HEURISTIC MODEL IN JOINT EEG-FMRI ANALYSIS

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Abstract: This work deals with the joint EEG-fMRI analysis based on the heuristic model. There is described principle of the heuristic model which assumes that the BOLD (blood oxygen level depend) signal measured by fMRI (functional magnetic resonance imaging) is directly proportional to the spectral shift in the EEG signal. The paper describes algorithm of calculations which was implemented and tested on real data from 22 subjects. The study also monitors effect of different EEG information selection from electrodes of interest (averaging or principal component analysis).

Keywords: heuristic model, simultaneous EEG-fMRI, BOLD, HRF, SPM8, PCA

1. INTRODUCTION

Simultaneous EEG-fMRI belongs to multimodal imaging techniques which use benefits of both, especially better temporal resolution in EEG measurements and much better spatial resolution in fMRI. Scalp EEG records amplified voltage differences between electrodes that are placed on the scalp. fMRI uses changes in the flow of oxygenated and deoxygenated blood in active areas of the brain. Although both modalities simultaneously record the changes of one activity, both are doing it for different signal frequencies. It is 1-40 Hz for EEG after preprocessing and 0,012-0,1 Hz for BOLD signal. Heuristic model uses calculation of neuronal activity from BOLD signal and EEG signal. This empirical model uses dimensional analysis and biophysic model, describes the relationship between changes of EEG spectrum and the BOLD signal during neuronal activity [1], [2], [3].

2. DATA

Same visual oddball simultaneous EEG-fMRI data with same data preprocessing steps from 22 subjects (7 women, age 23±2 years; 1 left-handed man) were used as in Labounek and Lamoš EEICT 2012 study [4].

3. JOINT EEG-FMRI ANALYSIS

3.1. THE HEURISTIC MODEL

The heuristic model of joint EEG-fMRI analysis assumes that hemodynamic changes which are measured by fMRI reflect energy of neuronal changes. We can assume that the BOLD signal at every moment is proportional to the energy dissipation of neurons. We can say that the BOLD signal is directly commensurate to the transmembrane current and transmembrane potential. This premise will not be true immediately. Increase of oxygen supplying occurs with a time lag against of neuron energy dissipation, which we are able to measure with EEG. Kilner et al. declared the neuronal model and the effect of the neuronal activity on the BOLD signal and the EEG signal [1].

Brain activity leads to a shift of the spectrum of EEG signal to higher frequencies. In the spectrum is apparent loss of lower frequencies compared to higher frequencies. And simultaneously, the total

power of the spectrum decreases. This shift of spectrum characterizes activation of neurons. Neuronal activity leads to an increase in the BOLD signal. Based on Kilner et al. model, BOLD changes are directly proportional to the EEG spectrum shift and can be expressed with following equation [1].

$$(\frac{b'}{b})^2 \sim (1+\alpha)^2 \sim \frac{\int \omega^2.p'(\omega)d\omega}{\int \omega^2.p(\omega)d\omega} \quad (1)$$

Where b‘ is value of BOLD signal during activation of neuronal population, b BOLD in stationary phase. α is the neuronal activation, ω is frequency of EEG signal and p‘ is normalized power spectrum during activation and p normalized power spectrum in stationary phase [1].

3.2. EXTRACTION OF USEFUL INFORMATION FROM EEG AND FMRI DATA

For simplicity, we can assume stationary phase as a constant value. If we choose the denominator which corresponds with stationary phase as a constant value, we can modify the formula (1) to next form [2].

$$b' \sim \sqrt{\int \omega^2.p'(\omega)d\omega} \quad (2)$$

If we calculate the vector values of the EEG spectrum shift corresponding to the fMRI scanning repetition times (TR), we can use this vector as a regressor in a general linear model for finding BOLD based active sections of the brain related to the shift [2].

3.3. ALGORITHM OF DATA PROCESSING

In the Figure 1, you can see block diagram of the analysis. A vector of normalized power values with EEG spectrum in the times of fMRI scans is calculated in the first step. In the first approach, vectors are calculated for each electrode separately and then are averaged across the electrodes of interest (all 30 electrodes). Second approach uses the principal component analysis (PCA). Main components are computed from the electrodes of interest using PCA. Vectors of spectrum shifts are calculated from these components. Third access computes vectors from each electrode of interest and PCA is used on these vectors. We want to extract signal coming from activated brain regions by using PCA, which is reflected in some of the components computed from all electrodes. The exact component location should be then estimated with fMRI data fusion. In this work, each approach is individually evaluated. When we have vector of spectrum shift values, we need to convolve this vector with hemodynamic response function (HRF) which is an impulse response function of hemodynamic model. HRF models the delay in BOLD signal compared to beginning of the neuronal activity. By contrast, EEG spectrum shift occurs immediately after beginning of neuronal activity. Furthermore, the vector values are normalized and enter as a regressor into general linear model in statistical analysis with fMRI data. Statistical Parametric Mapping version 8 (SPM8, *Wellcome Trust Centre, London*) is used for this analysis.

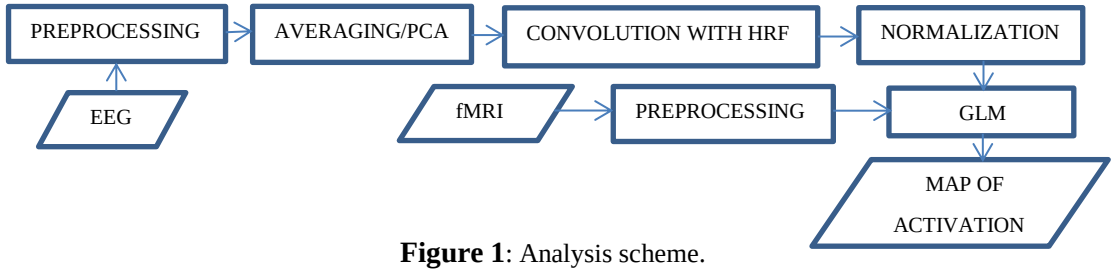

Figure 1: Analysis scheme.

3.4. DATA ANALYSIS

There were calculated activations maps based on EEG spectrum shift regressors from averaging method and from PCA methods. Single subject analysis was performed as separate GLM estimation for each regressor method calculation. Group analysis across subjects was computed as one sample t-test separately for each regressor method calculation and evaluated with p-value of statistical significance <0.001 uncorrected for multiple testing errors.

4. RESULTS

Results with group EEG-fMRI activation map for averaging of electrodes, you can see in the figure 2 on the left side. For comparing, you can see same group result from 1st component calculated from EEG data in the middle. This component describes the biggest variability in EEG data. On the right side, you can see same group activation map from 1st component from vectors of the spectrum shift. Correlation coefficients for regressors from all 30 components were calculated and showed that some of regressors are highly correlated and thus some components carry similar information describing information about neuronal activity. For this reason, it is inappropriate to use all regressors into one model matrix of the general linear model. We must create own model matrix for each regressor.

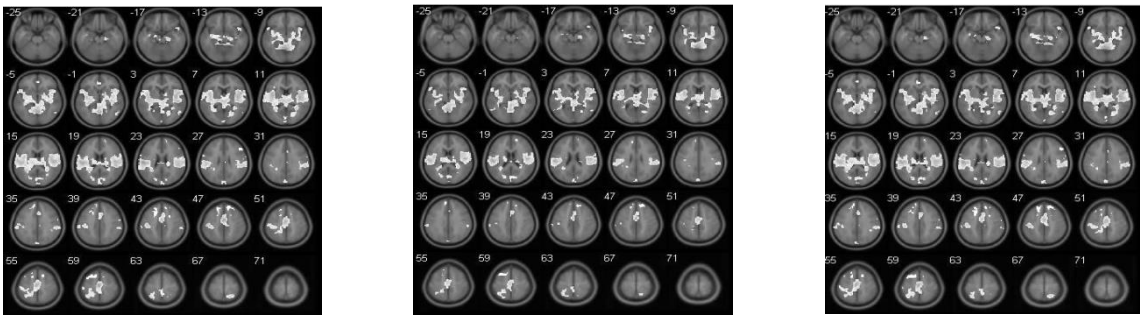

Figure 2: Activations maps calculated for averaging electrodes of interest (left), 1st component from EEG data (in the middle), 1st component from shift of spectrum (right).

5. CONCLUSION

The aim of practical part was to extend the program EEG Regressor Builder about joint analysis based on heuristic model. We can see from figure 2, different methods of calculations can produce more or less different final results of group activation maps. We are able to see that activations maps for the 1st component from EEG data and 1st component of spectrum shift are very similar. In comparison to the averaging of electrodes, components contain fewer active areas. But it is possible that this effect could be affected only with statistical thresholding and that averaging gives only higher statistical significance than PCA components.

In future work, we would like to compare this results with results obtained from relative power based regressors which were computed with same dataset. To extract other useful information about the neural activity from all EEG electrodes, we would like to use independent component analysis (ICA) and to compare them with results from averaging of the electrodes and from PCA. With ICA, we could get components which could be associated with different neuronal activities. Most ideally, some of them could be related to specific task-external stimuli.

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