Improved Artifact Correction for Combined EEG/fMRI

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Introduction

Simultaneous EEG and fMRI has been made possible by the development of EEG hardware and correction methods that allow artifacts generated by the scanner gradients and cardiac pulse to be characterised and then subtracted [1]. Correction methods generally rely on the generation of reproducible gradient artifacts and accurate detection of cardiac R-peaks. Here, we describe the implementation of two methodological developments aimed at improving the reliability of artifact correction: synchronization of EEG sampling to the MR scanner clock [2] and use of the scanner's physiological logging in identifying cardiac R-peaks.

Methods

fMRI and EEG data were acquired simultaneously using a Philips Achieva 3.0 T MR scanner and a BrainAmp MR EEG amplifier, Brain Vision Recorder software (Brain Products, Munich) and the BrainCap MR electrode cap with 32 electrodes (5 kHz sampling rate). The ECG electrode was placed at the base of the subject's back. A standard EPI sequence was implemented (64×64×20 matrix, 3.25×3.25×3.00 mm^3 voxels). Cardiac and respiratory cycles were simultaneously recorded using the scanner's physiological monitoring system (vector cardiogram (VCG) [3] and respiratory belt) whose output is sampled at 500 Hz. Triggers marking the beginning of each volume acquisition were recorded on the EEG system. Each study was carried out on 3 healthy volunteers. *Study 1:* Data were recorded for 6 minutes (180 volumes) for 3 different situations: (i) the EEG sampling and imaging gradient waveforms were synchronised by driving the BrainAmp clock using a 5 kHz signal derived from the 10 MHz MR scanner clock (*TR* = 2 s); (ii) the EEG sampling was not synchronised to the scanner clock (*TR* = 2 s); (iii) the EEG and MR clocks were synchronised, but a *TR* of 2.0001 s which is not a multiple of the scanner clock period, was employed. In each experiment, the time between repetitions of scanner waveforms was *TR*/20 = 100 ms, so that gradient artifacts occurred at multiples of 10 Hz. *Study 2:* A visual stimulus consisting of a flashing (7.5 or 10 Hz) checkerboard was presented in 30 cycles of 5s on and 5s off. Data were recorded both with and without synchronisation of the MR scanner clock and EEG sampling. A *TR* of 2.2 s was employed so that dominant gradient artifacts occurred at multiples of 9.09 Hz, thus avoiding the frequency of the visual stimulus.

Off-line EEG signal correction for both studies was based on averaging and then subtracting gradient and pulse artifacts, as implemented in Brain Vision Analyzer [1]. Gradient artifact correction employed an artifact template formed from the average over all *TR*-periods, using the scanner-generated markers. Pulse artifact correction was based on R-peak markers derived from the ECG or VCG traces. The VCG is formed from a four-lead measurement [3] on the chest, which is relatively insensitive to gradient artifact and allows orthogonalisation of the pulse artifact and R-wave. After artifact correction data were down-sampled to 500 Hz sampling rate using cardinal splines and an anti-aliasing filter.

Results and Discussion

Figure 1 shows the attenuation (-20log$_{10}$(corrected/uncorrected)) of the EEG voltage at multiples of 10 Hz after gradient correction for one subject, indicating that synchronisation of the EEG sampling to the MR scanner clock, leads to significantly improved correction of gradient artifacts. This reduction in residual artifact at high frequencies, which was manifested in the data from all three subjects, will be particularly advantageous for measuring gamma band activity during MR scanning. Figure 1 also shows that even with synchronisation it is imperative to employ a *TR* which is a multiple of the scanner clock period in order to achieve good gradient artifact correction. Table 1 shows the ratio of the standard deviation of the EEG signal before and after gradient artifact correction averaged in the time-domain over all channels and subjects. It shows that the improved artifact correction that can be achieved with synchronisation significantly reduces the EEG signal variance. Figure 2 indicates that using the VCG rather than ECG trace to define R-peak markers provides a slightly improved level of pulse artifact correction. Use of the VCG consequently offers an alternative approach to pulse artifact correction where difficulties in obtaining an adequate quality ECG trace occur. This may be a particular problem at high field due to the increased magnitude of the pulse artifact. Figure 3 shows the results of Study 2 for one subject, with all three subjects showing similar signal behavior. It shows the Fourier transform of the EEG signal from channel Pz acquired with and without synchronisation, using VCG-derived markers for pulse artifact correction. Peaks corresponding to electrical activity at multiples of the stimulus frequency are evident in traces obtained with synchronisation (A and C), but are obscured by gradient artifact peaks when synchronisation is not employed (B and D).

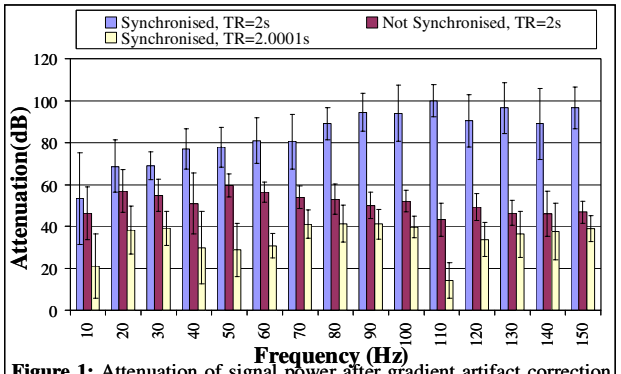

Figure 1: Attenuation of signal power after gradient artifact correction averaged over all channels. Error bars show variation in attenuation across all channels.

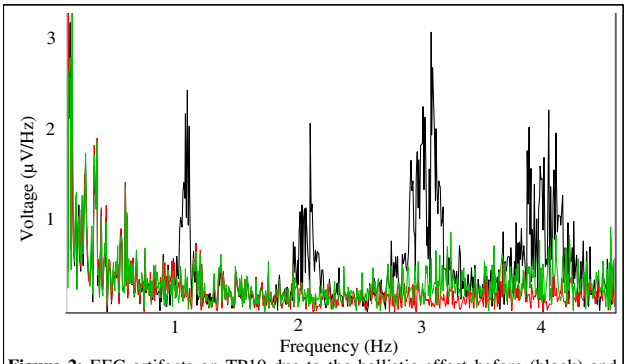

Figure 2: EEG artifacts on TP10 due to the ballistic effect before (black) and after correction using markers derived from VCG (red) and ECG (green) traces.

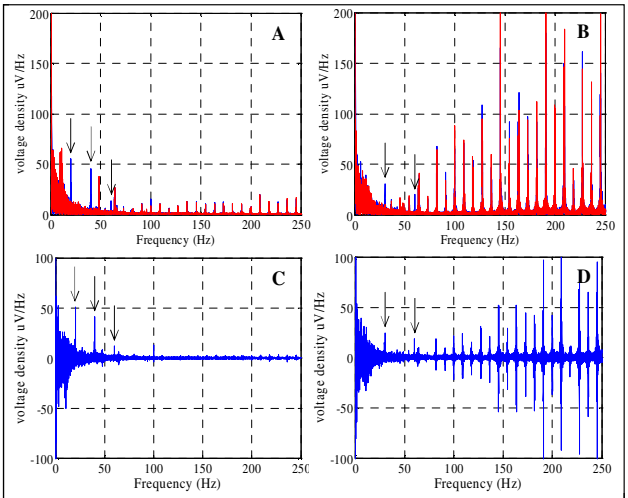

Figure 3: **A** and **B** FFT of the neuronal activity, from channel Pz, after correction in active (blue) and passive (red) contrast windows for synchronised (**A**) and unsynchronised (**B**) data acquisition. **C** and **D** show the difference in the active and passive contrast windows for synchronised (**C**) and unsynchronised (**B**) acquisition. Arrows identify spikes of neuronal activity. The visual stimulus frequency was 7.5Hz for **A&C**, and 10Hz for **B&D**.

Synchronised, TR=2s	0.14
Not Synchronised, TR=2s	0.17
Synchronised, TR=2.0001s	0.18

Table 1: The ratio of standard deviation in the signal corrected:uncorrected, averaged over all channels and subjects.

References: **[1]** Allen *et al.* Neuroimage **8**:229-239,1998. **[2]** Mandelkow *et al.* Neuroimage, **32**(3):1120-1126,2006 **[3]** Chia *et al.* JMRI, **12**:678-688,2000.