Simultaneous EEG/fMRI Phantom Experiments with a Realistic Neuronal Signal

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Introduction:
Simultaneous EEG/fMRI is hampered by large artefacts produced in the EEG signal by: (i) rapid gradient switching during fMRI acquisition, (ii) the effects of pulsatile blood flow and (iii) subject movement, the latter two of which increase linearly with field strength. One of the most prevalent correction methods for the pulse and gradient artefacts is averaged artefact subtraction (AAS)[1,2],but the precise effect of this artefact correction method on neuronal signals is unknown. Previously[8] we have developed a spherical conducting dipole phantom for use in EEG/fMRI development. Here, an event-related neuronal response, derived from a real MEG experiment, is used to drive a dipole, located inside this EEG phantom. The effect of interference from gradient fields and pulsed flow through the phantom is investigated, along with the efficacy of AAS in artifact correction.

Methods:
Phantom Construction: A 9.5 cm diameter spherical agar phantom with 0.9% NaCl and 2.5% glycerine was made. Moulded in the agar was a 1 cm twisted-pair dipole and a 1 cm diameter flow channel, approximately 2.5 cm below the surface of the sphere. To produce the flow, the phantom was connected to a computer-controlled pump outside the scanner room, which pumped 0.5% saline solution at intervals based on R-peak timings acquired from a vector-cardiogram recording on a human subject.. The flow was initiated with a constant pulse for a few seconds and the duration of the following pulses was 100 ms.
The dipole was driven with a virtual sensor trace[6] taken from the peak of activity during a median nerve experiment (2 Hz stimulus, 8son/8s off, 480 stimuli) which had been recorded in MEG. The dipole was driven with a peak to peak amplitude of 210 nAm.
Data acquisition: All experiments were performed on a Philips Achieva 3T scanner. A 64 electrode EEG cap (Easy Cap, Herrsching, Germany) with the reference electrode positioned between Cz and Fz was placed on the phantom. Contact between the agar and the electrodes was made with an abrasive electrolyte gel (Abralyte). Three MR visible capsules were placed on the surface of the cap to allow for co-registration of the phantom image to electrode locations measured using a Polhemus Isotrak digitiser. The phantom was placed in the scanner such that the orientation of the EEG cap and flow channel was realistic for a subject in a supine position. EEG data were recorded with Brain Vision Recorder using Brain Amp MR-plus EEG amplifiers (Brain Products, Munich) with the scanner and EEG system clocks synchronised to improve artefact correction with AAS[5]. EEG/fMRI was recorded using a standard EPI sequence with TR=2.2 s, TE=35 ms, 20 slices, 100 dynamics.
Corrections for gradient and pulse artefacts were carried out in Brain Vision Analyzer version 1.05.0005 (Brain Products, Germany). The gradient artefact was created using a template over all TR periods whilst a sliding template for the pulse artefact was created using the previous 10 pulse periods[1]. Subsequently data were baseline corrected. Cross-correlation analysis of the EEG signals with the whole neuronal response curve and for 10, 23, 46, 115, 230 and 460 averages of each were carried out in Matlab.

Results and discussion:
Figure 1 shows a clear correlation between the time-course of the average neuronal signal fed into the dipole and the average EEG signal recorded at an electrode close to the dipole. The spatial topography of the EEG signals from the peak in the timecourse is shown in Figure 2. The maximum amplitude in the EEG signal was consistently observed to be at Pz (positive peak in Figure 2). The maximum in Pz corresponds well with the proximity of Pz to the dipole.

Cross-correlation analysis of data recorded at 3 T is shown in Figures 3 and 4. In the absence of gradient and flow artifacts Figure 3 shows that the correlation increases with the number of averages as expected. Figure 3 also shows that an extremely high correlation (>0.9) is achieved for data affected by pulse artifact and corrected data. However, this is only the case when > 46 stimuli are averaged. Data recorded in the presence of both gradients and pulse artefacts showed improved correlation with the median nerve response signal after gradient artefact correction. A further improvement occurred after pulse artefact correction (see Figure 4). Again correlation coefficients above 0.9 were recorded after all artefact and baseline corrections. However, averaging across trials is essential to achieve such high correlation.

Conclusion:
We have shown that a signal resembling an event-related response can be produced in the phantom. This can be used to test and develop artefact correction methods including exploration of the effect of heart rate variability and movement. It has previously been suggested that different artefact correction methods affect the spectra of neuronal signals differently [9]. With the methodology described here it is possible to investigate how different experimental conditions and artefact correction methods affect different types of neuronal responses, which can be used to tailor experiments and analysis to the stimulus being applied.

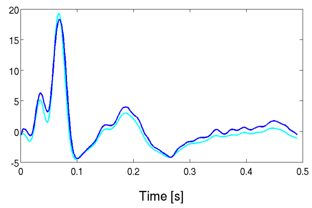

Figure 1: *Averaged median nerve response curve (cyan) and average EEG signal, scaled by 10, in Pz (blue) for 480 stimuli, recorded in the absence of gradients and pulsed flow.*

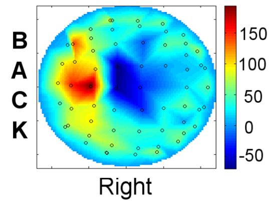

Figure 2*: A topographical map of the dipole signal at the time of peak amplitude, recorded with no gradients or flow at 3* T.

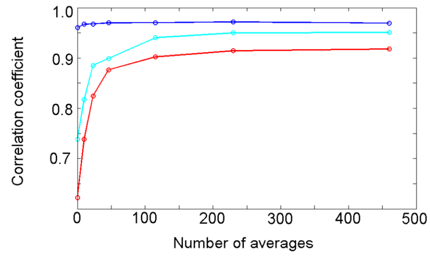

Figure 3: *Correlation coefficient comparing median nerve response signal with EEG signal from Pz as a function of number of averages without gradients and pulses (blue); for uncorrected data recorded with R-peak timed pulses (red); and for pulse artefact and baseline corrected data (cyan).*

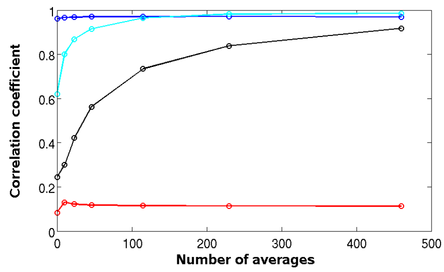

Figure 4: *Same as in Figure 3, for dipole signal (blue) in absence of artefacts, raw signal with gradient and pulse artefacts (red), that same signal corrected for gradient artefacts (black) and also pulse artefact corrected (cyan).*

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[7] Debener et al. Int. J. Psychophysiol.. 67:189, 2008 [8] Geirsdottir et al Proc. 16th ISMRM 2008 #3626 [9] Ritter et, al. MRI, 25:923-932, 2007