A Model Phantom for Investigating Concurrent EEG/fMRI

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Introduction: Simultaneous EEG/fMRI is a technique that makes functional imaging with high spatiotemporal resolution possible. However, the pulse and gradient artefacts induced in EEG recordings make this challenging [1]. Several methods have been developed to remove such artefacts, but complete removal is still not possible, particularly at ultra high field (i.e. 7T) [1-3]. The use of an EEG phantom to conduct simultaneous EEG/fMRI experiments provides a means for validating and improving artefact rejection techniques, and for investigating possible sources of the observed artefacts. Here, two different types of saline loaded agar phantoms are described, a dipole phantom which enables measurements of signals with a specific timecourse, and a flow phantom with an added aqueduct designed to mimic blood flow.

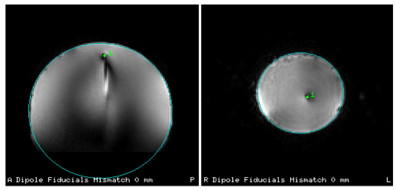

Figure 1: MR images of the dipole phantom

Methods: A 1cm long current dipole was placed in a spherical (10cm radius) phantom with the dipole oriented in the x-y plane. The phantom was made from 4% w/v agar and 2.5% glycerol, dissolved in a 154mol/L NaCl solution. The conductivity of the agar was measured as 2.7(±0.3)S/m. A 220kΩ resistor was connected in series with the dipole and a 9.9Hz sinusoidal signal of p-p amplitude 5, 10 or 22V applied, giving dipolar source strengths of 227, 454 and 1000nAm respectively.

7T Experiment: EEG data were recorded with a 64 channel *Brain Products* EEG system at a 5kHz sampling frequency. EPI data were acquired simultaneously using a 7T Philips Achieva MR scanner (scan parameters TR= 2.2s; TE=25ms; 96×96 matrix; voxel size 2×2×2mm; 20 axial slices). The scanner and EEG system clocks were synchronised to allow for improved artefact correction [4-5] with markers placed at the beginning of each volume. A T_1-weighted image was also acquired. EEG electrode positions with respect to the phantom were obtained using a 3D digitiser (Polhemus Isotrack).

In order to compare the potentials measured at the surface of the phantom with those expected theoretically, gradient artefacts were initially corrected in *Brain Vision Analyzer* using averaged artefact subtraction (AAS) [1]. Corrected EEG data were then Fourier transformed (FFT) and the spatial topography of the 9.9Hz peak plotted. A forward model [6] was estimated using a dipole location measured from the T_1-weighted image data (Fig 1). Simulated EEG data were then generated using a 9.9Hz oscillating signal and source strengths equal to those used in the phantom experiments. The spatial topography of the 9.9Hz peak in the power spectrum of the simulated data was plotted and compared to that of the measured phantom data. In addition, the raw signals from electrodes at the peak of the forward solution were compared.

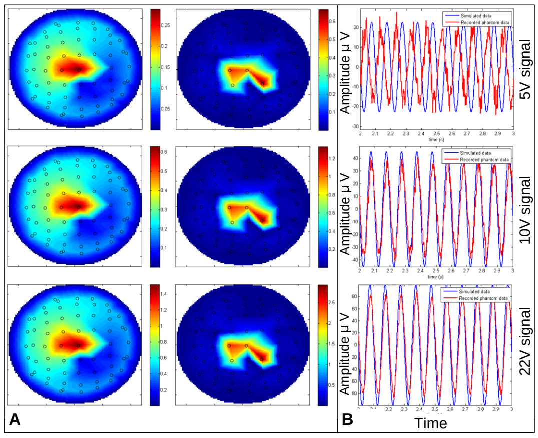

Figure 2: Results of the 7T experiment **A**) topographical maps of real and simulated 9.9Hz power. **B**) amplitudes of real (red) and simulated (blue) channel level signals

3T Experiments: Simultaneous EEG and fMRI (TR= 2.2s; TE=40ms; 20 axial slices) data were acquired using a 3.0T Philips Achieva MR scanner, with and without synchronisation of EEG and MR scanner clocks. This was done in order to show that phantom measurements would follow the previously reported finding that synchronisation allows for better EEG gradient correction using AAS. The dipole was driven using a 10.5Hz sinusoidal signal. EEG data were corrected in *Brain Vision Analyzer,* as before.

Finally, a flow phantom was made as described above, with a 1.05 cm diameter conducting aqueduct sited in the same x-y plane as the dipole. The phantom was placed in the bore of the magnet and a 5g/L saline solution was pumped through the aqueduct. The flow rate was pulsed to investigate the temporal form of resulting EEG artefacts. fMRI data were acquired simultaneously to mimic a real recording. Gradient and pulsatile flow artifacts were then corrected using AAS.

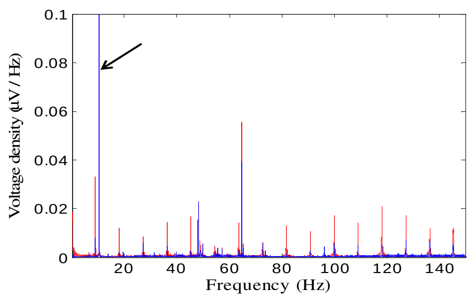

Figure 3: An FFT of the gradient corrected signal at 3T with (blue) and without (red) synchronisation. The 10.5Hz dipole signal is arrowed.

Results and Discussion: Figures 2A and B show measured and modelled field patterns for the dipole. The largest signals are measured at electrodes Cz and CPz. The measured signals consistently show the same pattern for all dipole strengths. Furthermore the spatial topography of the measured and simulated EEG signals is similar. The amplitudes of the channel level data from the measured and modelled EEG signals are in reasonable agreement. This confirms that the dipolar source in the phantom behaves as a single dipole in a homogeneous conducting sphere.

An FFT of the EEG signal with and without synchronization is shown in Figure 3. A 10.5Hz signal from the dipole is clearly visible from the Fourier spectrum (arrowed). The integral of the FFTs from 0-150Hz showed a 15% reduction in power when synchronisation was employed, indicating improved artefact removal in agreement with previous findings [4-5]. Data acquired with both pulsatile flow and gradient artefacts are shown in Figure 4A for a single channel. Figure 4B shows the gradient artefact corrected data for the same channel (black line) revealing the pulsatile flow artifact, and the data following correction for the pulsatile flow artifact using AAS (red line). As shown the flow artifact can be largely eliminated using AAS.

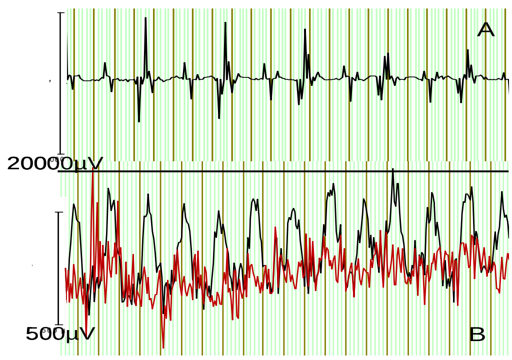

Figure 4: Comparison of data collected on the phantom before gradient correction (A), and after (B, black line) with subsequent artificial pulse artefact correction (B, red line).

Conclusion: We have shown that it is possible to construct EEG dipole phantoms for use in the development of methodology for combined EEG/fMRI. We have demonstrated that the spatial topography and amplitude of the recorded EEG from a dipole phantom is in approximate agreement with the effects expected theoretically. Using such a phantom, we have confirmed previous results that gradient correction using AAS is improved by synchronisation of the scanner and EEG clocks. Finally we have shown that flow effects can be added to dipole phantoms to investigate the effects of pulsed flow on the recorded EEG.

References: 1) Allen *et al.* NeuroImage **12**:230-239,2000 **2)** Brookes et al. Proc. ISMRM, Berlin, 2007 Abs 699 **3)** Naizy *et al*. Neuroimage 2005;28(3):720-737 **4)** Mandelkow et al. NeuroImage **37**:149-163, 2007 **5)** Mullinger et al. Proc. ISMRM, Berlin, 2007 Abs 3441 **6)** Zhang, Phys. Med. Biol. 40:335-349. 1995.