A comparison of source localisation techniques in concurrent EEG/fMRI

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Introduction: Simultaneous fMRI and EEG is an attractive means by which to investigate non-invasively human brain function. The combination of the two techniques offers high spatial and temporal resolution. Furthermore, the two metrics derive from different physical mechanisms (electrical activity and haemodynamics) meaning that their combination may shed light on the process of neurovascular coupling. Recent work[1] has shown that it is possible to localise sources of electrical activity using EEG data recorded during simultaneous fMRI. Further it was shown that source localisation can reduce the level of interference in EEG timecourses caused by the MR scanner. Previous work was however conducted *in vivo*, meaning that the accuracy of source localisation and time course estimation could not be tested. In this study we employ an EEG dipole phantom to achieve this. *A priori* knowledge of the dipole location and timecourse allows assessment of the accuracy of two source localisation techniques (dipole fitting and beamformer) which are tested in the presence and absence of MR gradient fields. The interference reduction properties of beamformers and dipole fitting are compared, and the advantages of high EEG channel density discussed.

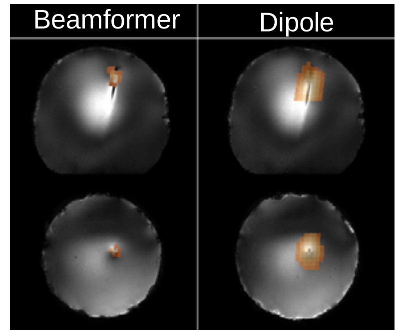

Fig. 1. *Localisation of the dipole using beamformer and dipole fitting. Sagittal (top) and axial (bottom) aspects shown*

Methods: A 1 cm long current dipole was placed in a spherical homogeneous conducting (1±0.3S/m) phantom[2] and orientated in the x-y plane. An 8.5Hz sinusoidally oscillating current was applied to the dipole to simulate an active current dipole. An MR compatible EEG cap with 64 Ag/AgCl electrodes (EasyCap, Herrsching, Germany) was placed on the phantom which was then placed in the MR scanner.

MR data were collected using a Philips Achieva 7.0T scanner running EPI (96×96 matrix, 2mm isotropic voxels, TE = 25ms, TR = 2.2s, SENSE factor 2). 20 contiguous transverse slices were acquired. The slice acquisition frequency was 9.1Hz meaning that gradient artefacts occurred at this frequency and its harmonics. EEG data were recorded using a BrainAmp MR+ amplifier and Brain Vision Recorder (Brain Products, Munich, Germany). Experimental set up followed the protocols described by Mullinger *et al*[3].

132s of simultaneous EEG/fMRI data were collected with the 8.5Hz oscillating current set with peak-peak (p-p) dipole strength 10±2nAm. A further 132s of data were collected with p-p dipole strength 24±2nAm and a final 132s of data were collected with the dipole switched off. This was then repeated without simultaneous fMRI, but with the phantom *in-situ*. An MPRAGE structural image of the phantom was also acquired (1mm^3 isotropic voxels, 256x256x160 matrix, TR = 8.1ms, TE = 3.7ms, TI = 960ms, shot interval = 3s, FA = 8° SENSE factor = 2). Three MR visible markers were placed on the phantom surface. The locations of all EEG electrodes were measured relative to these markers using a 3D digitiser (*Polhemus isotrack*). The locations of the electrodes relative to the MR scanner were then found by matching digitised marker locations to their equivalent positions in the MPRAGE image.

Dataset	Image type	Difference between localisation and MR image	Standard deviation of mean location
Gradients	*Dipole fit*	1.2 cm	0.7 cm
Gradients	*Beamformer*	1.1 cm	0.4 cm
No Gradients	*Dipole fit*	1.1 cm	0.1 cm
No Gradients	*Beamformer*	1.0 cm	0.3 cm

Table 1*: Quantitative assessment of accuracy of source localisation*

EEG data were corrected for gradient artefacts using AAS[4] in *Brain Vision Analyzer*. Following this, EEG data were analysed using custom-written algorithms in MATLAB. Beamformer and dipole fitting were used to localize the dipole. For both techniques, the forward model was based on a conducting sphere[6]. 50 images were constructed using different data segments. The average and standard deviation of the position of the maximum in the source images were computed. The peak location was compared to the site of the dipole identified in the structural MR image. Source images were derived using data recorded with and without simultaneous MR acquisition.

Having localised the dipole, the interference correction properties of the beamformer and dipole fit were assessed using different channel counts. For this purpose, only data recorded with MR gradients were used. The time courses of electrical activity were derived from locations based on the peaks in the functional images generated using beamforming and dipole fitting. These time courses were Fourier transformed and amplitude spectra plotted.

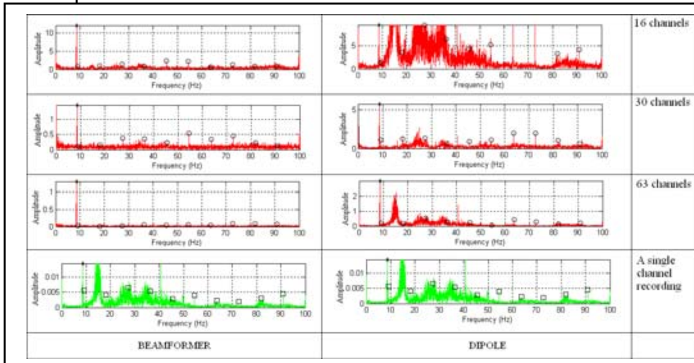

Fig. 2: *Amplitude spectra of EEG signals recorded during concurrent fMRI.*

Results and discussion: Figure 1 shows the results of source localisation in the phantom. Quantitative analysis of source localisation is given in Table 1 (for a dipole strength of 24nAm). Results suggest little difference in accuracy between source localisation methods, although the peaks in the dipole fit images were generally more diffuse than those in the beamformer images. Results show little dependency on MR field gradients. For both techniques, localisation errors were largest in the radial direction with the dipole location appearing ~1cm deeper than its apparent location in the MR image. This is because the dipole used is an extended source, whereas the model[6] assumes a point source.

Figure 2 shows amplitude spectra of the beamformer and dipole signals reconstructed using 16, 30 and 63 channels (source strength 10nAm). The amplitude spectrum of the best single channel recording is also shown for comparison. In all cases the 8.5Hz signal of interest can be seen. Whereas source localisation demonstrated little dependence on localisation technique, here we see a clear benefit to using the beamformer reconstruction. Beamformer estimated spectra exhibit significantly less interference than dipole-estimated or single channel spectra. Beamformer results also improve as the EEG channel count is increased[5]. The marked peaks in the spectra represent signals at the frequency of repetition of gradient waveforms and its harmonics, showing that that AAS alone does not completely attenuate gradient interference. Results suggest that AAS + 63 channel beamforming allows for significant improvement. Interestingly, the dominant residual interference is not at the gradient frequencies. Results show that source localisation acts to reduce this additional interference, and 63 channel beamforming eliminates it.

Conclusion: We have shown quantitative evidence that both dipole fitting and beamformer techniques can be used for accurate source localisation in concurrent EEG/fMRI. The beamformer is markedly more effective at reducing interference in a time course estimate, as shown in Figure 2. Source localisation using beamformers will therefore be an important tool in concurrent EEG/fMRI, particularly at high magnetic field where the magnitude of the EEG artefacts is increased.

References: 1) Brookes *et al*. NeuroImage, 40, 1090–1104, 2008. 2) Giersdottir *et al*, abs 3626, Proc. ISMRM 2008, Toronto. 3) Mullinger *et al*, MRI 26 (7) 968-977, 2008. . 4) Allen *et al*. NeuroImage 12, 230-239,2000. 5) Brookes *et al*, abs 2429, Proc. ISMRM 2008, Toronto. 6) Zhang, Phys. Med. Biol. 40:335-349. 1995.