Exploring the feasibility of simultaneous EEG/fMRI at 7T

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Introduction

Combined EEG-fMRI is increasingly being used to probe the spatial and temporal characteristics of brain activity in experiments at 1.5 and 3 T [1-2]. Increases in BOLD contrast to noise ratio at 7 T make the implementation of combined EEG-fMRI at this ultra-high field desirable. However, increasing the static magnetic field strength causes larger artefacts in the EEG trace due to increased effects of motion and blood flow, and the increase in the Larmor frequency could lead to greater interaction of the applied RF with the electrodes and wires used for EEG recording [3]. Here, measures taken to allow recording of EEG signals from human subjects at 7 T are described, and the first results of carrying out combined EEG and fMRI at 7 T using commercially available equipment are presented.

Methods: All experiments were carried out using a Philips Achieva 7 T MR scanner with a T/R head RF coil and a BrainAmp MR EEG amplifier, Brain Vision Recorder software (Brain Products, Munich) and the BrainCap MR electrode cap with 32 electrodes (following the 10/20 system, sampled at 5 kHz). A number of experiments were carried out before any human EEG recordings could take place.

Phantom testing: The cap was placed on a spherical phantom containing saline-loaded agar gel with a layer of Abralyte 2000 gel between the outer surface of the phantom and the electrodes. *Heating*: A Luxtron FOT Labkit with TrueTemp software was used to measure temperature changes. Probes were placed between four electrodes (Ref.–[sited between Fz and Cz], Pz, T7 and T8) and the phantom. Temperature changes were monitored over 21 minutes during execution of a TSE sequence employing an average RF power of 9.87 W. *Noise sources:* To allow identification of sources of EEG noise, other than the applied field gradients, various elements of the MR support system (compressor pumps for the cold heads, magnet bore and gradient coil air-flow and the screened room lighting) were turned off sequentially whilst recording EEG data from the phantom. *Human Experiments:* Experiments were carried out on 3 healthy volunteers. A standard EPI sequence was implemented with TR=2.2s and TE=25ms (64×64 matrix, 3×3×3.5mm^3 voxels). 20 coronal slices were acquired. The EEG sampling and imaging gradient waveforms were synchronised by driving the BrainAmp clock cycle using a 5 kHz signal derived from the 10 MHz imaging spectrometer clock [4]. The head was held in place using a vacuum cushion to reduce the ballistocardigram (BCG) and movement effects. The scanning was carried out under the optimal conditions identified from the phantom experiments. A simple visual stimulus consisting of a flashing (10 Hz) checkerboard was presented for 30 cycles of 10 s with the stimulus on and 20 s with no stimulation. MPRAGE image data acquired at 3T were used to determine the electrode positions. Analysis of fMRI data was carried out using standard techniques in SPM99. Off-line EEG signal correction was based on averaging and then subtracting gradient and pulse artifacts, as implemented in Brain Vision Analyzer (Brain Products, Munich) [5]. Data were then analysed using a beamformer [6]. This involves a linear transformation of EEG data into source space allowing estimation of dipolar source strength in three orthogonal directions for any location in source space (i.e. the head).

Results and Discussion

Phantom testing: Heating: The temperature rise found at each of the four electrodes that were monitored was less than 0.5°C over the 21 minute scanning period. *Noise Sources*: Figures 1&2 show the modulus of the Fourier transform (FT) of EEG signals averaged over all channels recorded over 2 minutes, with different elements of the scanner equipment turned off. The most significant noise source was found to be the compression pumps for the cryocoolers (Fig. 1), making it imperative to turn these off during scanning. Switching off the airflow through the patient bore and gradient tube was also found to cause a significant reduction in EEG noise (Fig. 1). This noise seems to result from vibration of the beam supporting the patient bed, upon which the EEG amplifier sits. Since it is not possible to scan with the airflow off, an alternative method of reducing the effect of these vibrations was developed. This involved mounting the EEG amplifier on a cantilevered beam, which was inserted into the magnet bore without making mechanical contact to any magnet structure. Figure 2 shows that use of the beam significantly reduces the low frequency noise when airflow is on. This arrangement was used for the human studies.

Human Experiments: A comparison of the FT of the signals obtained from electrode Oz during the on and off periods (Fig. 3A) shows strong electrical signals occurring at 20Hz and higher harmonics of the visual stimulus frequency. Although neuronal activation could be detected, there was still a relatively large amount of noise in the signal especially at lower frequencies, which could make studying alpha band activity particularly problematic. A beamformer was therefore employed for noise reduction. Figure 4A shows the T-statistic image reflecting electrical activity in the 19.5-20.5 Hz frequency band, which corresponds with the BOLD activation map shown in Fig. 4B, although spatial resolution is relatively poor. Figure 3B shows the FT of the largest component of the temporally varying dipole strength from a virtual electrode (VE) placed at the site of peak activity (Fig. 4A). Comparison with Fig. 3A indicates an improvement in the ratio of signal peak strength to noise has been achieved via use of the beamformer.

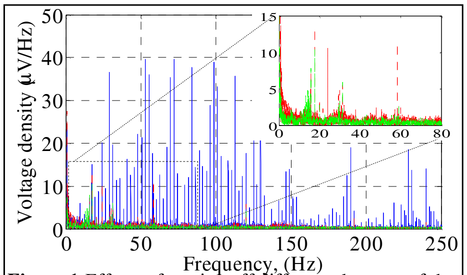

Figure 1: Effects of turning off different elements of the MR scanner support on the FT of the EEG signal averaged over all channels. All equipment on (blue), compression pumps turned off (red) and all other equipment mentioned turned off (green).

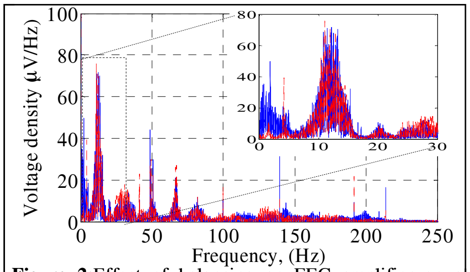

Figure 2: Effect of balancing an EEG amplifier on a beam (red) compared with not (blue)

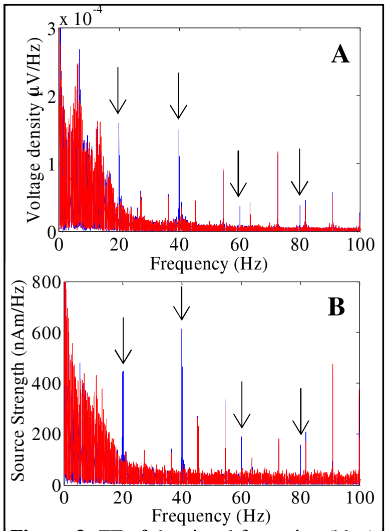

Figure 3: FT of the signal for active (blue) and passive (red) contrast windows for electrode Oz (**A**) and VE (**B**). Arrows indicate peaks of interest

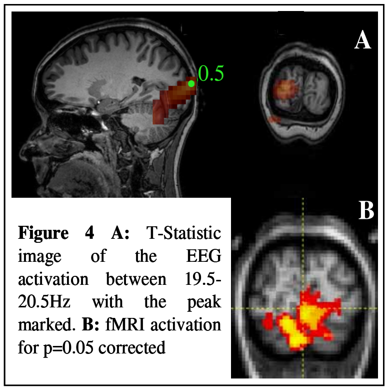

Figure 4 A: T-Statistic image of the EEG activation between 19.5-20.5Hz with the peak marked. **B:** fMRI activation for p=0.05 corrected

Conclusion:

We have investigated the issues involved with performing combined EEG and fMRI on human subjects at 7T and described initial solutions for mitigating the most significant sources of EEG artefact. Using these in conjunction with a beamformer EEG analysis, a comparison of the electrical and BOLD activation evoked by a visual stimulus at 7 T has been made.

References

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