A multi-channel recursive least squares filter for motion and ballistocardiogram artefacts in EEG recorded in the MR scanner

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Introduction: Recording EEG during fMRI scanning permits the identification of hemodynamic changes associated with EEG events. However, subject motion within the MR scanner can cause unpredictable and frustrating artefacts on the EEG that may appear focally, bilaterally or unilaterally [1] and can sometimes be confused for epileptiform activity [2]. Motion may arise from a number of sources: small involuntary cardiac-related body movements (ballistocardiogram) [3]; acoustic vibrations due to the scanner machinery [4]; and voluntary subject movements.

A number of methods have been suggested for filtering the ballistocardiogram (BCG) component of the motion artefact that rely upon synchronisation with the cardiac cycle [5, 6]. However, to our knowledge, the only published method for filtering motion artefacts in general uses a linear adaptive filter to remove signal from the EEG that is linearly related to a piezoelectric motion sensor signal [7]. A potential problem with this approach is the assumption that the motion sensor signal is linearly related to the artefact induced in the EEG. The artefact arises when a motion changes the area of a loop formed by the electrode leads normal to the magnetic field [8] – a relationship that may not be adequately described by a linear transformation. As a simple example, two motions of equal magnitude but opposite sign may result in an equal change in loop area normal to the field.

Here we present a new method for recording motion in the MR scanner that is particularly suited for filtering motion artefacts from the EEG.

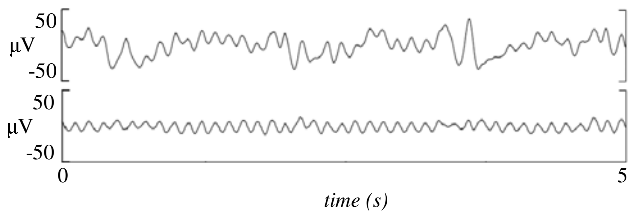

Figure 1 – Simulated EEG: Nodding produced a large artefact on the simulated EEG (top). After filtering the artefact was significantly reduced whilst preserving the 10 Hz sinusoid signal (bottom).

Methods: To measure motion we use our standard EEG amplifier to record from three loops of carbon-fibre wire roughly 10cm in diameter and with a common ground distributed evenly across the surface of our EEG cap. The loops are electrically isolated from the subject so only record induced voltages from movement in the magnetic field. We use a Multi-channel Recursive Least Squares (M-RLS) algorithm [9] to filter the motion artefact from the EEG in real-time using the signal from the three motion loops. We expect these signals to exhibit a linear relationship with the artefact in the EEG and hence be better suited to the linear filtering task than a piezoelectric motion sensor.

We applied our filter to both simulated data and real EEG recordings from 5 epilepsy patients who underwent 30 minutes of simultaneous EEG and fMRI. For the simulated data, a healthy control was fitted with the EEG cap and attached motion loops and placed in the MR scanner. A further motion loop was attached to the cap obliquely to the other three and a sinusoidal signal generator placed in series with this loop. The signal generator produced a 10 Hz sinusoid - providing a crude simulation of the human alpha rhythm. The subject was instructed to lie still for a period and then separately nod, sway and twist their head slightly for one minute periods. This produced a signal subject to both real motion artefact and simulated EEG. For the purposes of comparison we also acquired a baseline epoch of simulated EEG outside the MR scanner using the same setup.

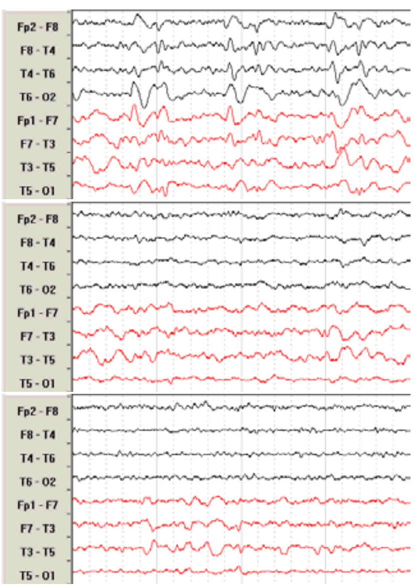

Figure 2 - EEG from epilepsy subject: The unfiltered EEG (top) shows widespread BCG artefact. After filtering (middle) the EEG closely resembles EEG acquired outside the scanner (bottom).

Results: We measured the artefact size in the simulations by calculating the root mean square error (RMSE) between spectrograms of the EEG (Hamming windowed sections of 2 seconds with a 1 second overlap) and the mean power spectrum of the baseline EEG recording outside the MR scanner. In all simulations the filter produced a reduction in the artefact size. The greatest amount of artefact and correspondingly the greatest reduction thereof was in the nodding condition (artefact reduction = 5.04±0.77113 dB). The least amount of artefact and reduction thereof was in the twisting condition (artefact reduction = 2.19±1.04 dB). Figure 1 demonstrates how our filter markedly reduced the motion artefact during the nodding condition whilst retaining the 10 Hz signal. We assessed the filtering of the epilepsy subjects' EEG using power reduction and similarly saw a reduction in EEG power for every epilepsy subject. The greatest power reduction was in the delta frequency band (5.881±4.257 dB) and the lowest in the beta band (1.625±1.512 dB). Figure 2 demonstrates that the filtered EEG - including the slow activity focussed around the T3 electrode - closely resembles EEG recorded outside the MR scanner.

Discussion & Conclusion: We have demonstrated a new method for recording subject motion in the MR scanner and used it to filter motion artefacts from the EEG. Our method is easy to implement, requiring only inexpensive loops of wire and spare channels in the EEG amplifier. Our filter makes use of multiple motion loops which we believe enables better modelling of head motion (for instance pulsatile expansion and contraction of the scalp) than a single motion sensor which can only model rigid body motion. Motion artefact filtering may be particularly important when the EEG events of interest may be correlated with motion, for instance interictal epileptiform discharges with associated myoclonic jerks.

References:

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