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Source Concordance Analysis of Simultaneously Recorded Steady State Visual Evoked Potentials and fMRI

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The aim of the study;

- As the temporal resolutions of EEG and fMRI are in different scales, a reliable exploration of the relationship between the neuroelectrical activity patterns and the hemodynamic response requires the alignment of the temporal resolution of both signals on a common scale. Steady-state evoked potentials are well-controlled rhythmic EEG patterns that are stationary for the time period of the BOLD signal.
- In this study, a direct comparison between the steady state EEG and BOLD activities is performed on the spatial domain. Steady state visual evoked potentials (SSVEP) and BOLD responses are recorded simultaneously with photic stimuli at 6, 8 and 10 Hz. SSVEP data is projected to the source space. Afterwards, unimodal GLM analyses are performed for the fMRI and EEG source images. Finally, spatial concordance of the statistically corrected fMRI and EEG source maps are investigated.

Which methods did we use?

- The neuroimaging analyses are performed separately for the simultaneously recorded SSVEP (30 channels) and fMRI data of 32 subjects.
- Prior to the fMRI data analysis, spatial preprocessing steps are performed using SPM8 toolbox.
- All images are spatially normalized into a standard space (MNI152, 2mm). GLM time series analysis with local autocorrelation correction is used to find BOLD related signal changes devoting the visual stimulation periods from the rest periods.
- Resulting contrast images are used as inputs to one-sample t-test to extract the voxels whose mean activation is significantly greater than zero. Apart from this, EEG data is projected to the source space to form source energy maps.
- Forward problem is solved to compute the lead field matrix using the 5124 vertex points of the segmented cortical mesh [1]. The EEG source reconstruction methodology based on empirical Bayes approach [2] enabled us to compute the source energy within a given frequency band.
- The SSVEP source energy maps are extracted at the fundamental frequency of the stimulus and its two harmonics. By selecting the time resolution for the source energy computation as the TR value, EEG source images are formed within the time resolution of the fMRI.
- The same approach used in fMRI analysis is applied to EEG source images.
- In the GLM design matrix, the experimental paradigm onset vector is used and the computed contrast images are used in the second level analysis. The thresholded images are obtained using corrected threshold with $p<0.05$.

What were our findings?

- ✓ Unimodal fixed effect analysis of BOLD time series for each stimulus frequency yielded significant activations in the occipital lobe especially in the primary (BA17), secondary visual areas (BA18, BA19) and lingual gyrus.
- ✓ The extent of the fMRI activation maps were approximately similar for all stimulation frequencies.
- ✓ On the other hand, SPM analysis of EEG source energy maps for each stimulus frequency exhibited significant increase of activity in stimulation blocks mainly in the primary and secondary visual cortices near the surface.
- ✓ All of these activations were observed as spatial subsets of the activation maps obtained from the corresponding fMRI time series.

To conclude

- ❑ The results show that synchronized EEG rhythms evoked with steady-state visual stimulation around the alpha frequency in contrast to the spontaneous alpha rhythm [4] necessitate an increased cortical metabolic demand, which can be observed in the result that the sources of the driven electrical rhythms consist of a subset of the hemodynamic activation maps.
- ❑ Whether the electrical activity in the voxels near the scalp surface with a significant BOLD increase are reflected in other characteristics of the EEG than the SSVEP response, needs further analysis of the data including the modulation of spontaneous activities as for example the desynchronisation of the on-going alpha rhythm in visual stimulation blocks.

Thanks to

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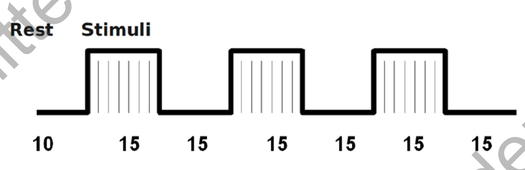
What did we cited?

[1] Esposito, F., Aragri A., Piccoli, T., Tedeschic, G., Goebel, R., Di Salle, F. (2009), 'Distributed analysis of simultaneous EEG-fMRI time-series: modeling and interpretation issues', Magnetic Resonance Imaging, vol. 27, no. 8, pp. 1120–1130.
[2] Phillips, C., Mattout, J., Rugg, M.D., Maquet, P., Friston, K.J. (2005), 'An empirical Bayesian solution to the source reconstruction problem in EEG', NeuroImage, vol. 24, no. 4, pp. 997–1011.
[3] Nunez, P.L. (2000), 'Toward a quantitative description of large-scale neocortical dynamic function and EEG', Behav Brain Sci, vol. 23, no. 3, pp. 371-398; discussion 399-437.
[4] Goldman R., Stern J., Engel J., and Cohen M. (2002), 'Simultaneous EEG and fMRI of the alpha rhythm', NeuroImage, vol. 180, no. 13, pp. 2492–2587.

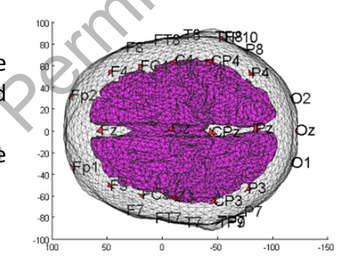
Experiment Paradigm

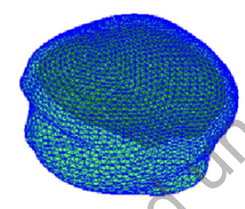


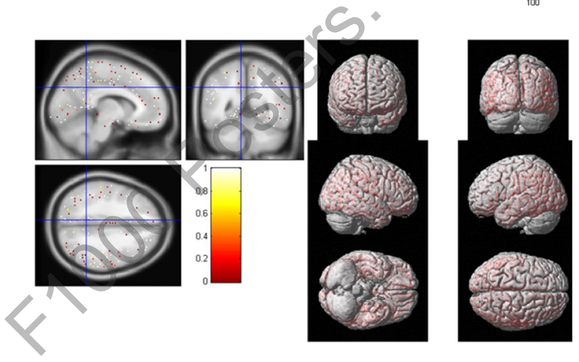
LEDs are used to present the stimulus. Stimuli start with a rest period of 10 TR duration (TR=2.98 seconds)

- 1.5 T Philips – Achieva (Neuropsychiatry – Istanbul Hospital)
- 30 channels EEG and 1 channel ECG (BrainAmp MR+, Brain Products, Germany).
- MR scanner and the EEG digitizer synchronized using SynchBox (Brain Products, Germany)
- EEG signals between 0.01 and 250 Hz digitized with a sampling rate of 5 kHz.

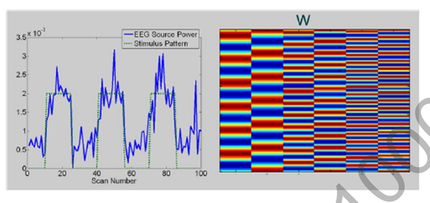
•Scalp, skull and brain surfaces are trianguated to form the realistic head model.
•EEG electrodes are registered to the realistic head model.



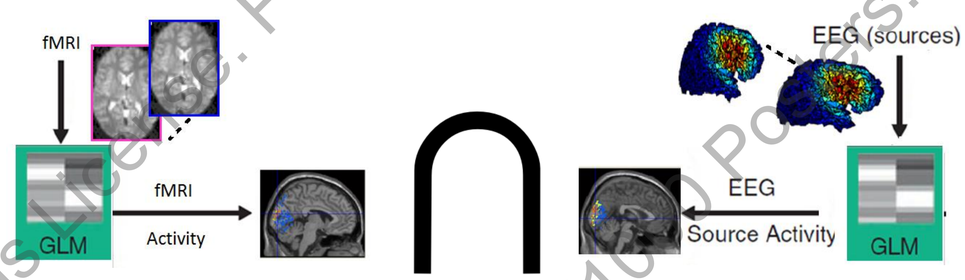




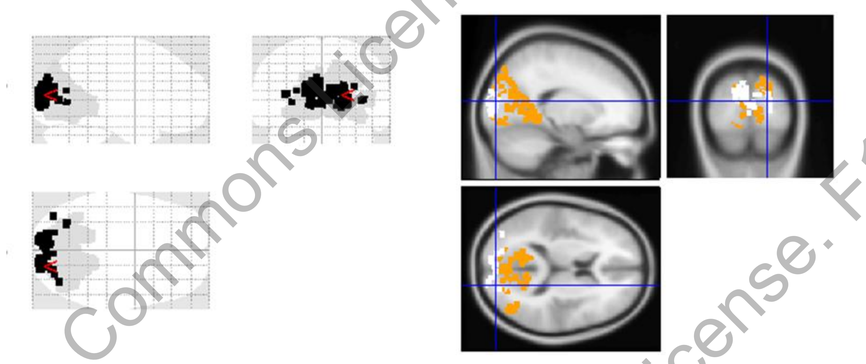
•Gray matter – white matter boundary is sampled to form inverse solution space and denoted with dots.
•5124 vertex positions are selected (red points)



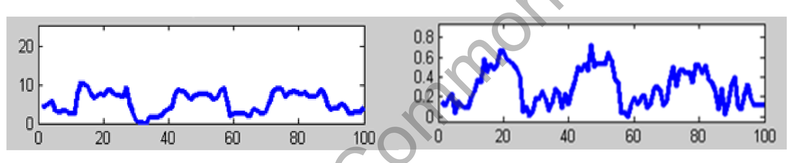
•EEG source energy maps are computed using time-frequency constraint matrix. The matrix consists of the stimulation frequency, first and second harmonics of the stimulation frequency for 6 Hz (right part of the figure).
•EEG source power of a voxel (left of the figure)



•fMRI activity and EEG statistical maps are obtained through the GLM analysis.
•Activity maps are spatially intersected.



Orange points denote the activation pattern of the fMRI recordings at 8Hz stimulation frequency while the white dots represent the EEG source activity in a glass brain view. White dots are the subset of the fMRI activation map.



Left: The mean fMRI BOLD change of the activated voxels. Right: Mean EEG source power series of the activated voxels.