Is the neuromagnetic field in the human brain detectable by MRI in practice?

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INTRODUCTION

Recent theoretical studies as well as measurements in phantoms have suggested that neural bulk activity like alpha waves, which are believed to involve current dipoles of up to 100nAm in humans, may lead to a modulation of the phase and amplitude of the MR signal just above the detection limit of modern-day MR systems [1, 2]. Attempts to confirm this prediction by in-vivo measurements of alpha waves have so far yielded promising but not entirely conclusive results [3]. Other experiments designed to detect the even weaker (~10nAm) visually evoked potentials have shown negative results [4] or could not be reproduced.

METHODS

Our combined EEG and MRI experiment aims to detect alpha waves (8-12Hz), one of the most prominent and robust EEG phenomena in humans. Measurements are performed on a 3T Philips Achieva scanner using a dynamic gradient-echo single-shot EPI sequence (TR=40ms,TE=24ms, FA=20°). The Nyquist limit for recording a 12Hz signal constrains TR to 40ms or less. This allows for the acquisition of only a single transversal slice, which we orient either along the calcerine fissure or the pario-occipital sulcus. Simultaneous acquisition of EEG and MRI data necessitates the compensation of MRI gradient artefacts in order to obtain a useful EEG signal [5]. The MR-compatible 64 channel EEG system by Brain Products GmbH (Munich/Germany) comes with a phase-locking device to synchronize its clock with the time base of the MR system. We have shown that synchronized recordings ensure optimal gradient artefact reduction. Additionally, we developed post-processing algorithms based on principal component analysis (PCA) similar to those used in [6]. These methods were extended to the removal of the so-called cardio-ballistic (pulse) artefact and complemented by auto-regressive filtering. Four human subjects with previously measured strong alpha waves were scanned with their eyes closed for 3-6 min. (4096-8192 slice acquisitions at 25Hz) while simultaneously recording their EEG at 5kHz sampling rate. Windowed cross-spectra are computed between one EEG channel exhibiting alpha waves (e.g. O1,O2) and complex MRI voxel time courses, making efficient use of short data segments (1-3 sec) by Thomson's multi-taper method for spectral estimation. This technique also provides a statistical test for the detection of significant spectral lines in locally white noise, which we use to determine a significance threshold for the CNR in our in-vitro experiments (**Figure 2**). In vivo measurements were quantified by computing the *coherence* (mean normalized cross-spectra) between EEG and MRI time series and applying a Gaussianizing transform to assess significant peaks. Spatial filters matching the characteristic of a dipole field were found to be useful for enhancing contrast in in-vitro measurements of extended dipole sources. All data analysis was performed on conventional PC hardware using the software Matlab (The MathWorks Inc., Natick, MA, USA).

RESULTS & DISCUSSION

We find that most apparent peaks in the cross-spectra of simultaneously measured EEG and MRI time series can be attributed to cardiac pulsation and respiration (**Figure 1**). Following the effective removal of these signal components (**Figure 3**) the statistical maps show no distinct localization of coherence in the alpha band. The phantom measurements show good agreement with theoretical calculations of the current induced magnetic field variation (**Figure 2**) and indicate that an SNR improvement of 3-6 would be required for the detection of oscillating dipoles in vivo with a realistic strength of about 100nAm. This hypothesis could in principle be tested by additional averaging (e.g. 12 instead of 3 minutes scan time) and moving the experiment to a higher field strength (e.g.7T). Of course, current sources in vivo need not be stationary or stable in their oscillations. Physiological noise and limited stability of the in-vivo measurement will further reduce SNR in practice. Spectral analysis of pulsatile brain motion measured by MRI [7] shows that harmonics of the cardiac frequency extend well beyond the alpha band. Furthermore, correlations between alpha wave activity and cardiac frequency are not uncommon (both liked to the subject's state of arousal (see **Figure 3**)). Unless removal of such physiological confounds were perfect, both effects will limit the specificity of any kind of correlation analysis.

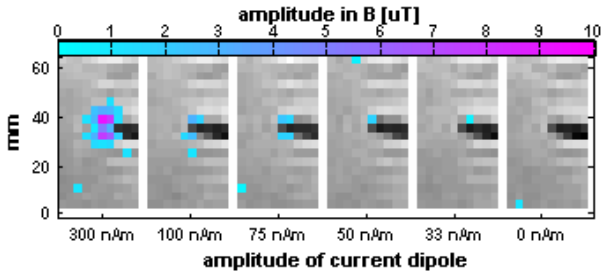

Figure 2 MR images of an electrode forming a horizontally oriented current dipole. The dipole oscillates at 8.2Hz with amplitudes ranging from 300 to 0nAm (left→right). The colour map indicates the amplitude of the resulting B-field modulation in µT. This B-field map is estimated from an MR time series of 512 samples. It shows only those voxels which pass the statistical F-test for the detection of a significant (p=1%) spectral line at 8.2Hz.

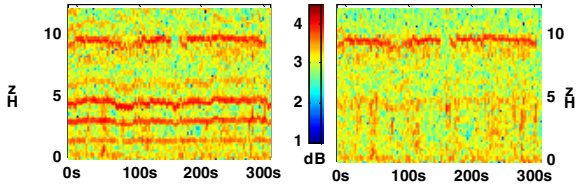

Figure 3 Spectrograms showing alpha waves around 9.8Hz as well as harmonics of the cardiac frequency (1.6Hz) in EEG channel O1 before (left) and after (right) subtraction of the cardio-ballistic artefact. Correlations between alpha wave activity and cardiac frequency are observed e.g. around t=80s.

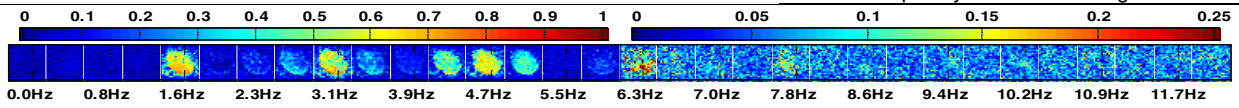

Figure 1 Spectral coherence maps showing common signal components between MR voxel time courses and the signal of EEG electrode O1. Coherence ranges from 0 to 1 by definition. Note that the upper half of the spectrum (right) is presented on a magnified colour scale. We see no significant coherence corresponding to the marked alpha peak present in the EEG signal around 9.8Hz (**Figure 3**). Instead, harmonics of the cardiac frequency at 1.6Hz stand out significantly and extend across the whole spectrum.

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