Improved FMRI artifact reduction from simultaneously acquired EEG data using slice dependant template matching

R. K. Niazy[1,2], G. Iannetti[1,3], C. F. Beckmann[1,2], M. Brady[2], S. M. Smith[1]

[1]Functional MRI of the Brain (FMRIB) Centre, University of Oxford, Oxford, United Kingdom, [2]Department of Engineering Science, University of Oxford, Oxford, United Kingdom, [3]Department of Human Anatomy & Genetics, University of Oxford, Oxford, United Kingdom

Introduction: Simultaneous acquisition of EEG and fMRI has promising applications in many clinical and research areas. A difficulty with this technique is that EEG data collected during FMRI acquisition is severely contaminated due to the changes in magnetic field induced by scanner gradients. An fMRI Artifact Slice Template Removal (FASTR) algorithm is presented, in which significant improvements are achieved over the most widely used method today of Imaging Artifact Reduction (IAR) [1] using subtraction of an average artifact.

Problem: During an EPI sequence, involved and rapid (up to 800Hz or higher) changes in magnetic field induce currents in the EEG recording system, which are reflected as severe artifacts in the EEG data (over 9000% amplitude increase at 3T). Several methods were proposed to remedy this problem [1-5]. The most popular method (IAR) [1] used in commercial systems assumes constant artifact epochs that repeat during each slice acquisition and averages blocks of at least *N* epochs each, where *N* is an arbitrary number over which EEG is assumed to be uncorrelated. The average artifact is then subtracted from the data. Two problematic assumptions are made in this method: Firstly, it assumes microsecond consistency in the scanner timing from one volume to another. Secondly, it assumes constant artifacts across all slices. Imaging artifacts vary from on slice to another within a volume. Averaging these artifacts together means averaging artifacts that might have slightly different shapes, lengths and amplitudes. Optimally, this method works best if the TR value is adjusted slightly to achieve perfect synchronization between the scanner and the EEG acquisition hardware and the average is taken over blocks of volume acquisitions (every TR) using a moving window. Experiments have shown that even when perfect calibration is achieved, the scanner tends to drift across experiments, and even in the well calibrated data some misalignment does still occur between same slice artifacts from one volume to another. This introduces residual artifacts in the cleaned data, which are the main reason for degrading the quality of the recovered EEG. Adaptive filtering is used to decrease this problem but does not completely resolve it. Modifications to this algorithm were proposed [3] where an arbitrary number of *N* "frames" (assumed to mean slice artifacts) are constructed by aligning every *Nth* frame together then averaging. This still assumes exact repetition of the artifact across slices.

Methods: It was observed that the assumption of constant slice artifact is only valid between artifacts generated during the acquisition of the same slice in every volume. Further, low frequency drifts in the artifact amplitudes sometimes occur during long experiments. FASTR constructs unique artifact templates for each slice in each volume. Firstly, the EEG data is sinc interpolated by a factor of 10 and high pass filtered at 1.6Hz. A marker channel that identifies the location of each slice artifact is then constructed using the mean of all recorded channels. A threshold is set and the location of each slice artifact is marked. For each slice in each volume in each EEG channel, an artifact template is computed

$$T_{s,v} = \frac{1}{2N+1}\sum_{k=v-N}^{k=v+N} A_{s,k} \qquad (1)$$

where *T* is the artifact template for slice *s* in volume *v*, *A* is the contaminated data at slice *s* in volume *k* and *N* defines the width of the averaging window. Before the average is computed, the first slice artifact is taken as a reference and the rest of the artifacts are aligned with it. This is done by shifting the marker for each artifact by ~ ± 500μs (depending on the imaging protocol) in fine steps and choosing the marker location so as to maximise the correlation between the slice artifacts. The procedure is repeated when aligning the artifact template to the actual data for subtraction. After subtraction, the data is low-pass filtered at 40 Hz. A window width of 11 volumes (N=5) was used. Relevant imaging parameters were TR=3s, 21 slices using a Varian 3T scanner (Palo Alto, CA). EEG data were collected using NMR-SD, an MRI compatible system, with a sampling frequency of 1024Hz and appropriate RF protection and anti-aliasing filters, and using System98 software (Micromed s.r.l., Treviso, Italy).

Results: Figure 1 (b) shows the severe contamination of the EEG signal during fMRI acquisition (9500% increase in amplitude compared to (a) showing EEG without fMRI). Results of optimized IAR (c) and FASTR (d) showed a decrease in signal power by 2.5% and 14%, respectively, compared to (a). By running the IAR cleaning algorithm on clean EEG data (a), it was estimated that a mean loss of 8.4% in real signal power should be expected. Figure 2 shows the time-frequency plots of one EEG channel before (b) and after cleaning the artifacts using IAR (c) and FASTR (d). It can be seen that all major artifact frequencies were removed by both methods. However, residuals of the main artifact frequency of 7Hz (21 slices / 3s) are much more prominent in the data recovered using IAR. Although FASTR causes a slight signal loss, its superior performance in minimizing artifact residuals yields a better quality cleaned EEG data.

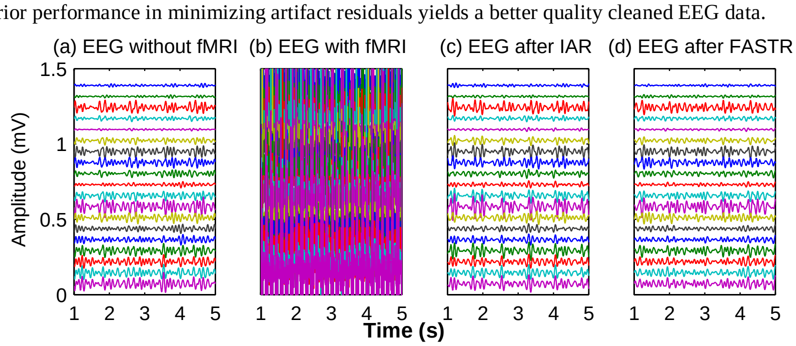

Figure 1: Comparison of the same recording of 19 EEG channels (a) inside scanner without fMRI, (b) during fMRI, (c) after cleaning with optimized IAR and (d) after cleaning with FASTR. Figure (b) clearly shows the severe distortion of EEG during fMRI.

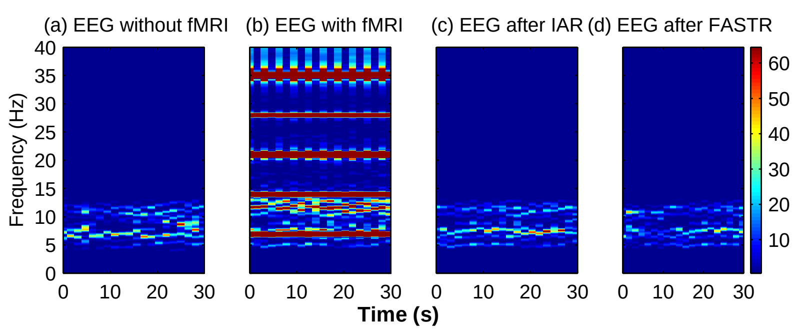

Figure 2: Time-Freq. plots of an EEG channel (a) without fMRI, (b) during fMRI, (c) after IAR and (d) after FASTR. The horizontal lines in (b) represent the constant artifact frequencies in the raw data.

Discussion: An algorithm that maximises the potential of subtraction -based artifact removal was proposed. Quantitative and qualitative examination of time and frequency properties revealed improvements over currently used methods. The algorithm was further validated (data not shown here) by identifying modulation of alpha rhythm (8-12Hz) during eyes opened/closed paradigm. Opening the eyes blocks this strong rhythm. The data shown here were chosen because they were collected with settings that maximise the operation of the IAR algorithm, against which our results are compared. Employing FASTR increases the validity of fMRI/EEG joint analysis of EPs, ERPs, brain rhythms and any other analysis combining the two modalities.

References: [1] Allen *et al.* (2000) *NeuroImage* **12**, 230-9. [2] Anami *et al.* (2003) *NeuroImage* **19**, 281-95. [3] Bénar *et al. (*2003) *Clin Neurophysiol* **114**, 569-80. [4] Bonmassar *et al.* (1999) *NeuroReport* **10**, 1893-7. [5] Hoffman et al. (2000) *Magn Reson Med* **44(5)**, 791-8.

Acknowledgments: This work was partly sponsored by UK EPSRC, GSK and the SA Cultural Bureau in the UK.