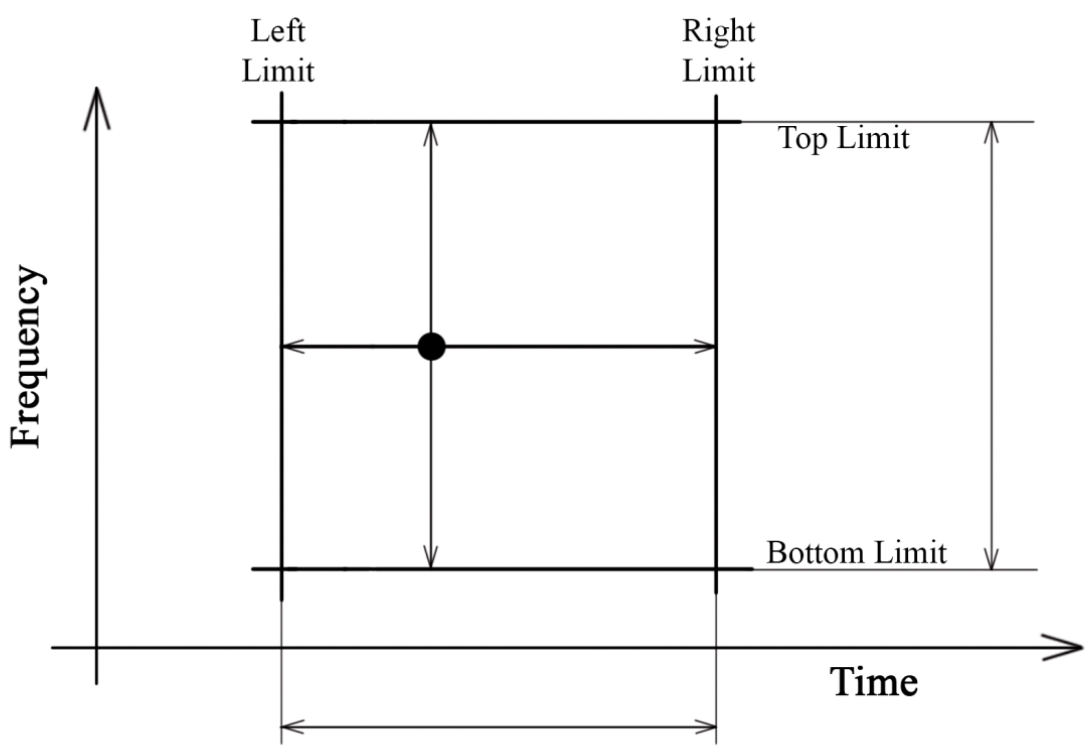


Duration threshold

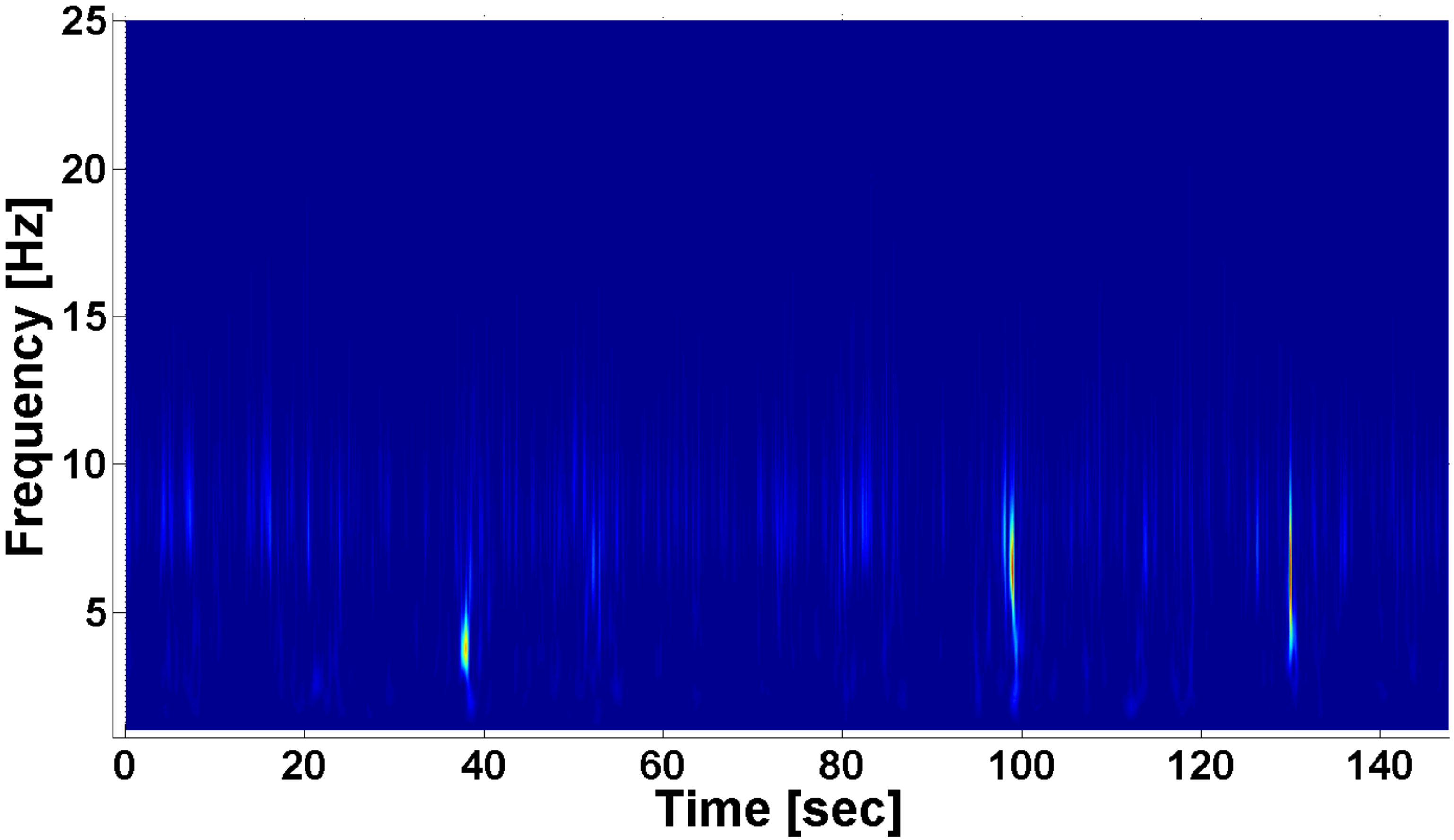
$$FWHM_{TIME} >= N_P / f, \;\; N_P = 2,$$

Step 1: Detection of wave trains

- Calculation of full width of half maximum (FWHM) in the time cross-section and in the frequency cross-section of a local maximum.
- Check of a rectangular area around a local maximum in wavelet spectrogram. We check if there are no values inside the rectangular area that are bigger than the local maximum.
- Check if a local maximum is long enough.

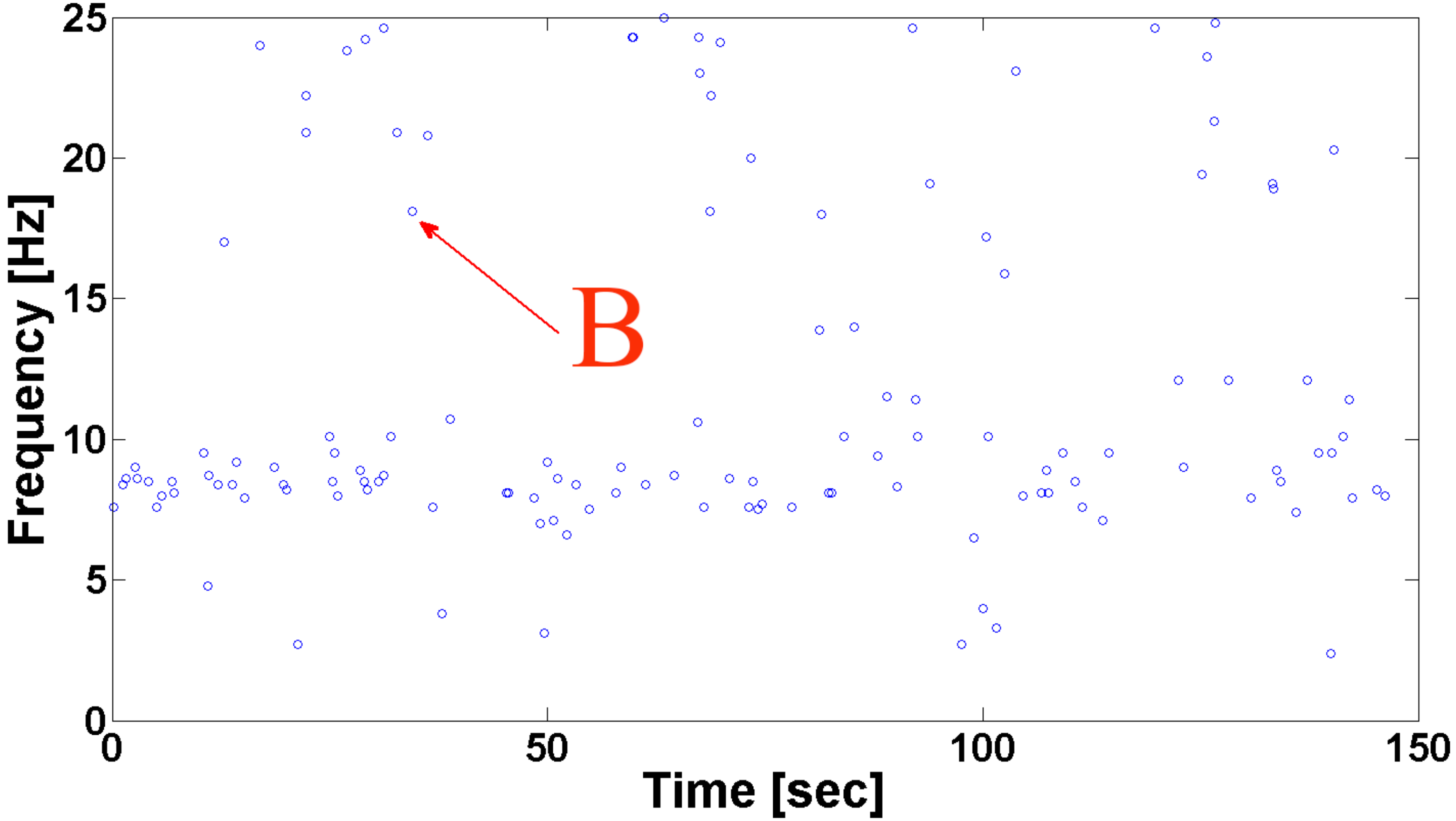


A top view of a wavelet spectrogram



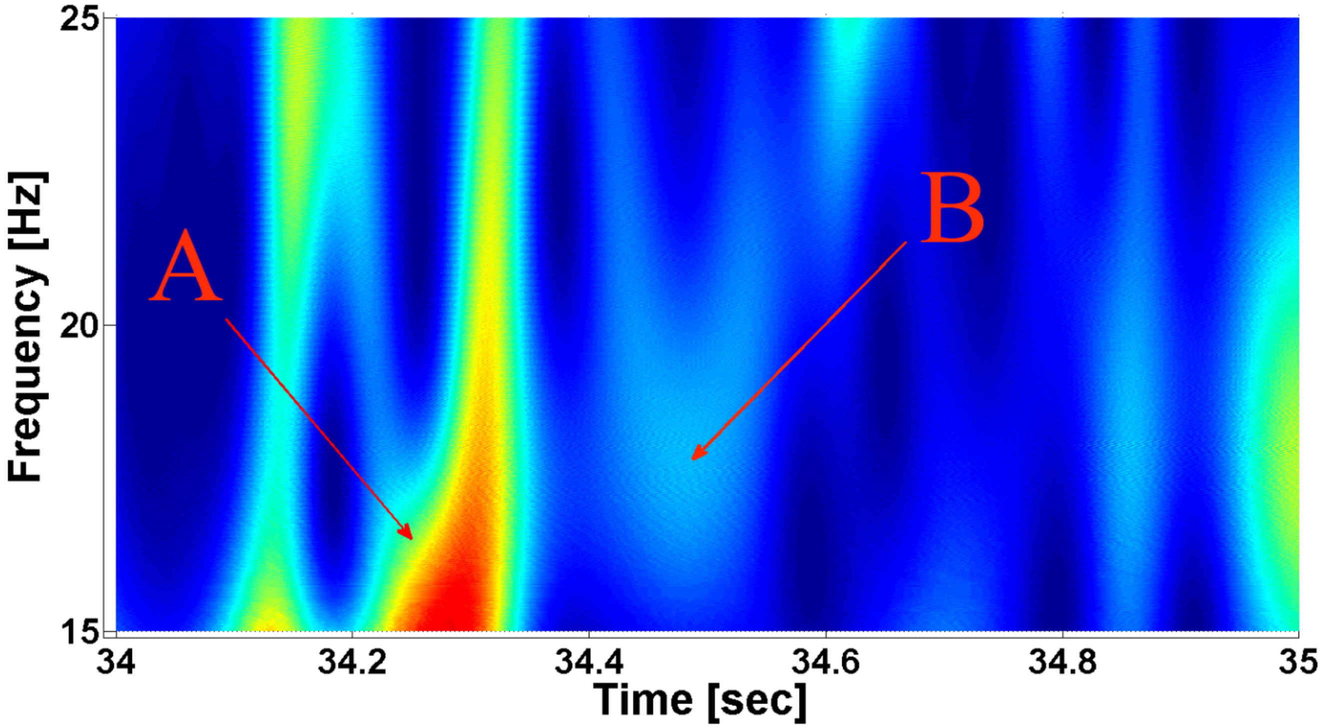
A top view of a wavelet spectrogram of the background EEG of an early stage Parkinson's disease patient.

A top view of the wavelet spectrogram



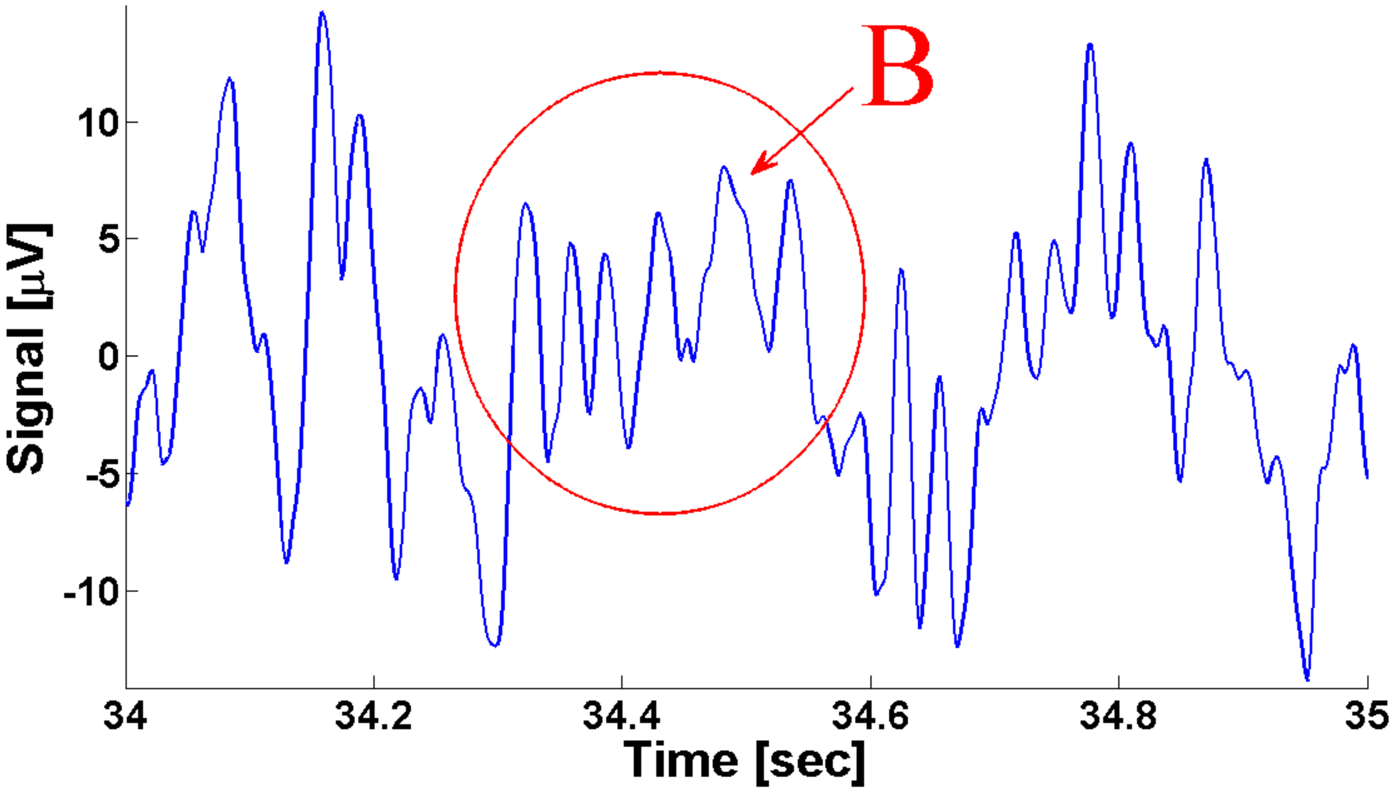
A set of EEG wave trains in the time-frequency domain.
Let us consider the *B* wave train (it is indicated by the arrow).

Wave train analysis of Parkinson's disease experimental data



A spectrogram of the *B* wave train in the beta band. One can see a pronounced tail of another local maximum *A* at the left of *B*, that is originated in the alpha band. The developed method prevents incorrect detection of the local maximum tail *A* as the electrical activity in the beta frequency band.

The original EEG signal

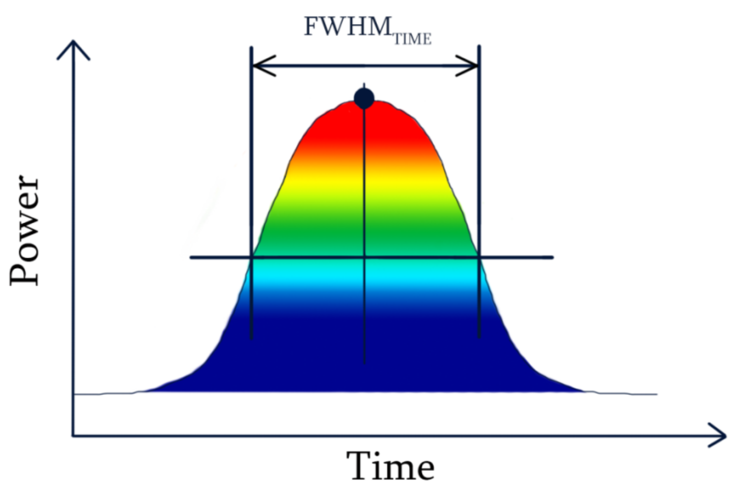


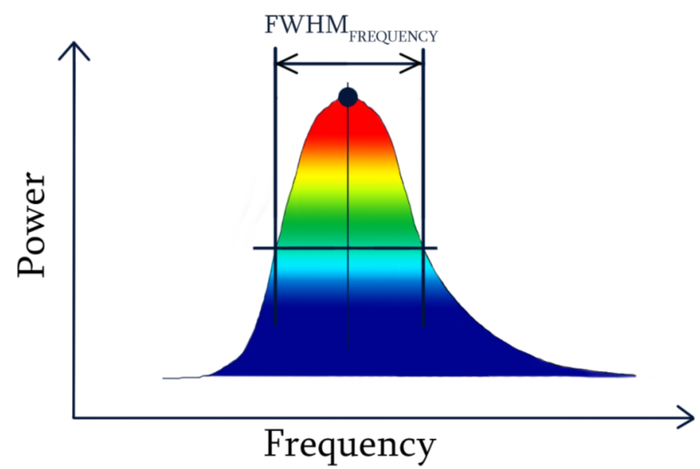
The *B* wave train is indicated by the arrow.

Step 2: Estimation of wave train characteristics

- Estimation of wave train characteristics:
  - Counting of quantity of wave trains.
  - Calculation of central frequency and amplitude of wave trains.
  - Calculation of duration and bandwidth of wave trains.

Cross-sections of a local maximum of a wavelet spectrogram





The experimental setting

A group of 17 patients with right-hand tremor and 11 patients with left-hand tremor of the first stage Parkinson's disease receiving no treatment and a group of 15 healthy volunteers as a control were recruited.

The age

- The ages of patients with right-side tremor ranged from 38 to 70 years; the mean age was 58 years.
- The ages of patients with left-side tremor ranged from 49 to 71 years; the mean age was 61 years.
- The ages of controls ranged from 48 to 81 years; the mean age was 58 years.

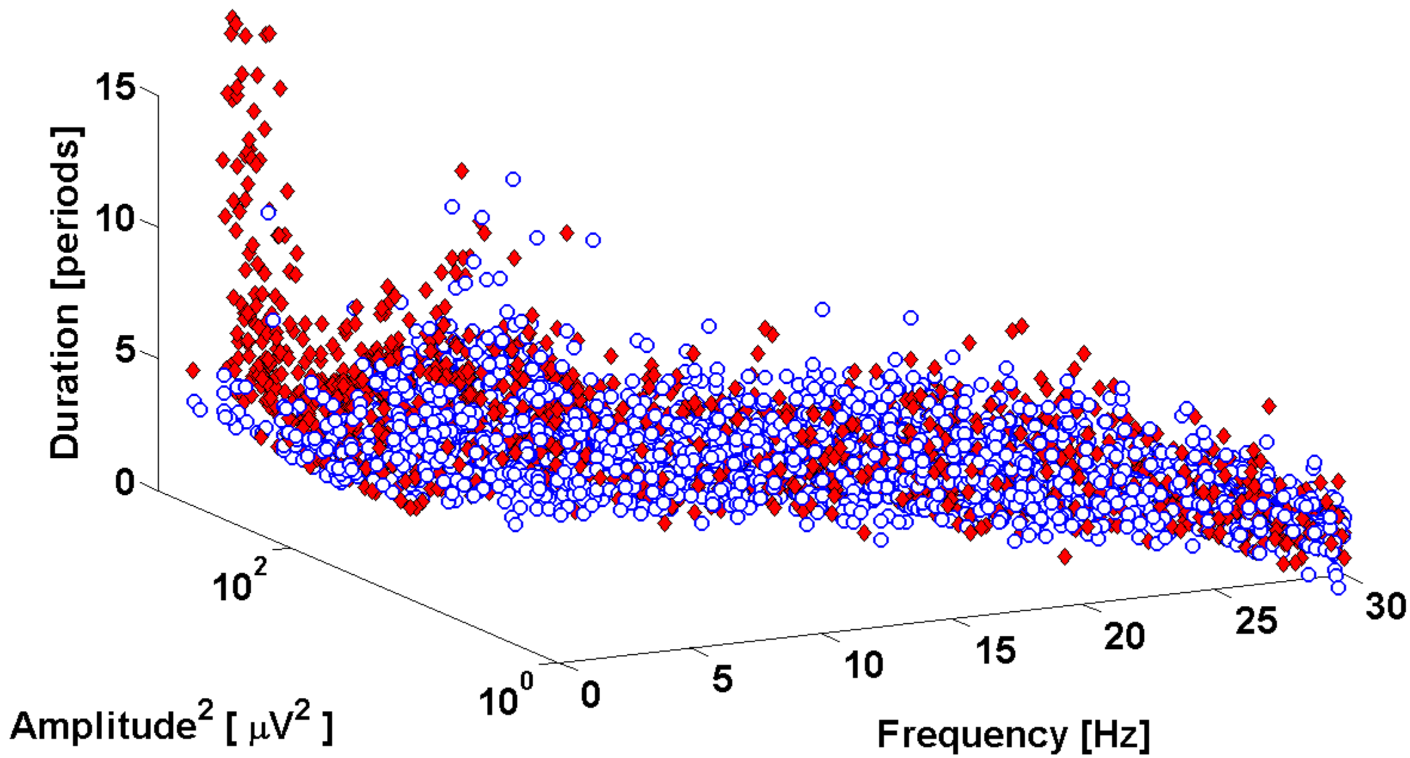
No statistically significant differences between the ages of the patients and the controls were detected.

Data analysis

A special program was developed for analyzing the data in Matlab. The analysis includes the following EEG pre-processing operations:

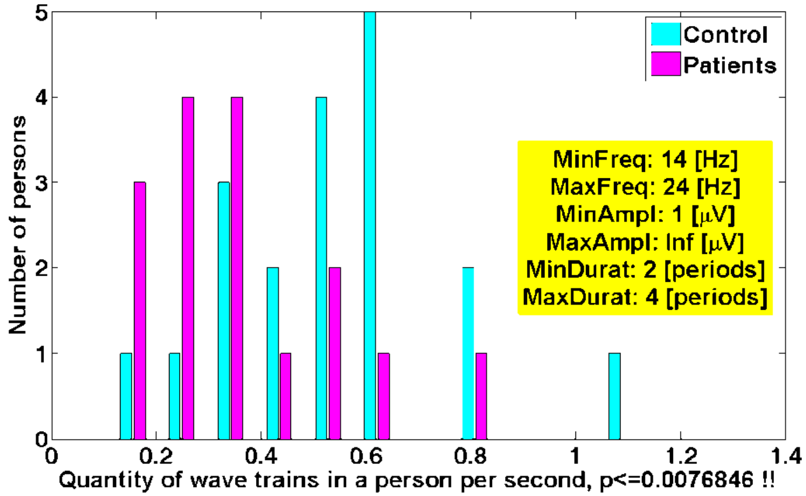
1) The Huber's X84 method for outlier rejection was used for removing EEG artefacts.
2) A set of notch filters was applied for removing a power line noise at 50, 100, 150, and 200 Hz.
3) The eight order 2-240 Hz band pass Butterworth filter was applied. Signals were filtered in the forward and reverse directions to eliminate a phase distortion.
4) Signals were decimated with the decimation factor 4.

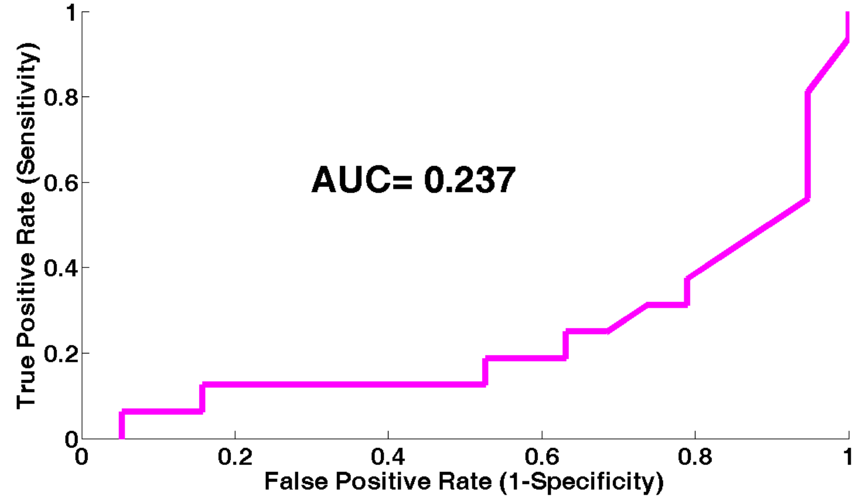
Step 3: Visualizing wave train characteristics



The set of wave trains are detected in the group of de novo Parkinson's disease and the control group. The abscissa indicates frequencies of the wave trains. The ordinate indicates squared amplitudes of the wave trains in a logarithmic scale. The applicate indicates durations of the wave trains. The patients are indicated by dark red diamonds and the healthy volunteers are indicated by light circles.

ROC-curves and AUC

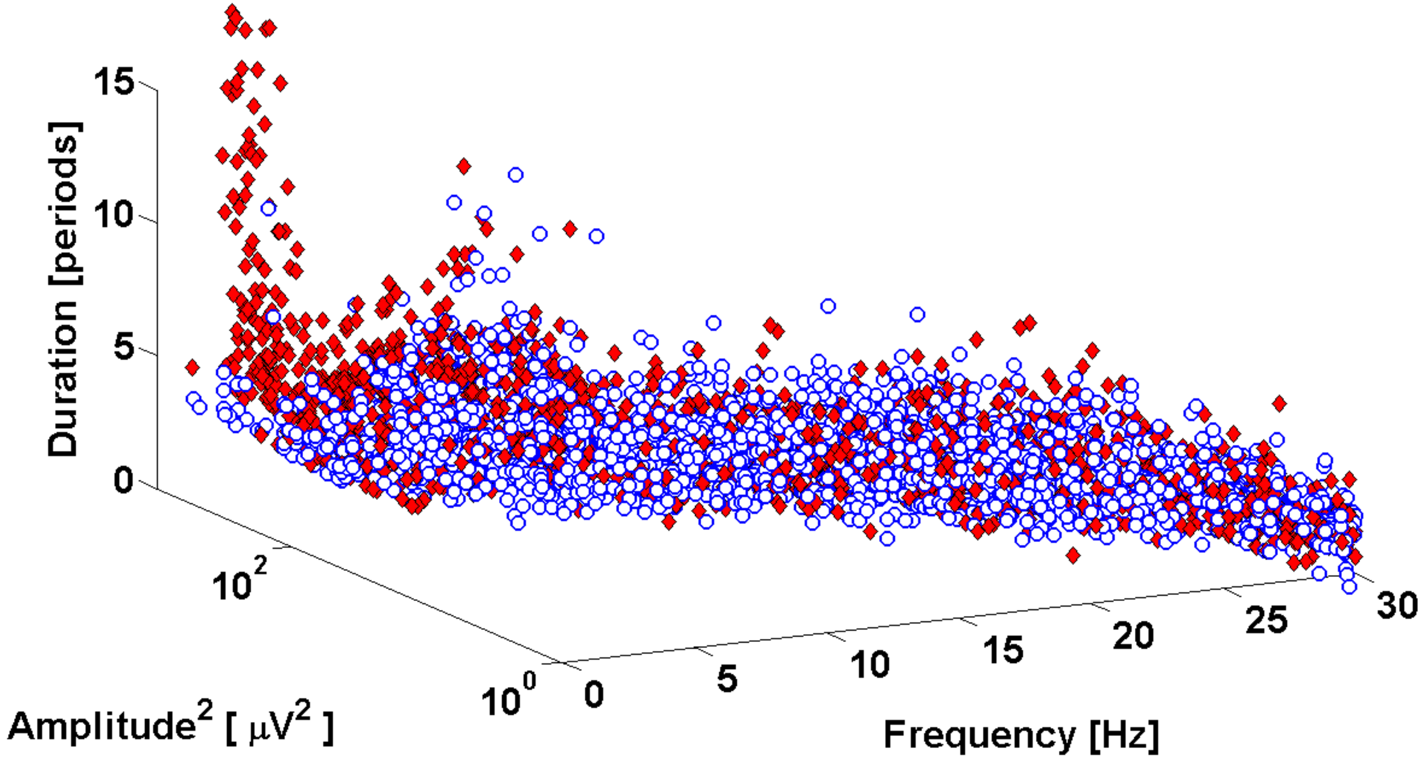




Histogram of the quantity of the wave trains per second in the patients and the control group. The wave trains are considered in a parallelepiped *S* bounded by the following limits: a frequency range is 14-24 Hz, an amplitude range is 1 uV^2 and more, the duration range is 2-4 periods. The patient histogram is indicated by the dark magenta color; and the control histogram is indicated by the light cyan color.

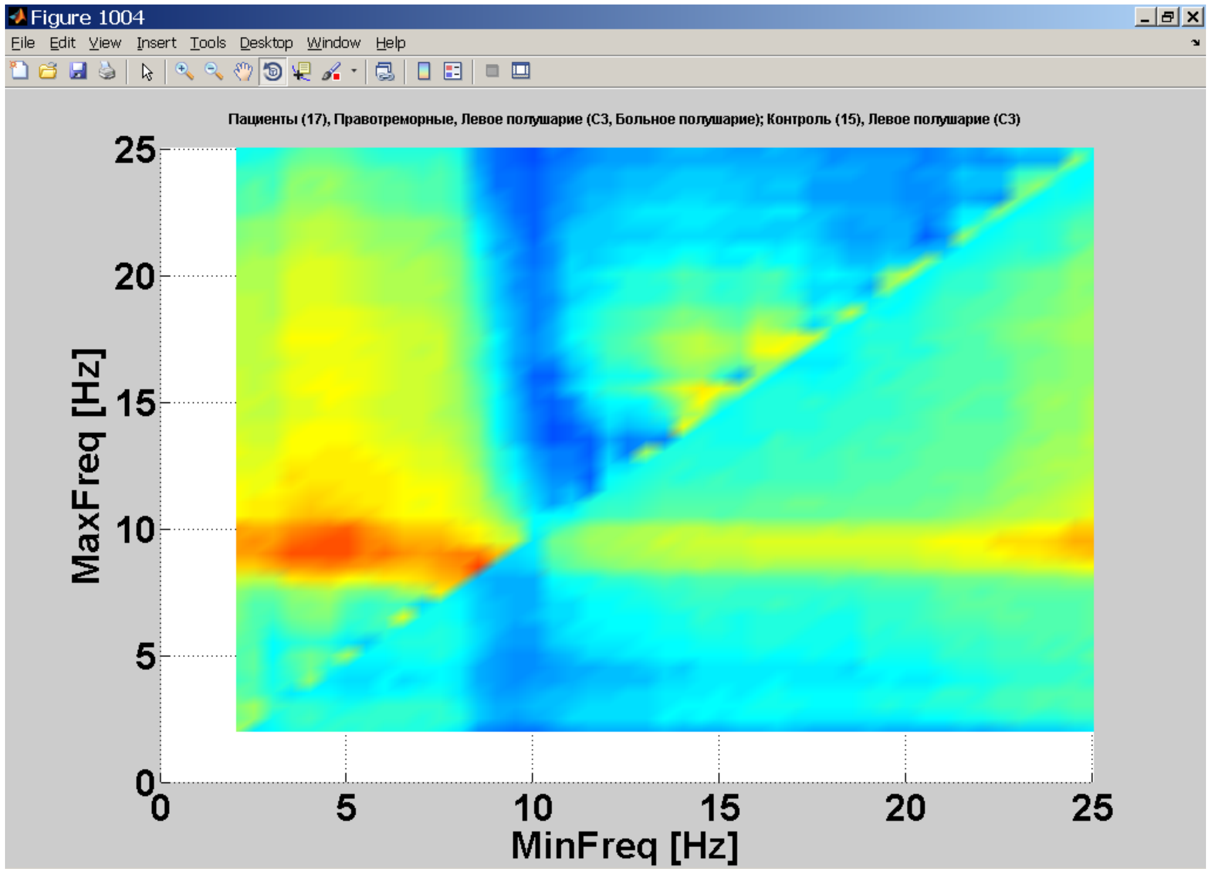
The abscissa indicates the False Positive Rate. The ordinate indicates the True Positive Rate. The area under the ROC curve (AUC) indicates whether the area *S* is applicable for separation of the patients and the control group. AUC < 0.5 indicates that the wave trains quantity is greater in the control group than in the patients.

Searching areas in the wave train space, where AUC is the best



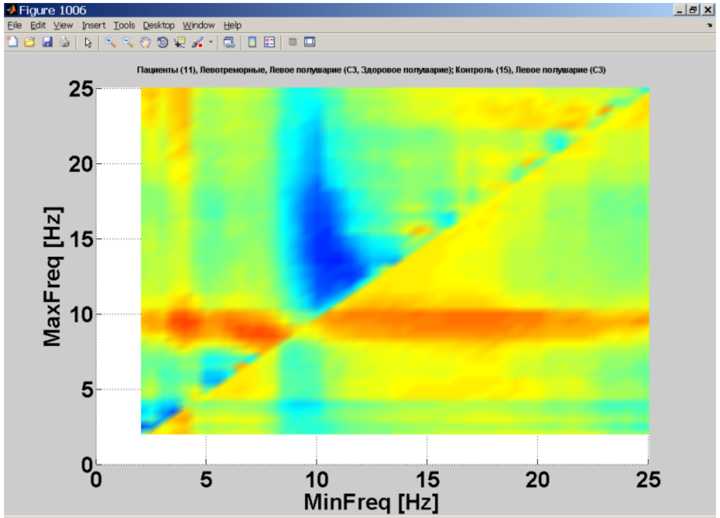
The abscissa indicates frequencies of the wave trains. The ordinate indicates squared amplitudes of the wave trains in a logarithmic scale. The applicate indicates durations of the wave trains. The patients are indicated by dark red diamonds and the healthy volunteers are indicated by light circles.

A diagram of AUC values calculated for various Frequency bounds

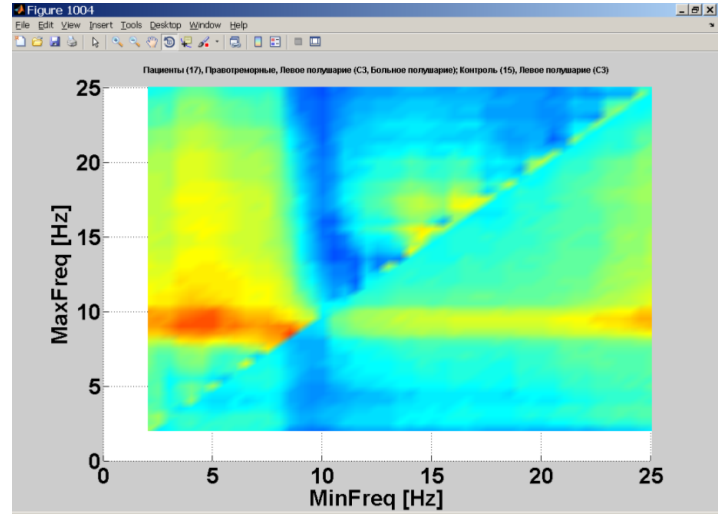


The ordinate is upper bound of frequency band, the abscissa is a lower bound of frequency band. The frequency varied from 2 to 25 Hz with the 0.5 Hz step. Minimal Amplitude = 1, Maximum Amplitude = infinity, Minimal Duration = 0, Maximum Duration = infinity.

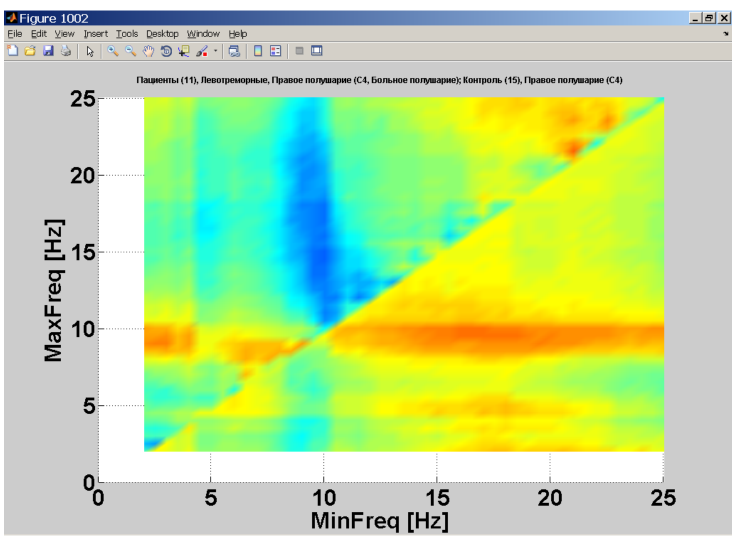
Left-hand tremor patients C3 **background**



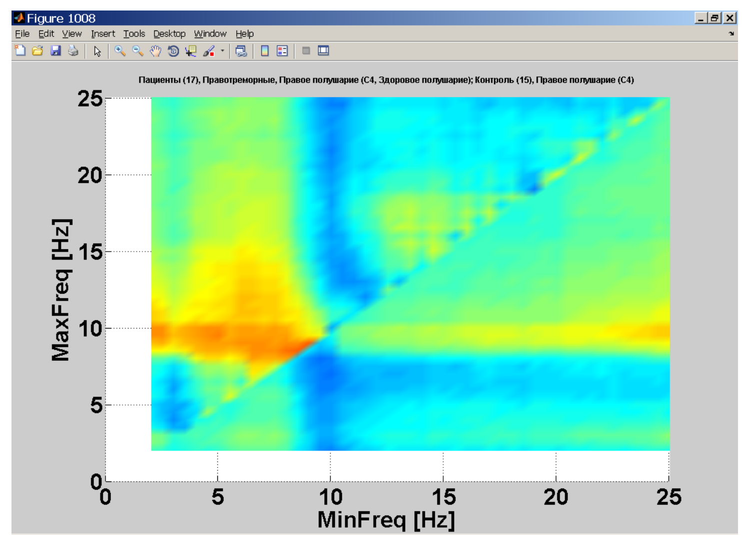
Right-hand tremor patients C3 **background** and C3



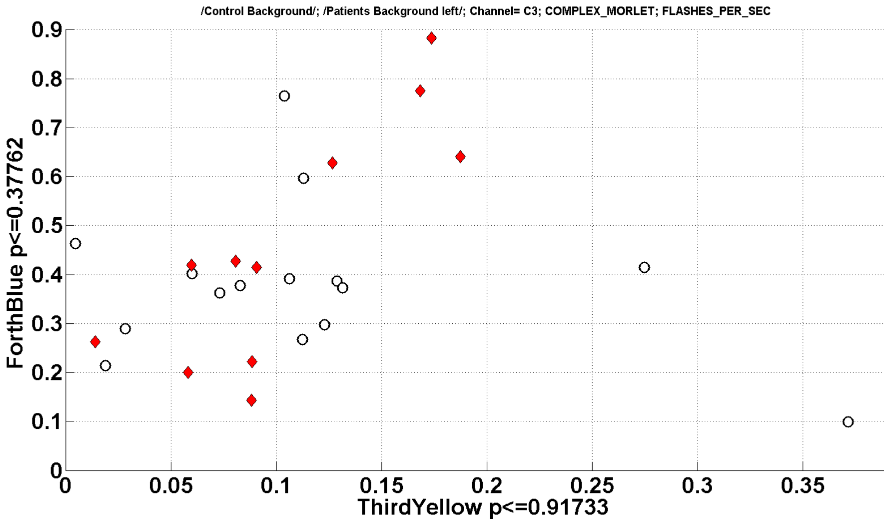
Left-hand tremor patients C4 **background**



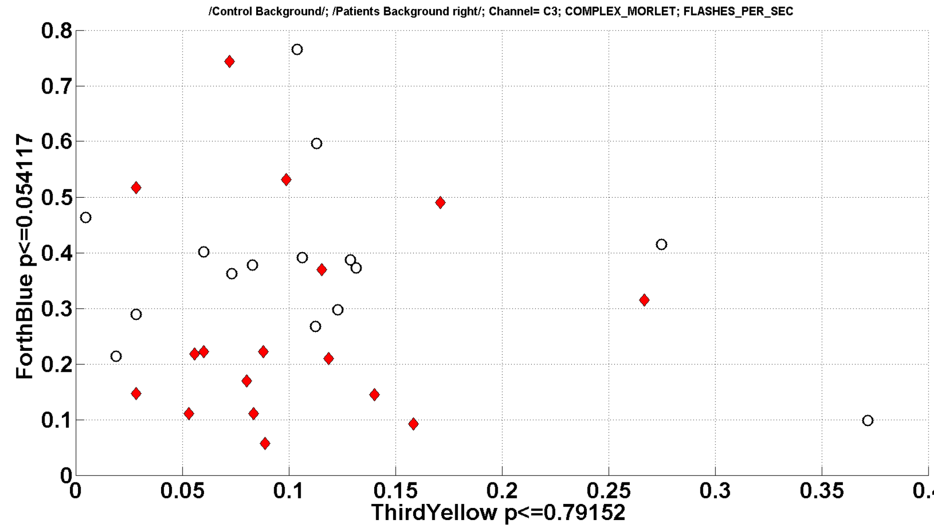
Right-hand tremor patients C4 **background**



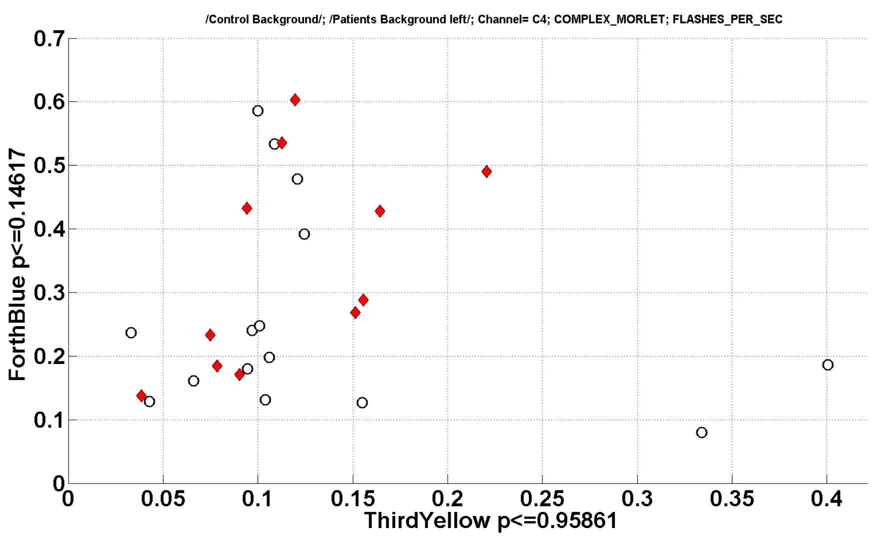
Left-hand tremor patients C3 **background**



Right-hand tremor patients C3 **background** and C3



Left-hand tremor patients C4 **background**



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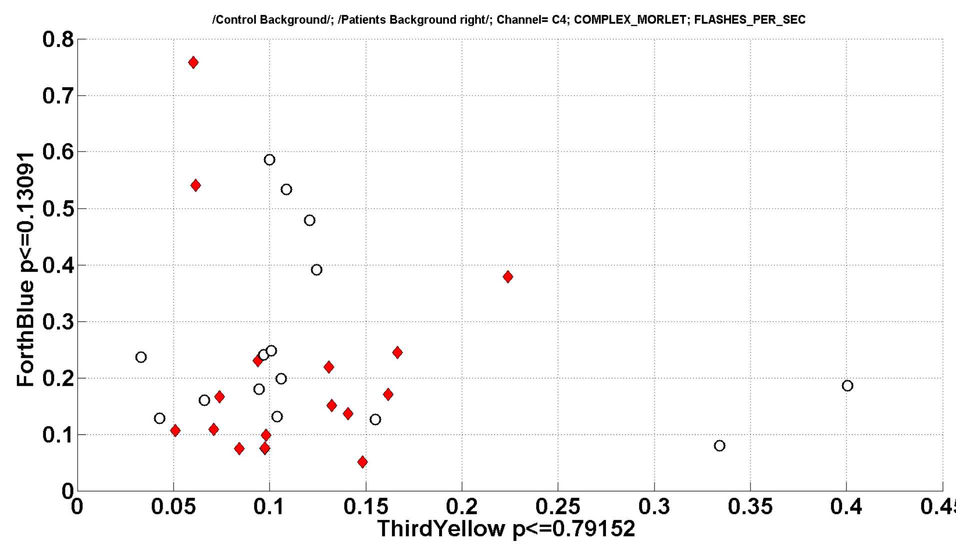
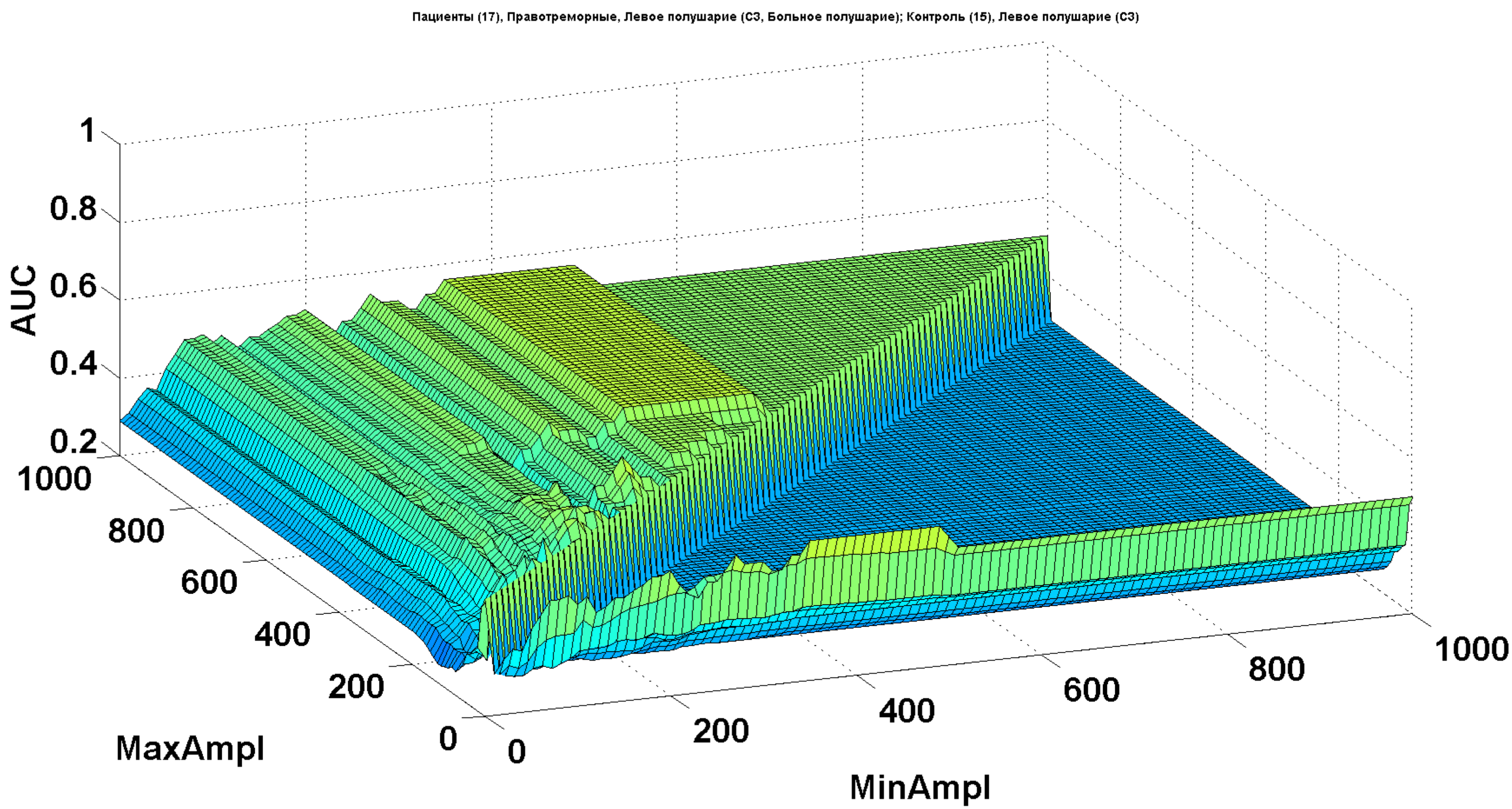
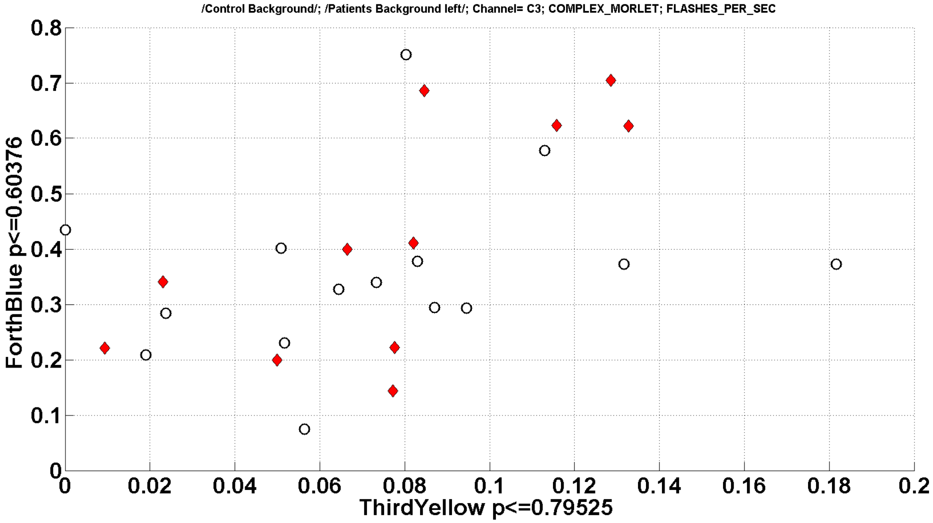


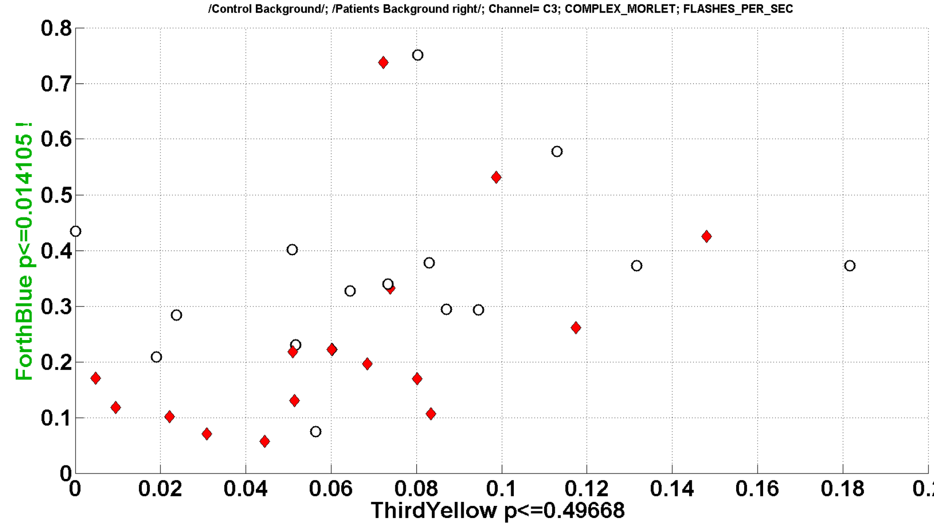
A diagram of AUC values calculated for various Amplitude bounds



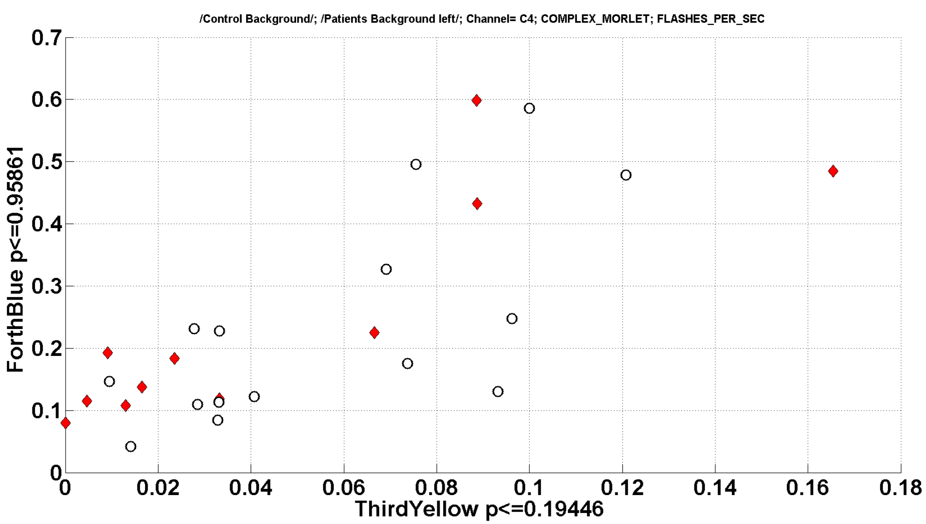
Left-hand tremor patients C3 **background**



Right-hand tremor patients C3 **background** and C3



Left-hand tremor patients C4 **background**



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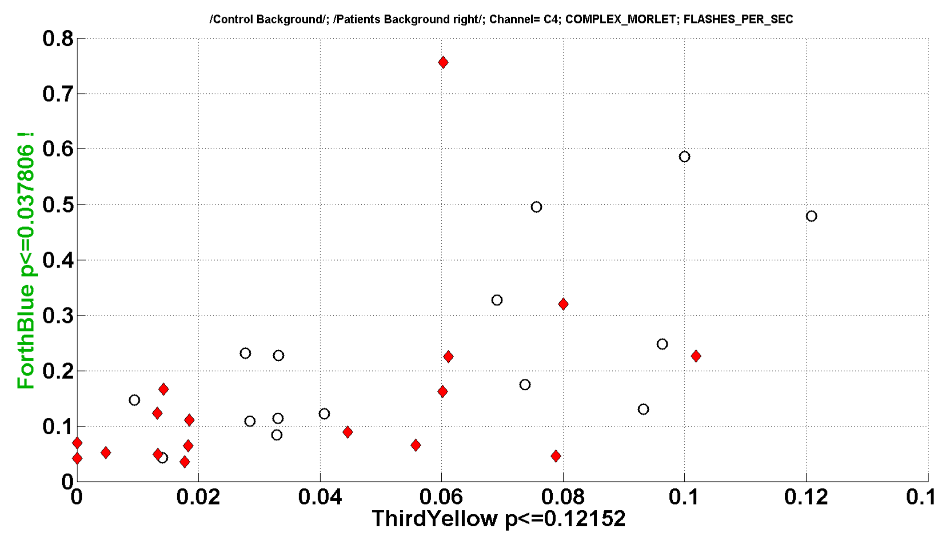
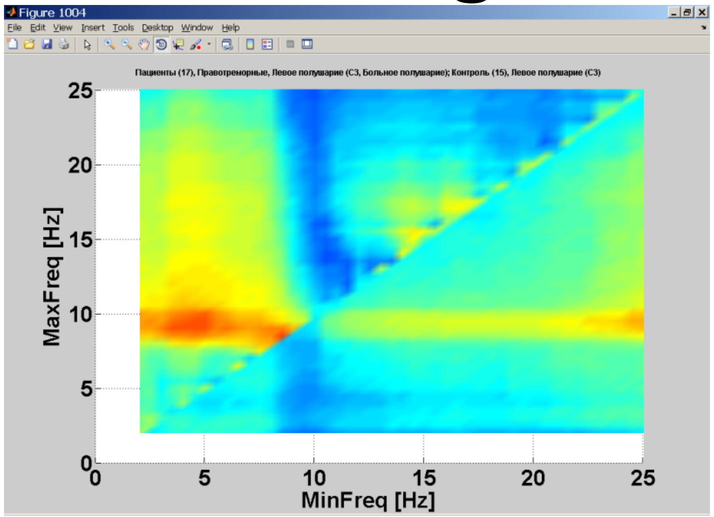


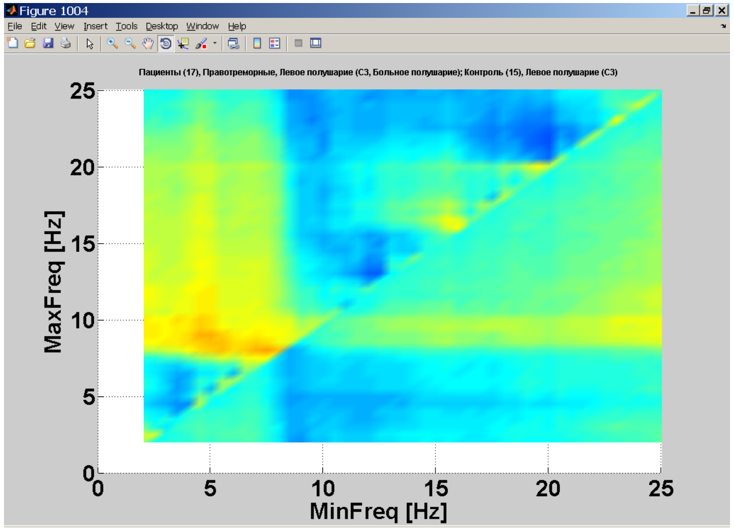
Conclusions

- The **method of a brain electrical activity investigation** based on the EEG wave train analysis is developed.
- A **new method of visualisation of electrical brain activity** is developed.
- The preliminary results of the research give evidence that EEG analysis method based on the wave trains is prospective for:
  1) Looking for group regularities in the early stages of Parkinson's disease that gives a basic knowledge about the disease and compensatory mechanisms in the cortex;
  2) Searching EEG features that are prospective for the early stages and, possibly, the preclinical period of Parkinson's disease diagnostics.

Thank you for attention!

Right-hand tremor patients
C3 **background** and C3 **special pose**





Right-hand tremor patients
C4 **background** and C4 **special pose**