# Best practice EEG-MRI: The utility of retrospective synchronization and PCA for the removal of gradient artefacts.

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## INTRODUCTION

The EEG recorded during MRI inside the scanner is obstructed by the all but inevitable *MRI gradient artefact* (MGA) originating from the 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 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 *adaptive noise cancellation* (ANC). 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 substitutes hardware synchronisation and makes post-processing beyond AAS dispensable. 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 method for simulating the MGA and we propose new concepts for quantifying and comparing the performance of post-processing algorithms for EEG-MRI data.

## METHODS

By analysing the theoretical and practical properties of the MGA the *relative timing error* (RTE) i.e. the mismatch between TR and the nearest multiple of the EEG sampling interval is identified 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 corrects for it by *continuous-time* interpolation. Resync avoids up-sampling by performing all operations in the spectral domain, which is efficient by the use of FFT. All of the above distinguish Resync from previous interpolation approaches. To quantify and compare the performance of EEG-fMRI post-processing algorithms we developed simulations of the MGA, which take into account the high bandwidth of the MGA signal before EEG sampling. Also, in contrast to previous approaches [5, 6] we emphasise the necessity to spectrally resolve the sharp line spectrum of the MGA. This allows us to study the effects of the RTE and other recording parameters on the SNR of the EEG after post-processing. The performance of Resync and other algorithms were tested with data recorded in vivo using an MR-compatible EEG system (BrainProducts GmbH, Munich, DE) inside a Philips Achieva scanner at 3T field strength (details [7]).

## RESULTS & DISCUSSION

The four graphs in Figure 1 illustrate the effect of re-synchronisation on the mean, variance and auto-correlation sequence (ACS) of the simulated MGA signal as well as the estimated *relative timing error* (RTE). Figure 2 compares different post-processing methods in terms of the achievable SNR. Without re-synchronisation (solid lines) SNR decreases strongly with bandwidth. With re-synchronisation global AAS (without PCA) excels especially at high frequencies. PCA confirms the effectiveness of re-synchronisation, as MGA-related components among the strongest 10 are eliminated (Figure 3).

## CONCLUSIONS

The optimal strategy for EEG-fMRI experiments should focus primarily on minimising the *relative timing error* (RTE) by means of the re-synchronisation techniques presented here. The proposed simulation and quantification methods reveal the strengths and weaknesses of various recording and post-processing techniques. This insight helps to extend the limits of EEG-fMRI toward higher frequencies and points toward an optimal recording and post-processing strategy for EEG-MRI experiments.

## REFERENCES

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**Figure 1 The MGA mean and auto-correlation are maximised by *re-synchronisation* while the MGA variance and the RTE are minimised.**

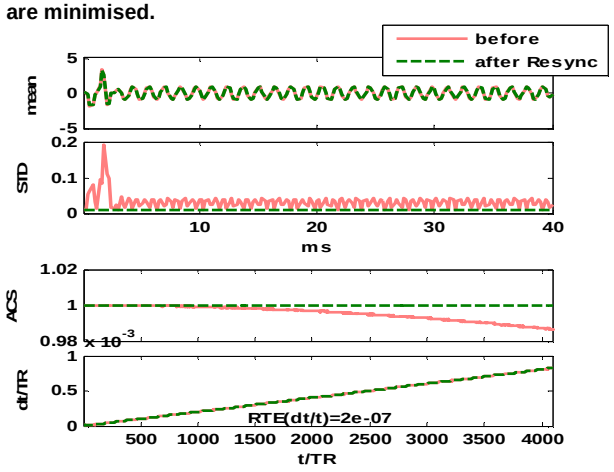


**Figure 2 Plot of SNR over bandwidth for 7 post-processing methods applied before/after Resync (solid/dashed lines)**

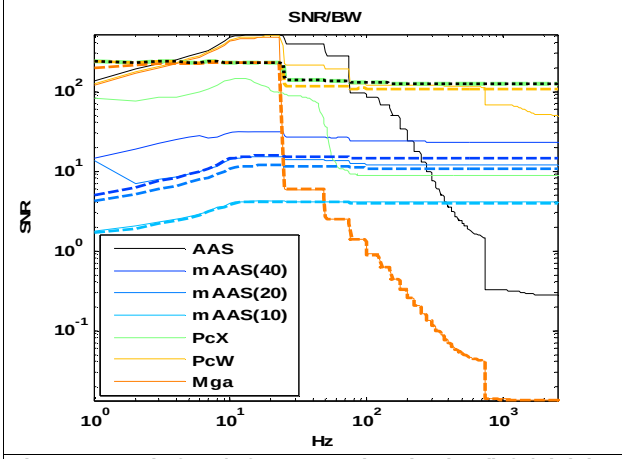


**Figure 3 PCA before / after re-synchronisation (left / right) showing the mean MGA and 10 PCs of highest variance.**