

## User Research

### Spatial filters for concurrent EEG/fMRI

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#### Introduction

Blood oxygenation level dependent functional MRI (BOLD fMRI) has revolutionized the field of neuroscience by providing a non-invasive means of mapping the spatial distribution of brain activity. The technique achieves excellent (~1mm) spatial resolution, particularly at high magnetic field. However the protracted haemodynamic response means that fMRI suffers from poor temporal resolution. Electroencephalography (EEG) measures the electrical potentials generated at the scalp by neuronal activity, and therefore offers excellent temporal resolution, but the ill-posed EEG inverse problem and inhomogeneous conductivity profile in the head mean that its spatial resolution is poor. For these reasons, concurrent fMRI and EEG measurements represent an attractive technique to image human brain function with high spatial and temporal resolution. Unfortunately, simultaneous measurement of EEG and fMRI is made difficult due to EEG artifacts caused by the MR scanner. Techniques are available to remove such artifacts, however, even after correction, some interference remains in EEG data. This is a particular problem at high magnetic field. In this article we summarise our recent work on the application of spatial filters to EEG data recorded concurrently with fMRI. We demonstrate beamformer approaches that, if applied in addition to standard correction techniques, reduce residual artifacts in EEG data. In addition this approach allows for electrical source localization and extraction of time course estimates from regions of interest in the brain.

#### Spatial Filters

A spatial filter can be thought of as being somewhat analogous to a frequency filter. In much the same way as a frequency filter extracts components of a signal containing a particular temporal characteristic; a spatial filter extracts the components of a signal with a specific spatial characteristic. This means that it retains signals that originate at some predetermined location in space. The spatial filter to be used is a linearly constrained minimum variance (LCMV) beamformer<sup>1</sup>. Using the beamformer, an estimate of electrical activity at some predetermined location in the brain is constructed based on a weighted sum of the EEG electrode measurements. The weighting parameters are based on power minimization; the overall power in the beamformer-estimated signal, within a time-frequency window of interest, is minimized, with a linear constraint that power originating from a source at some location of interest must remain in the output signal. The output is a time course estimate of electrical activity at the chosen location. Sequential application of this algorithm to a number of locations (voxels) in the brain can yield volumetric images of source power. Further, computing source power in stimulus specific 'active' and 'control' time windows results in a volumetric image of stimulus induced change in electrical power. The beamformer acts as an efficient means to reduce interference. This is because in general, the spatial topography (at the EEG sensor level) of interference fields differs from that of genuine electrical sources in the brain. Since interference fields do not appear to originate from any chosen brain location, they are rejected by the beamformer.

#### Experimental Evidence

In our initial experiments<sup>2</sup>, concurrent EEG/fMRI data were collected using a Philips Achieva 3T MR system and a Brain Products MR compatible 32 channel EEG system. Subjects were asked to passively view an alternating (8.6Hz) checkerboard pattern, which was presented at two contrasts (Michealson contrasts of 0.5 and 1). A single trial comprised 6s visual stimulation followed by 14s rest and 30 trials were presented. Echo planar images (3.25x3.25x3.0mm<sup>3</sup> resolution; 64x64x20 matrix; TE = 40ms; TR = 2.2s; SENSE factor 2) were acquired concurrently with EEG (recording frequency 5kHz). The EEG and MR sampling clocks were synchronised to allow maximum artifact removal using subtraction techniques. The locations of the electrodes on the scalp surface were recorded using a Polhemus isotrack 3D digitiser. The shape of the subjects head was also digitised and this was fitted to the extracted head shape from the subject's anatomical MRI in order to compute the location of each electrode with respect to the brain anatomy. EEG data were pre-processed using Averaged Artifact Subtraction (AAS)<sup>4</sup> in BrainVision Analyzer. Following this, data were down-sampled to 600Hz and processed using custom written beamformer algorithms in Matlab. Figure 1 shows the results from a single subject. The image on the left shows areas of significant electrical (upper panel) and haemodynamic (lower panel) activity. Timecourses extracted from regions of interest in the visual cortex are shown on the right. The oscillatory electrical response is clear in the upper plot; the red trace represents half contrast, whilst the blue trace represents full contrast. The protracted haemodynamic responses to full and half contrasts are shown in the lower plot.

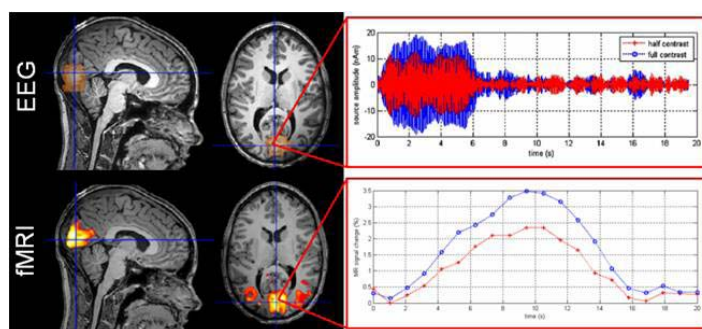


Figure 1: Results of the 3T visual experiment<sup>2</sup>

Following experiments at 3T, phantom experiments were conducted to investigate the feasibility of the beamformer approach at 7T<sup>3</sup>. A 1 cm long current dipole was placed in a spherical conducting phantom. An 8.5Hz oscillating current was applied to the dipole to simulate brain activity. MR data were collected using a Philips Achieva 7.0T scanner (96x96x20 matrix, 2mm isotropic voxels, TE = 25ms, TR = 2.2s, SENSE factor 2). EEG data were recorded using a Brain Products 64 channel system and electrode locations were digitised. Again, AAS was applied to the data, followed by custom written beamformer algorithms. Results are shown in figure 2. The image on the left shows that the beamformer approach accurately localizes the dipole within the phantom. Power spectra on the right

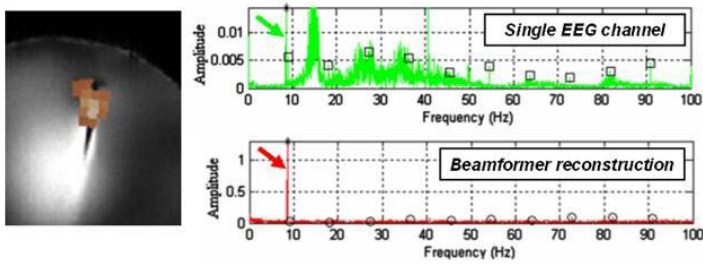


Figure 2: Results of the 7T phantom experiment<sup>3</sup>

show the reduction in residual interference that the beamformer provides. The upper plot shows the best EEG channel recording, whereas the lower plot shows the beamformer reconstruction. The marked peaks in the power spectra represent the fundamental frequency of the MR gradient waveform repetition and its harmonics. Note that this residual gradient artifact, remaining after AAS, is largely eliminated by beamformer application.

In the final experiment<sup>3</sup>, concurrent EEG/fMRI data were acquired from two subjects who underwent a median nerve stimulation experiment by beamformer application, whereas the 8.5Hz signal of interest remains prominent. The subjects median nerve was stimulated by applying a small voltage across two electrodes placed on the wrist. This experiment was conducted at 7T. Data acquisition

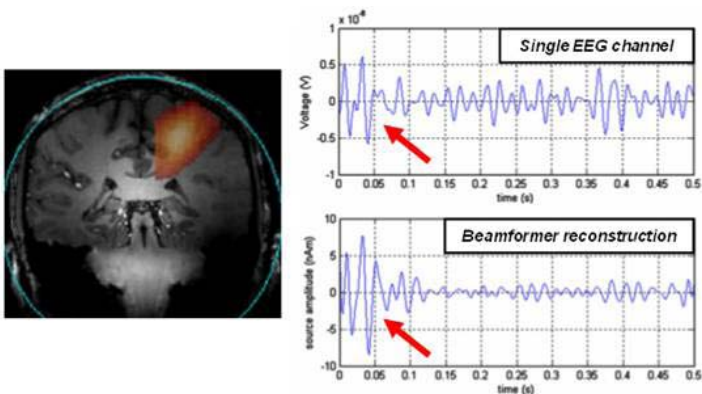


Figure 3: Results of the 7T somatosensory experiment<sup>3</sup>

and processing were carried out in the same way as for the phantom experiment. Results are shown in figure 3. The image on the left shows beamformer localisation of the evoked response. The plots on the right show time course estimates of electrical activity in the gamma band (50Hz-100Hz). Notice that using the beamformer technique, gamma band oscillations are apparent in the ~100ms window following median nerve stimulation. This is in agreement with published MEG results. These gamma oscillations were not apparent in single channel EEG data.

## Discussion

These initial results show that the beamformer is a promising approach for data processing in concurrent EEG/fMRI. The beamformer allows localisation of stimulus induced changes in electrical brain activity and these appear to be in approximate agreement with the associated changes in haemodynamics. In addition this approach allows extraction of time course estimates of electrical activity from regions of interest. Most importantly, the beamformer technique acts as a means to reduce residual interference from non-brain related sources in EEG data recorded concurrently with fMRI. This represents an advantage, particularly at high field where artifacts can remain even after data correction using, for example, AAS. Our recent work<sup>3</sup> has shown that this interference rejection is not afforded using other source localisation methodologies such as dipole fitting.

There are limitations to the beamformer approach. Firstly, it is reliant on an accurate EEG forward solution. In these initial studies we used a simple volume conductor model comprising three concentric spheres to represent brain, skull and scalp. Whilst this proved adequate, better accuracy in localisation would result from more realistic head models. Secondly, in these experiments the locations of EEG electrodes on the scalp were recorded using a 3D digitizer. This process increases the total experimental time. In addition, some labs may not have access to a 3D digitizer. The beamformer methodology is sensitive to the accuracy of electrode locations and it remains to be seen whether the use of standard electrode positions would result in an accurate output. Ultimately the solution would be to construct MR visible EEG electrodes. ●

## References

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