An improved ICA 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 groups have suggested the use of independent components analysis (ICA) to filter the ballistocardiogram (BCG) component of the motion artefact [5, 6]. After ICA decomposition of the raw EEG signal, artefact-related components are identified by comparison with the ECG either visually [5, 6] or using correlation [5], and a filtered signal obtained by reconstruction with those components removed.

Here we present an improvement to this method using an independently acquired measure of subject motion to automatically select components for removal. This improvement removes the need for visual selection of components and also generalises the method to filter all motion artefacts rather than only BCG artefacts.

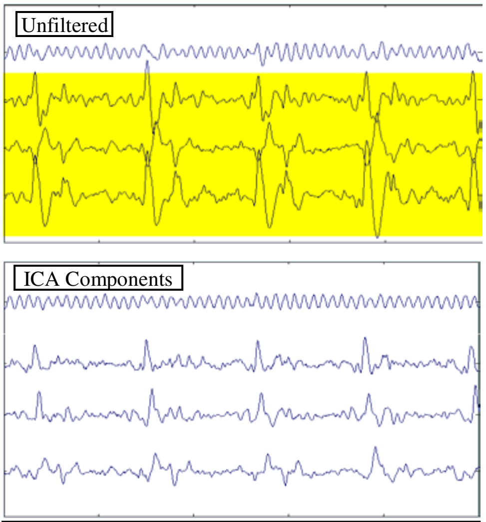

Figure 1: BCG artefact filtering in simulated EEG – The unfiltered EEG (top row, top image) shows ballistocardiogram artefact (motion signals are highlighted in yellow). After ICA decomposition (bottom image) the 10 Hz signal and motion artefacts are separated into different components.

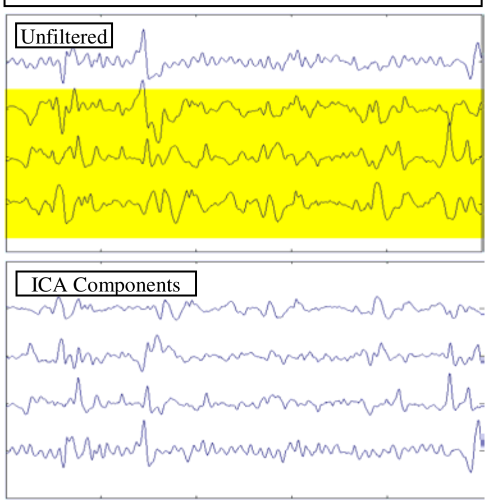

Figure 2: Motion artefact filtering in simulated EEG – The unfiltered EEG (top row, top image) shows widespread motion artefact (motion signals are highlighted in yellow). The ICA decomposition (bottom image) does not provide a clear separation between the 10 Hz signal and motion artefacts.

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 (Faraday's Law). This is precisely the same process that causes the motion artefacts observed in the EEG.

To filter the motion artefact we include the signals recorded from the motion loops in the ICA decomposition and select the three components having the largest contribution to each of the three motion signals (i.e. up to 9 components). The filtered EEG is obtained after removal of these components. ICA processing is performed using EEGLAB [7].

We first tested the ability of ICA to separate the EEG and artefact signals using simulated data. To create 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.

We then applied the filter to real EEG data acquired during fMRI scanning.

Results: In our simulations the artefact and sinusoid signals were well separated by the ICA decomposition when the subject was still (Figure 1). However in the presence of voluntary subject movement ICA did not provide a clear separation (Figure 2). When applied to real EEG data recorded in the MR scanner the filter produced a clear reduction in BCG artefact (Figure 3).

Discussion & Conclusion: The key improvement our filter introduces is the use of an independent measure of motion to provide an automated method for selection of artefact-related components for removal. Additionally, our filter treats motion and BCG artefacts together whereas other methods have targeted BCG artefacts exclusively.

Our filter produced excellent results filtering the BCG artefact in simulations and from EEG acquired in the MR scanner. However, our simulation results suggest that ICA may perform poorly on other movement artefacts. This poor performance could be because the underlying signal consists of a greater number of independent components or alternatively the motion artefact and EEG signals may not mix linearly.

Further work is needed to optimise this method for non-BCG motion artefacts.

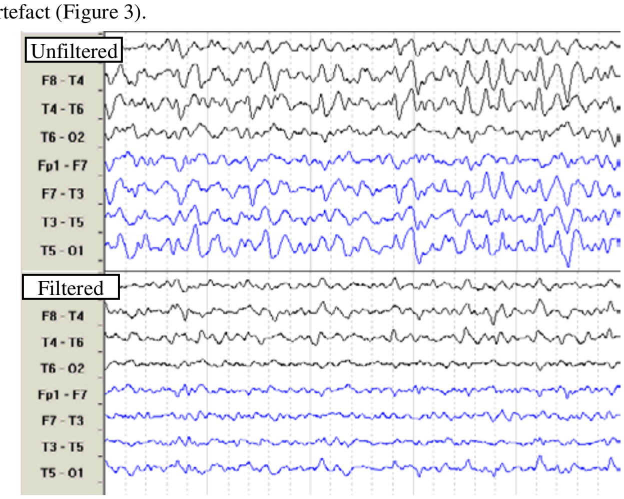

Figure 3: Filtering real EEG – A five second epoch of unfiltered EEG (top) showing a large BCG artefact. After filtering (bottom) the artefact is significantly reduced.

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