fMRI and concurrent EEG in patients with focal epilepsy: Processing of EEG signals for fMRI analysis

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Introduction
Two ways of performing fMRI with concurrent EEG are possible: fMRI sequence triggered manually after identification of inter-ictal spikes [1] or continuous and simultaneous fMRI and EEG acquisition. First method suffers from arbitrary selection of waiting time between appearance of inter-ictal spikes and fMRI acquisition, nonuniform MR image contrast due to T1 saturation, possible nonefficient lengthy examination which can deteriorate results due to patient movements and nonflexibility of evaluation in cases when patients have series of spikes (it applies simple "ON/OFF" paradigm). Second method is more promising if it is possible to separate "true" EEG signal from artifacts due to changing gradient fields and ballistocardiographic artifacts.

Patients and Methods
15 patients with focal epilepsy were examined in 1.5 T MR scanner. T2* weighted EPI sequence for acquisition of 16 slices (128x128 matrix) with TR=6 sec ("true acquisition time" 2400 ms), flip angle 90 deg. 300 volumes were acquired (30 min.) if patient condition allowed such examination. EEG was performed with MR compatible equipment (16 channels, 1000 Hz sampling rate). After examination, EEG was processed using in-house developed software capable of automatically identifying MR-gradient artifacts (onsets of MR gradient artifacts were used for - time scaling with fMRI data) and to eliminate them using selective averaging filtering technique (two components were present: long term - exponential decay component and short-term gradient bursts) -possibility of linear separation of "true EEG signal" and MR gradient induced artifacts is shown in [2] and [3]. With our algorithm it was possible to eliminate gradient induced artifacts within one volume acquisition. After reduction of MR gradient artifacts EEG signal was examined for determination of inter-ictal epileptiform activity. Inspection of EEG signal was performed by experienced neurologists. Windowed FFT (Gabor transform) was performed in the areas of marked spikes, to get characteristic spectral power of the interictal spikes for the EEG channel with highest spike amplitude. As a result of EEG analysis 3 data sets were produced which were used for SPM [4] data analysis: 1. Easiest "ON/OFF" - correlation, 2. "modulation" of data with the frequency of interictal spikes, 3. Analysis with model which was taking in account spectral power of individual inter-ictal spikes.

Results
In 3 cases there were no reliable activations - due to lack of inter-ictal spikes and/or large motion. "ON-OFF" paradigm was successfull only in one case, and in 8 cases, successful using second method. With third method, the most general form of General Linear Model, 12 patients showed activation which was in good correspondence to the clinical data and EEG data. Results for one child with Rolandic epilepsy are shown on Fig1-Fig3.

Discussion and Conclusion
Most convincing results were obtained in cases of Rolandic epilepsy (3), but the other fMRI results were also in good agreement with EEG findings. Inter-ictal spikes may vary in amplitude and this must be taken in account for fMRI analysis in cases where those amplitudes are significantly different. In cases in which amplitudes do not differ significantly and there is high frequency of spike onsets, frequency of interictal spikes reliably modulate hemodynamic response.

Conclusion: EEG signal during fMRI examination can be reliably coupled with fMRI using general linear model, which appeared to be valid also in cases with very high frequency of inter-ictal spikes. Activation maps represent - volume which is affected by interictal epileptiform activity - useful for EEG localization modalities - which are heavy model dependent (single point sources - one or multiple dipoles, dielectric properties of the head). Method which we presented can be used in other cases of EEG&fMRI examinations (evoked potentials, alpha-waves, K-complexes in sleep). With this method of EEG&fMRI examination it is also possible to determine hemodynamic response function.

References