Using Simultaneous EEG recording to test the feasibility of directly detecting neuronal currents due to alpha wave activity by MRI

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Introduction - Recent publications[1,2] have described different methods of directly detecting neuronal currents by MRI. It has been calculated that the magnetic fields associated with current dipoles of strength of order 10nAm should be detectable *in vivo* with MRI from perturbations of the image phase[3]. MEG results suggest that spontaneous alpha wave oscillations in the brain can be modeled as the effect of point current dipoles whose strength is of order 100 nAm. Here we describe an attempt to detect directly the magnetic fields associated with alpha wave activity.

Methods Echo-planar imaging (EPI) of a coronal posterior slice of the occipital lobes was implemented on a 3.0 Tesla scanner (TR = 40 ms, TE = 24 ms, flip angle = 22°, field of view of 25.6 x 25.6 cm^2, 64^2 matrix, 1.9 kHz switching frequency). During imaging EEG was recorded using a 10 channel MRI compatible EEG system and the subjects cardiac cycle was monitored using a two electrode ECG. Artifact correction to remove cardiac pulse and MRI scanner artifact from the EEG was performed using a method described elsewhere[4,5]. The paradigm consisted of four minutes of MR image acquisition with simultaneous EEG recording with subjects in darkness and eyes closed, EEG was then recorded for a further four minutes in this 'alpha on' state with no imaging. This cycle was then repeated while subjects were presented with an alternating checkerboard (frequency 4Hz) in order to block alpha wave activity. A repeat 4 minute 'alpha on' with EEG and MRI trial was then performed. The experiment was carried out on 3 male and 2 female subjects with no known pathology and on a spherical water phantom.

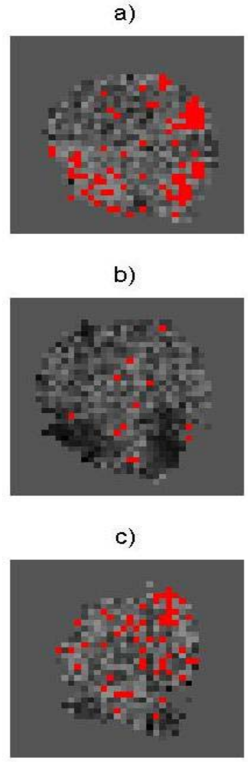

Figure 1 - Correlation coefficient maps of the imaged slice in the three subjects all are correlations with the O2 electrode performed in the α frequency bands. The I-S direction is up and down the page and L-R across the page.
a) 8 - 9Hz subject LL with no visual stimulus, **b)** 9 - 10Hz subject JL with visual stimulus, **c)** 10 - 11Hz subject RB with visual stimulus. Threshold is set at a p value of 5% uncorrected for multiple comparisons.

Subject and selected α freq	α on		α off		α on (repeat)	
	O1	O2	O1	O2	O1	O2
LL(8-9 Hz)	16.2%	15.5%	0.13%	0.13%	24.5%	20.2%
JL (9-10Hz)	5.4%	3.5%	1.7%	1.7%	switch gradient failed	
RB(10-11Hz)	14%	13.4%	12.9%	12.9%	8.2%	8.2%
phan	0.1%	0.1%	4.5%	3.8%	2.6%	0.32%

Table 1 the percentage of voxels correlated with the EEG (p-value of 0.05 uncorrected)

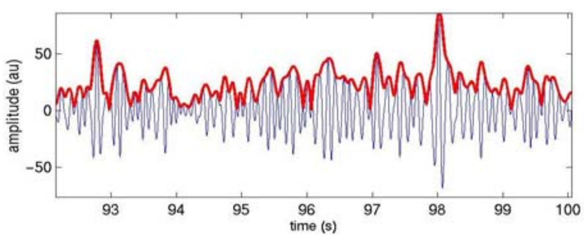

Figure 2 A sample of a filtered (10Hz BW centered on 10Hz) EEG acquired during scanning('alpha on' state). The red line indicates the amplitude envelope, α-rhythm is clearly visible

Processing - Images obtained in the first 10 seconds of each condition were discarded to ensure equilibrium had been established. Phase and modulus images were motion corrected and phase images spatially unwrapped using *FSL* software (fMRIB, Oxford, UK). Phase images were normalised by subtracting the mean phase of voxels included in a masked region to remove any global phase changes. The mask excluded the upper and lower quartile of image intensities (ie. regions of low SNR or through slice flow). Three frequency bands, 8-9Hz, 9-10Hz and 10-11Hz were chosen for analysis. The time integral of the power (energy), in each band was used to select the band showing strongest alpha power in each subject. The time courses were band-pass filtered and the Hilbert transform used to measure the envelope of the power modulation in each band of the signal from electrodes O1 & O2 and the timecourses of voxel phase variation equivalently. A map of correlation coefficients between power modulation in the EEG and the MRI was then calculated at each band. A null hypothesis distribution was derived from correlating EEG recordings with MRI time courses obtained from different subjects to describe the frequency distribution of random correlations. This distribution was generated from 343 'null' trials comprising comparisons of $2x10^5$ voxels, p-values were later assigned according to this null distribution. Before testing for MRI-EEG correlation the EEG was assessed for residual imaging artifact, residual rapidly varying high amplitude artifact will leak into all frequency bands of the EEG. The energy contained in two bands corresponding to the EPI repetition rate and its first harmonic (24-26Hz and 49-51Hz) was used to assess EEG quality. Trials where the energy in these artifact bands exceeded half of the total energy in the EEG signal were rejected. The data from two subjects were rejected on the basis of this criterion.

Results – Examples of the parametric maps obtained from a correlation with the O2 electrode are presented in Figure 1. Strong agreement between correlation maps obtained from the O1 and O2 electrodes was observed. The structure apparent in the correlation map of subject LL (Figure 1a) was present in both the 'alpha on' trials with this subject and there was good spatial agreement between the results of both trials. There was clear alpha activity in the EEG in both cases as shown in Figure 2. The above threshold regions of correlation maps for subject JL showed no spatial clustering in either condition (Fig 1b). Subject RB showed spatially clustered correlation with the EEG only in the 'alpha off' state however the EEG showed comparable alpha energy in both 'on' and 'off' trials. Table 1 shows the number of significantly correlated (p=0.05 uncorrected) voxels in each subject as a percentage of the number in the masked region of the imaged slice. A reduced alpha energy was observed during imaging compared to that measured with no imaging. This was true for all subjects in both the 'on' and 'off' conditions. Imaging rapidly enough to adequately sample alpha band frequencies makes considerable demands on the imaging system. During one trial (subject JL repeat 'alpha on') the amplifiers driving the switch gradient overloaded and the trial was abandoned. At this repetition rate the gradients produce very high levels of acoustic noise and mechanical vibration that are transmitted from the gradient set to the subject via the head RF coil. This may act as an alpha-blocking stimulus and confound 'alpha on/off paradigm' applications of this technique without the use of simultaneous EEG.

Conclusion –Using combined EEG and MRI it has been possible to observe spatially structured correlation between fluctuations in MR phase images and EEG power in the alpha band in some subjects. This finding suggests that the magnetic field from neuronal currents is measurable in the MR signal and that this effect requires further investigation.

References

1 Konn *et al*, Proc. ISMRM 2003. **2** Xiong *et al*, Hum. Brain Map.20:41-49(2003) **3** Konn et *al*. Mag. Reson. Med. 50: 40-49(2003) **4**.Allen *et al* Neuroimage 8:229-239 **5** Allen et al. Neuroimage 12:230-239