EVALUATION OF COGNITIVE ERP, ERD/ERS FROM INTRACEREBRAL ELECTRODES DURING THE TESTING OF EXECUTIVE FUNCTIONS, THE TIME – FREQUENCY ANALYSIS

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Abstract: In the present paper we describe the procedure of evaluation repeated EEG signals obtained from deep brain structures. Data are processed using the time-frequency analysis, which helps to determine individual frequency (IF) bands and afterwards are processed using complex demodulation technique to assess power envelope of IF band. We analysed phase-locked (Event-Related Potentials) and non-phase-locked (Event Related De/Synchronisation) signals obtained during different task conditions. Because of low signal to noise ratio, statistical tests of credibility and significance were used.

Introduction

The repetitive EEG event-related signals are studied to understand the function of different brain structures. We studied executive functions, which are associated with complex mental operations, such as planning, problem solving, working memory, inhibition, self-monitoring, verbal self-regulation, motor control, regulation of emotion and motivation. Cognitive models typically describe executive functions as higher-level processes that exert control over elementary mental operations (Norman and Shallice, 1986; Luu and Tucker, 2002). Our study was designed with the aim to investigate the neurocognitive network of executive functions (planning, abstract thinking, attention etc.) during performance of four different visual cognitive tasks. We evaluated the repetitive human EEG event-related signals, recorded from depth brain electrodes, which were implanted in order to localise the epileptogenic foci before neurosurgical treatment of some types of farmacoresistent epilepsy. The data are unique because were obtained from deep brain structures, inaccessible by scalp measurement.

Materials and Methods

Subjects

Nine human subjects (the number of patients is limited) performed four resembling tasks with the motor or mental response (writing, counting). Each patient received 6-12 platinum electrodes in the investigated brain structures using the methodology of Talairach et al. (1967) in order to localise the epileptogenic foci before a surgical treatment. Each electrode has from 5 to 15 measurement points (contacts). Standard MicroDeep semiflexible electrodes (DIXI), diameter 0,8 mm, contact lengths 2 mm, intercontact interval 1,5 mm were used for invasive EEG monitoring. The exact position of the electrodes and their contacts in the brain were verified using post placement magnetic resonance imaging with electrodes in situ. All the subjects were informed about the character of this study and gave their informed consent.

Procedure

The graphical symbols presented in a random order on a monitor were chosen as the visual stimuli. The duration of the stimulus exposure was 200 ms. The interstimulus interval was 16 seconds, the mean number of trials was 50. Subjects were instructed to stay calmly, to the eyes fixed to the monitor and avoid the unnecessary movements. The monitor was situated at the same place for all the subjects, 1,5 m in front of their eyes, at the end of the monitoring bed. Each recording was under video control, the failed trials were removed. Subjects performed three diversely difficult visuomotor cognitive tasks and one mental task. During the more complex tasks the executive functions were supposed to be engaged.

Recordings

The EMG, EOG and the scalp EEG (Cz, Pz and Fz electrodes) were registered simultaneously. For the first two patients the 96 channel BrainScope EEG system (M&I) was used. The others patients were recorded by EEG system TruScan 128 (Deymed diagnostic, Alien Technic) because of the EEG unit renovation. The recordings were unipolar, with a linked earlobe reference. The sampling rate was 256 Hz.

Data analysis

The EEG data were analysed from 70-120 electrode contacts. They were off-line processed and analysed using ScopeWin and ScopeMat software. They were segmented to the stimulation and to the reaction. The single trials were visually inspected to eliminate EEG

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segments containing any artefact activity or mistaken response and excluded from further analysis. Further processing was performed with artefact-free EEG trials.

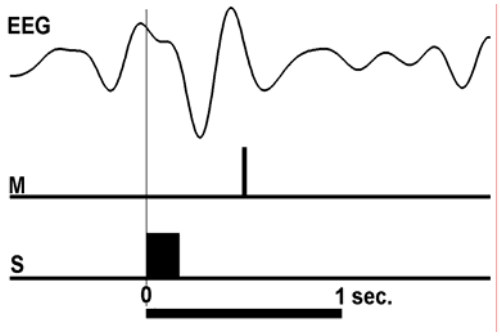

Figure 1: EEG – one EEG channel, pass band 0.5-5Hz, S – stimulus (symbol on the monitor), M – motor reaction to stimulus (switch pressing during writing)

Time frequency analysis

Numerous of recent studies based on scalp recordings have shown that the frequency limits of alpha band can vary in different subjects. They suggest results discussion on the most reactive frequencies. Therefore the time-frequency analysis was used for setting individual frequency (IF) band. Every raw of matrix (Fig. 2) was normalised according to baseline, which was taken from time region before stimulation (0.5-1.5 s from the beginning of the segment). IF´s were determined in three neurological pass-bands (Theta 3-7 Hz, Alpha 7-14 Hz and Beta 16-24 Hz) for each contact.

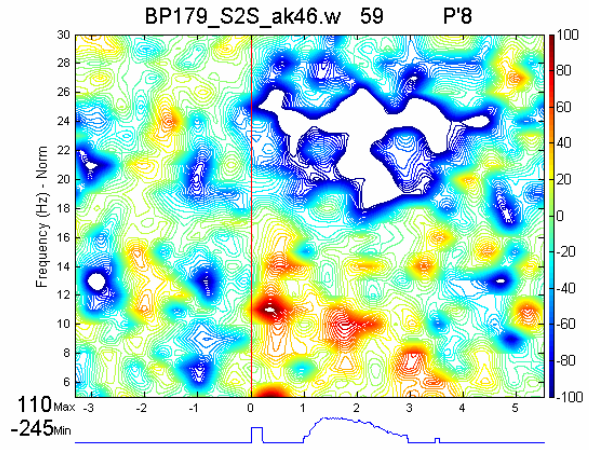

Figure 2: An example of Time-frequency analysis of P´8 EEG channel (the record from area 9, Dorsolateral Prefrontal Cortex) in pass band 4-30 Hz segmented to the reaction. Frequency step of y-axis is 2 Hz. Values over/below 100% are trimmed. Stimulus and motor reaction record is seen below the map. Stimulus (vertical line) is at the point "0".

Complex Demodulation

After IF parameters were specified the data were processed by complex demodulation technique (CD) to obtain its envelope of power in IF bands. Data were computed with and without background elimination.
The time-locked responses were evaluated with the aim to differentiate between evoked phase-locked (coherent) ERP (Event-Related Potentials) and induced not-phase-locked (non-coherent) ERD/ERS (Event-Related Desynchronisation/Synchronisation).

ERD/ERS evaluation

The occurrence of ERD/ERS was analysed in three or five time intervals A, B, C, D and E (Fig. 3) in the dependence on trigger type. For segmentation on stimulation intervals were defined A: (0.5, 1.5) s, B: (0.7, 2.5) s, C: (2.5, 3.5) s, whereas for segmentation on reaction A: (-4, -2.5) s, B: (-2.5, -1) s, C: (-1,0) s, D: -0.5,0) s, E: (0, 1) s.

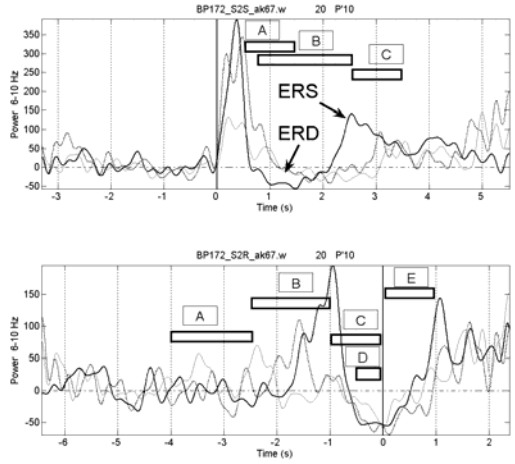

Figure 3: Analysed intervals for data segmented on stimulation (top) and reaction (below). Area of Evoked Potentials is about (0-0.7) s after stimulation (top), whereas designed intervals correspond to the induced response.

ERD/ERS (Fig. 3) are determined as decrease/increase of the power envelope for selected frequency range (Pfurtscheller and Aranibar, 1977).

$$ERD/ERS = \frac{m(t) - m_{ref}}{m_{ref}} 100\% \qquad (1)$$

ERD/ERS is measured after averaging the envelopes m(t). To be able to compare different tasks in one figure, ERS/ERD is related to the mean baseline region (m_{ref}) selected in an "activity free" time interval before stimulation. ERS is represented by positive values and ERD by negative values.
Generally the evoked potential could hide ERD/ERS especially in the short time after the stimulation. Usually ERP are removed while analysing ERD/ERS. We did not remove ERP because we were able compare both types of segmented data. Moreover not all contacts contained ERP. ERS/ERD was analysed in more outlying distance from stimulation (0.7s and more).

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Quantification of ERD/ERS

In our studies the ERD/ERS occurrence or maximal/minimal amplitude and corresponding latency were evaluated.

In the case we analyse the occurrence of ERD/ERS only, then the mean value from the selected interval is computed. The table represents electrodes, intervals and ERD/ERS in % related to the baseline for two differently demanding tasks (I,II). The table can be graphical interpreted (Fig. 4).

Table 1: ERD/ERS for two tasks and three intervals

Interval	A	A	B	B	C	C
Task	I	II	I	II	I	II
O'1	52	62	-2	31	-6	34
O'2	-9	5	-14	0	-9	4
O'3	-9	1	-8	-6	-8	-24
O'4	-5	-13	-5	-15	5	-16

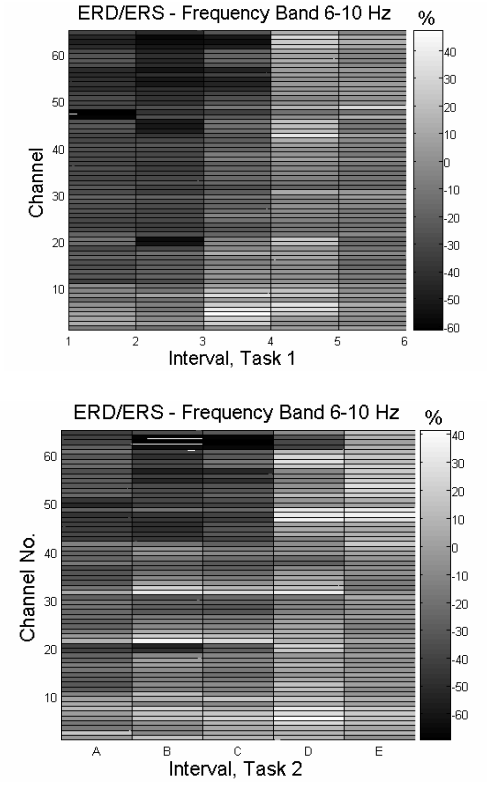

Figure 4: An example of ERD/ERS differences for sixty contacts and five intervals during easy (up) and more difficult (bottom) task. Selected frequency range is from 6 to 10 Hz. Usually the most reactive electrode contacts from defined brain areas are selected for additional interpretation.

In the case we analyse the ERS/ERD peak maximum/minimum and latency, the envelope of power is smoothed by floating window.

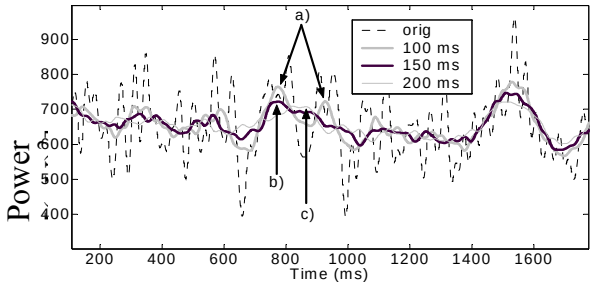

Figure 5: An example of analysed EEG power envelope in the frequency band (35-45) Hz. Using 100 ms (a), 150 ms (b) or 200 ms (c) floating window different graphical elements (maximum, minimum and latency) can be determined.

Detection of the latency can be multiple-valued and depends on the type of evaluation method and its parameters. The described analysis using smoothing floating window with different sizes can prevent the incorrect latency detection. Sharp peaks are detected using smaller window sizes whereas gradual changes in EEG power (wider peaks) are detected with an increasing window size.

Statistical analysis

Because of low signal to noise ratio (SNR), in comparison to scalp measurement, results were verified by methods of statistical analysis-method of credits (based on determination of SNR) and supplemented by pair-matched Wilcoxon tests.

Credits

Credits determinate the credibility of the useful signal in accumulated data (Fig. 6) using following equations 2 and 3.

$$C_{\max} = \frac{(A_{\max} - A_{mean})\sqrt{N}}{STD_{\max}} \quad (2)$$

$$CB_{\max} = \frac{(A_{\max} - A_{mean})\sqrt{N}}{STD_{baseline}} \quad (3)$$

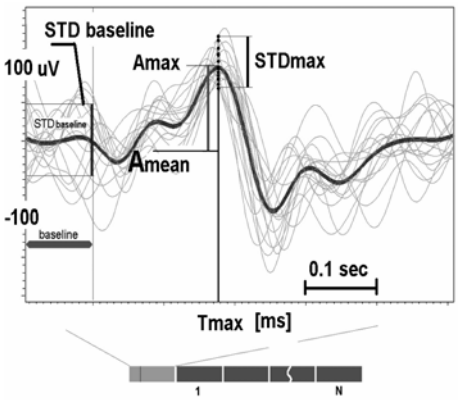

Figure 6: Computing of C_{max} and CB_{max} credits. C_{max} is related to maximal deviation, CB_{max} to baseline

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deviation. A_{max} is maximal amplitude of the accumulated signal, A_{mean} mean amplitude, STD_{max} standard deviation of all segments in the intersection of T_{max} line. T_{max} is the time position of the A_{max}, $STD_{baseline}$ is a standard deviation of all segments in baseline region and N number of accumulated segments.

Wilcoxon tests

The statistical significance of the differences between mean power observed during the reference period and those measured during subsequent after stimulus intervals was expressed as a probability value (p) using a non-parametric Wilcoxon Rank Sum (Signed rank) test for paired samples. Two vectors m_r and m_{ref} of values at the time position for the accumulated baseline maximum/minimum and accumulated response maximum/minimum were collected from all segments. The power changes were considered as significant when $p<0.05$.

In comparison between both methods, Credits helps to evaluate the signal credibility. This method has simpler computation and is more sensitive than robust statistical Wilcoxon test. In all processed data only this method was able to distinguish clearly the convenience of the segmentation method (according to the trigger given by stimulation or reaction). Credits do not replace the pair-matched statistical tests, but by using this method (especially Credit CB_{max} with $STD_{baseline}$ related to the whole data) we can better clarify our view to the significance of the processed EEG data.

Referencing methods

We also focused on the effect of reference electrode known during scalp measurements, where the frequency power of EEG can be affected by uncontrolled oscillations at the reference electrode and where the common average re-referencing is a typical way to avoid this problem.
We concluded that the unipolar reference is sufficient for our goals. Apart from muscular artefacts, which occurred in areas close to eyes (eye movement is recorded by EOG in vertical and horizontal direction), data obtained from deep structures were not affected by any artefacts.
Although all recordings were studied in unipolar reference, data in bipolar reference were processed too (Fig. 7). But there is an additional investigation needed.

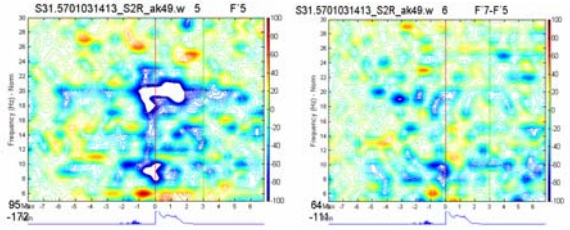

Figure 7: Time-frequency analysis applied on unipolar (left) and bipolar (right) data reference.

Results and conclusions

Because positions of contacts are determined by intended surgery, analysis of EEG data obtained from intracerebral electrodes claims individual subject processing and results discussion. Therefore we were able compare only a few subjects each to other for particular contacts. In spite of this disadvantage, data contain unique information from deep brain structures and obtained results are reproducible.
Described data processing procedure is lot of time consuming. Therefore it is automated as it is possible.

Acknowledgement

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