The utility of synchronization, PCA and filtering for removing MRI artefacts from simultaneous EEG recordings

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INTRODUCTION

In recent years the prospects of combining the spatial resolution of MRI with the temporal resolution of EEG for non-invasive brain mapping experiments in humans have spurred the development of methods to overcome the technical challenges of uniting the two complementary techniques into one fully simultaneous EEG-MRI measurement. Apart from MR-compatible EEG amplifiers with a large dynamic range and high bandwidth, post-processing algorithms proved to be essential for recovering an intelligible EEG signal from a recording heavily confounded with electromagnetic induction artefacts caused by the switching magnetic gradient fields inside the MR scanner. The removal of this MRI gradient artefact as well as the so-called cardio-ballistic artefact (CBA) related to mechanical pulsation as well as the flow of ion-rich blood inside the magnetic field is possible by exploiting the periodicity and reproducibility of these signal components. Event triggered averaging and subsequent *mean template subtraction* is at the heart of most published algorithms [1-3]. Furthermore, sampling time correction (STC), principal component analysis (PCA) and (adaptive) filtering have been suggested for removing remaining variations of the artefact wave form. Such variations can be effected by changes in the recording geometry (cable or subject motion), but mostly MRI artefact reproducibility is compromised by shifts in EEG sampling times relative to the MRI sequence when TR is not an exact multiple of the sampling interval (0.2ms) e.g. because both systems are usually driven by separate clocks.

METHODS

Simulations of the MRI artefact in EEG recordings were based on gradient wave forms at 0.1ns resolution exported through the scanner software. White or coloured noise was added as a reference (EEG) signal. To be in realistic proportion, its variance was scaled at 1% relative to the MRI artefact. The F-statistic served as a common test for significant differences in power spectral density. Simulations and all numerical analysis were performed using the software Matlab (The MathWorks Inc., Natick, MA, USA). Simulation results were confirmed by EEG-MRI measurements in vitro and in vivo. A frequency divider and phase-locking device was employed to achieve precise synchronization of the 5kHz clock driving the MR-compatible EEG amplifier (Brain Products GmbH, Munich/Germany) with the 10MHz time base (TTL) of the MR scanner (Philips Achieva 3.0T)[4]. Recordings were done using the product birdcage head coil and imaging sequences typically used for functional brain-mapping (BOLD-fMRI) experiments (multi-slice single-shot EPI with echo time TE= 35ms and repetition time TR= 1800ms). The phantom consisted of a simple jar of water with the immersed EEG electrodes fixed to the inner perimeter using tape. Ordinary tap water provided sufficiently low impedances around 10 kOhm including 5 kOhm resistors as part of the MR-compatible sintered Ag/AgCl ring electrodes.

RESULTS & DISCUSSION

The simulations in **Figure 1** show how pre-processing the EEG channel data influences the first 5 principal components computed across a set of 600 equivalent epochs capturing consecutive MRI artefacts. Systematic variations of the MRI artefact due to a drift in EEG sampling times with respect to the MRI sequence are largely captured by the strongest 2-3 principal components (PCs)(panel **B**,1-3). Eliminating this drift by synchronized recordings reduces the variability to a point where PCA does not yield any significant artefact related components (panel **A**). Likewise, STC (by minimizing linear phase shift in the spectral domain) will typically eliminate 1 or 2 components dominated by the artefact (**C**). Aliasing due to lack of filtering before down-sampling will render most PCs to be "contaminated" by the MRI artefact (**D**) and therefore prevent the localization of the MRI artefact in a low-dimensional linear subspace.

Spectral analysis of simulated data and phantom data alike shows that synchronized recordings yield the least residual MRI artefact power after mean template subtraction (**Figure 2**, **A**) even in the presence of aliasing (B) and without any additional processing by STC or PCA. Without synchronization PCA (**G**) will outperform STC by itself but the combination of both methods (**F**) yields little further advantage. Interestingly, in the crucial EEG range below 50Hz mean template subtraction alone shows the best results (E) even without synchronization while PCA and STC show a positive effect only at frequencies above 80Hz. In the presence of aliasing residual artefact power generally increases by 1-2 orders of magnitude after artefact removal by PCA (D) or STC (C).

CONCLUSIONS

EEG-MRI recordings are best done with synchronized EEG and MRI clocks. This ensures the most efficient MRI artefact removal by simple mean template subtraction. Without synchronization the resulting variations in MRI artefact amplitude can largely be captured and removed by PCA and/or STC, although the effect of these measures tends to be significant only at frequencies above 80Hz. Anti-alias filtering is important for PCA to work. A high EEG sampling rate will facilitate the use of steep software filters for this purpose and limit amplitude variations of the MRI artefact at the same time. Simple mean template subtraction is recommended to maintain signal fidelity in the crucial EEG range below 50Hz. We note that PCA may capture and remove (strong) sinusoidal components of constant frequency e.g. long periods of consistent alpha waves. Unsupervised subtraction of a fixed number of principal components is therefore not recommended for EEG artefact removal.

REFERENCES

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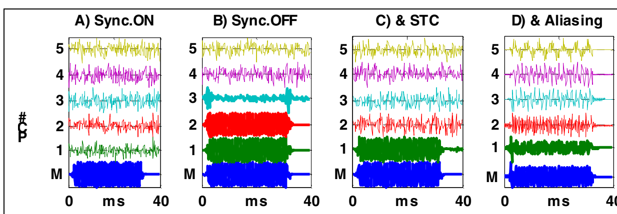

Figure 1 The mean (M) and first principal components (PC# 1-5) computed across a set of equivalent epochs capturing 600 consecutive MRI artefacts from one simulated EEG channel recording performed A) with and B-D) without synchronization, C-D) with sampling time correction (STC), D) with aliasing.

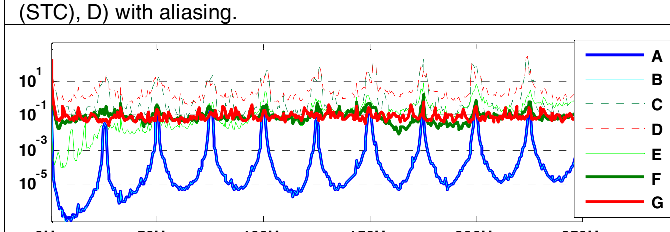

Figure 2 Average power spectra of the residual MRI artefact normalized by the white noise reference signal of the simulation. Peaks correspond to harmonics of 1/TR = 25Hz. (Note the log scale.)