Retrospective synchronization (Resync) avoids the residual MRI gradient artefact in EEG-MRI experiments.

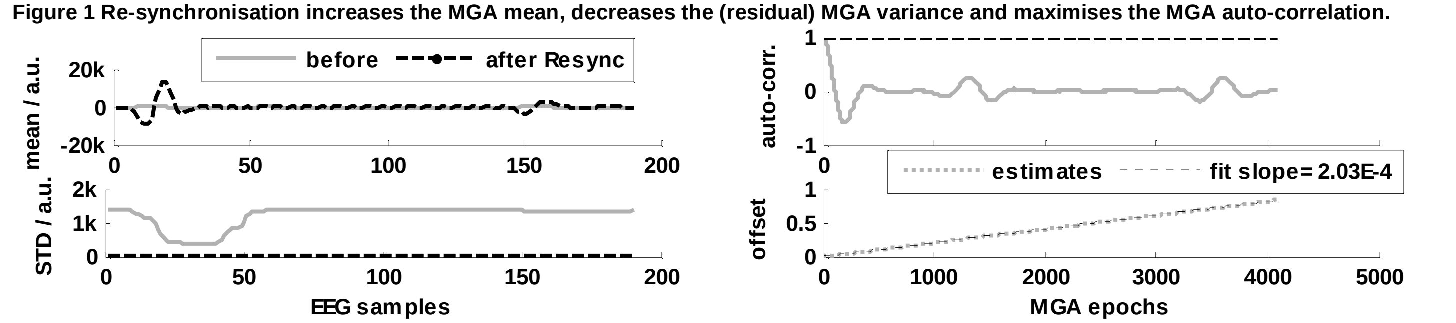
H. Mandelkow[1], P. Halder[2], D. Brandeis[3], and P. Boesiger[1]

[1]Inst. for Biomedical Engineering, University and ETH Zurich, Zurich, Switzerland, [2]University Hospital Balgrist, University of Zurich, Zurich, Switzerland, [3]Dept. of Child and Adolescent Psychiatry, University of Zurich, Zurich, Switzerland

INTRODUCTION

The EEG recorded during MRI inside the scanner is obstructed by the all but inevitable MRI gradient artefact originating from electromagnetic interference of the two measurements. Post-processing algorithms based on *average artefact subtraction* (AAS) have proven to be instrumental and efficient in removing the so-called *MRI gradient artefact* (MGA) [1-3]. However, the *residual MGA* after AAS still limits the quality and usable bandwidth of the EEG data despite further reduction through *slice timing correction* (STC), *principal component analysis* (PCA), and *regressive (adaptive) filtering*. We recently demonstrated that the residual MGA can largely be avoided by means of hardware synchronisation which ensures that the TR of the MRI sequence matches exactly a multiple of the EEG sampling interval [4]. Here we present a new software synchronisation method which can improve and even substitute hardware synchronisation. The effectiveness of the *retrospective synchronisation algorithm* (Resync) is demonstrated by comparison to some of the aforementioned techniques. For this purpose we also developed a new method for simulating the MGA and we propose a new procedure for quantifying and comparing the performance of EEG cleaning algorithms.

Figure 1 Re-synchronisation increases the MGA mean, decreases the (residual) MGA variance and maximises the MGA auto-correlation.



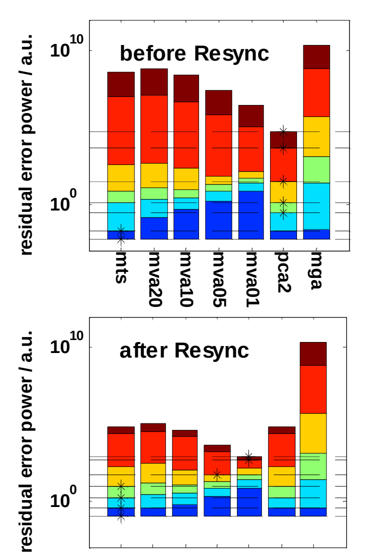
METHODS

By analysing the theoretical and practical properties of the MGA we identified the *relative timing error* (RTE) i.e. the mismatch between TR and the nearest multiple of the EEG sampling interval (normalised by TR) as the primary source of *residual* MGA and the key to avoiding it. The Resync algorithm requires no specialised hardware as it estimates the RTE directly from the EEG signal and then corrects for it by equidistant interpolation. Resync avoids up-sampling by performing all operations in the Fourier domain which is efficient by the use of FFT. All of the above distinguish Resynch from previously suggested interpolation approaches which represent only approximate solutions to the synchronisation problem. The new quantification method we propose for assessing and comparing the performance of various cleaning algorithms is based on spectral analysis. In contrast to approaches proffered previously [5, 6] we emphasise the necessity to spectrally resolve the sharp line spectrum of the MGA. This makes our method more sensitive to the residual MGA and allows better assessment of EEG signal preservation. The simulations we use take into account the high bandwidth of the MGA signal before EEG sampling. This is necessary to study the effects of the RTE and aliasing artefacts. While the most sophisticated quantification of residual error after cleaning requires simulated data, we also tested the performance of Resync with *in-vivo* data. EEG data was recorded using an MR-compatible EEG system (BrainProducts GmbH, Munich, DE) inside a Philips Achieva scanner at 3T field strength (PMS, Best, NL). (For details see [7].) Our results are theoretically independent of MRI sequence parameters. In practice we considered sequences typically used for BOLD fMRI experiments (multi-slice single-shot EPI, TE=20-40ms, TR=1-3s).

RESULTS & DISCUSSION

The four graphs in Figure 1 illustrate the effect of re-synchronisation on the mean MGA, the residual MGA variance after AAS, the auto-correlation of the MGA and the estimated cumulative timing error. The fit slope estimates the RTE which is subsequently compensated for. These results are computed from one representative data set and one arbitrary EEG channel recorded *in vivo* and without synchronisation *a priori*. In Figure 2 the normalised residual error power for 7 cleaning procedures applied to the same set of simulated data is split and stacked by frequency bands [<5, <20, <40, <90, <190, <690, <990Hz]. The optimum i.e. smallest error (indicated by asterisks) shifts from the PCA method to moving or global average (MVA / MTS) before / after Resync (top / bottom panel).

Figure 2 Residual error power for 7 cleaning procedures split and stacked by frequency bands [<20, <40, <90, <190, <690, <990Hz].



CONCLUSIONS

The optimal strategy for EEG-fMRI experiments should focus primarily on minimising the *relative timing error* (RTE) and thereby the *residual MGA* after AAS by means of the new (re-)synchronisation techniques presented here. Apart from demonstrating the effectiveness of the Resync method, the simulation and quantification procedures we proposed are generally useful for assessing and optimising post-processing algorithms with respect to specific sets of EEG data.

REFERENCES

[1] Allen PJ, et al. 2000 Neuroimage. **12**(2): p. 230-9.
[2] Negishi M, et al. 2004 Clin Neurophysiol. **115**(9): p. 2181-92.
[3] Niazy RK, et al. 2005 NeuroImage. **28**(3): p. 720-737.
[4] Mandelkow H, et al. 2006 Neuroimage. **32**(3): p. 1120-6.
[5] Ritter P, et al. 2007 Magn Reson Imaging.
[6] Grouiller F, et al. 2007 NeuroImage. **38**(1): p. 124-137.
[7] Mandelkow H, et al. 2007 Neuroimage. **37**(1): p. 149-163.