ANALYSIS OF SIMULTANEOUS EEG AND FMRI DATA

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Abstract: Neurologist are looking for connections between simultaneous EEG and fMRI data, trying to take advantages of both methods. EEG gives them a very good time resolution of the neuronal activity, while a great spatial resolution is provided by the MRI scanner, when the BOLD signal is measured. The analysis of fMRI images is mostly evaluated by the computer program Statistical Parametric Mapping (SPM). The EEG regressor builder is a software which was created in this study. It loads, processes and joins together parameters of simultaneous EEG and fMRI data into the analysis of the SPM. The second part of the study compares results from published analyses with the results calculated by the EEG regressor builder.

Keywords: EEG signal, fMRI imaging, general linear model, regressor, signal processing, statistical parametric mapping

1. INTRODUCTION

Electroencephalography (EEG) and functional magnetic resonance (fMRI) are two different methods of measuring neural activity of the brain. EEG describes electrical activity of neurons measured on the scalp of the head. FMRI imaging is based on measuring of BOLD signal (= blood oxygen level dependent) which corresponds with hemodynamic changes evoked by neuronal activity [1]. Hemodynamic changes are changes the ratio of concentrations diamagnetic oxy-hemoglobin and paramagnetic deoxy-hemoglobin. The joint analysis should yield more accurate results of the analyzed activity. The most common EEG-fMRI analysis uses general linear model (GLM) today [1]. The software *Statistical Parametric Mapping* (SPM; Wellcome Trust Centre for Neuroimaging, UK) serves for the evaluation of the GLM with fMRI data. EEG regressor builder was created because EEG-fMRI analysis is not possible with SPM directly. It preprocesses EEG signals for the joint analysis in the GLM. The software was tested on measured data.

2. DATA

A visual oddball task was performed by 7 persons (5 men, 2 women). There were three stimulus types (single capital letter), which were presented in a random order to the subject. Subjects were instructed to press a button whenever the target (letter X, 15%) appeared and not to respond either to distractor (letters other than X and O, 15%) or frequent (letter O, 70%).

Scalp EEG data were taken continuously during fMRI acquisition using 30-electrode MR compatible EEG system (BrainProducts, Germany). The measuring system was 10/10 with sampling frequency 5 kHz.

The imaging was performed on a 1.5 T Siemens Symphony scanner. Functional T2*-weighted images were acquired using gradient echo, echo-planar imaging sequence. The whole task was divided into four equal runs of 256 scans and 84 stimuli. Following the functional measurements, high-resolution anatomical T1-weighted images were acquired using a 3D sequence that served as a template for the functional imaging.

3. DATA PROCESSING

3.1. GENERAL LINEAR MODEL

After preprocessing, which is not describe here due to space constraints, the functional data enter into statistical analysis by fitting a general linear model (GLM). The calculation is based on linear regression analysis, which assumes that the BOLD signal is a linear combination of a constant member, weighted model functions and a vector of residues [1]

$$\boldsymbol{Y} = \boldsymbol{X} * \boldsymbol{\beta} + \boldsymbol{\varepsilon} \tag{1}$$

where $\boldsymbol{Y}$ represents the matrix of all measured scans (transformed into vectors) in time, $\boldsymbol{X}$ expresses the design matrix, which contains the regressors. The matrix $\boldsymbol{\varepsilon}$ represents the error signal, in other words the residual variability in the data. The program SPM8 estimates $\boldsymbol{\beta}$ matrix (parameters) with help of the least-squares error minimization. Typical regressor, which is occurred in almost each analysis, is a model of stimulation function convolved with the hemodynamic response function (HRF – the BOLD response to impulse neuronal activity) [1].

3.2. ANALYSIS OF CONNECTIONS BETWEEN SIMULTANEOUS EEG AND FMRI DATA

The main interest of the study was to create a software (*EEG regressor builder*) which would bring processed EEG signals convolved with HRF in the GLM as regressors. This step actually combines EEG and fMRI data. It was created to facilitate analysis of a large group of patients. The program allows loading and processing the EEG data according to defined parameters. Regressors are the output that is consequently used in the GLM based statistical analysis. Obtained regressors are saved in data structures used by SPM8.

3.3. EEG REGRESSOR BUILDER

EEG signals from investigated electrodes are separated from the whole EEG dataset. The vector length of the regressor is dependent on the time of one fMRI scan of the brain (TR time). Each EEG signal is divided into as many sections in time as there are the acquired fMRI images. Each section of EEG signal corresponds to the acquisition time TR of one scan. The frequency spectrum is calculated for each section using the discrete Fourier transform (DFT) [2]

$$DFT\{f_{n,a,m}\} = \left\{ F_{k,a,m} = \sum_{n=0}^{N-1} f_{n,a,m}\, e^{-jkn\frac{2\pi}{N}} \right\}, \tag{2}$$

where a is index of an electrode, m is index of EEG section, $f_{n,a,m}$ is a section of EEG signal, k is index of frequency lines in the frequency range $< 0\ ,\ f_{sample} >$ and N is sample number of the EEG section. Spectral lines which lie outside of the interval of interest *(given by input frequency bands)* are then reset to 0 for each input frequency band individually. One power value is estimated for each fMRI scan in each frequency band. Absolute powers are calculated like a sum of power spectral lines of the chosen frequency band [2]

$$P_{a,b,m} = \sum_{k=0}^{N-1} \left| F_{k,a,b,m} \right|^2 , \tag{3}$$

where b is index of the frequency band. Relative powers are evaluated as the filtered absolute powers divided by absolute power $P_{a,m}$ of non-filtered section of EEG signal:

$$\delta P_{a,b,m} = \frac{P_{a,b,m}}{P_{a,m}} \tag{4}$$

Signals of powers *(absolute or relative)* are convolved with HRF and the mean of power is evaluated for each frequency band across input electrodes. The reason of using convolution with HRF is the synchronization between differently timed activities in EEG and BOLD signal.

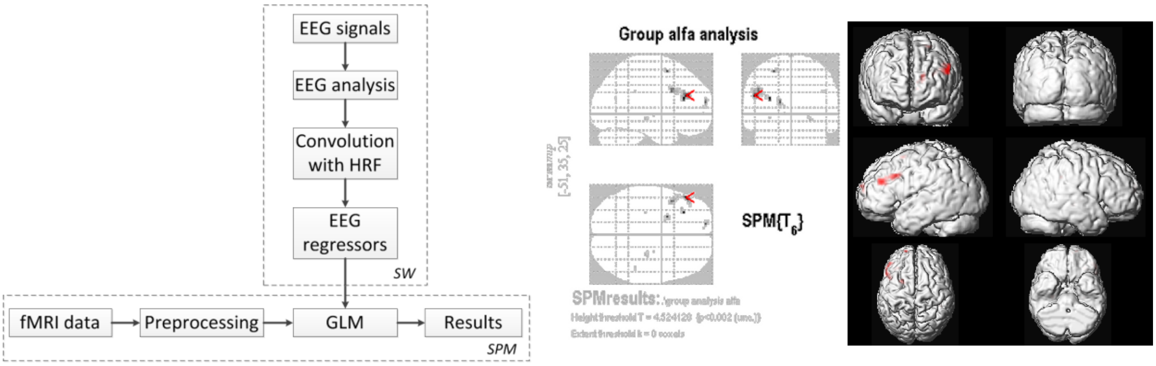

Figure 1: Scheme of analysis (left); Results of EEG-fMRI analysis for α band (right)

4. ANALYSIS AND RESULTS

Regressors of absolute powers were derived from 2 EEG signals from 2 electrodes (O1 and O2) for α band (8-12 Hz). O1 and O2 were chosen because visual stimuli were used and the visual cortex is placed on the occipital part of the brain. The 1st-level statistics was calculated for each measured person. The 2nd-level statistics was set then for the group analysis estimation of the positive correlation between α-band power of EEG and fMRI. 2nd-level statistics was evaluated like one sample t-tests. Activity of the α band was estimated as statistically significant on the left part of the frontal hemisphere with maximal activity in the voxel $[-51, 35, 21]_{MNI}$, ($p < 0.002$ uncorrected). MNI means Montreal Neurological Institute coordinates [1].

5. CONCLUSION

The created software is determined to facilitate the work of neurologists and those who are studying brain activity during common analysis of EEG and fMRI data. Although the relationship between EEG and fMRI data is currently not precisely known, publication of the existence of a negative correlation between α band of the EEG signal and BOLD signal was released [3]. It is not possible to compare the published results with results in this testing study exactly, because resting state data were used there contrary to data with stimuli, which were used here. We found positive correlation with BOLD signal for this case.

The EEG regressor analysis based on the power changes decreases the time resolution of the EEG signal because only a single power value is estimated per one fMRI scan. We assume that the development of the regressor derivation algorithm will continue with new approaches to the extraction of relevant information from EEG data in the future. It might provide a useful tool enabling simultaneous EEG and fMRI data analysis from different points of view. However, it is desirable to find another approach where the time resolution will not be decreased.

ACKNOWLEDGEMENT

The research was supported by grant GACR P304/11/1318. The funding is highly acknowledged.

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