Ballistocardiogram Removal and Motion Correction for EEG in the Magnet

Patrick L. Purdon[1], Iiro P. Jaaskelainen[1], Victor Solo[2], Emery N. Brown[3], John W. Belliveau[1], Giorgio Bonmassar[1]
[1]Massachusetts General Hospital, NMR Center, Building 149, 13th St., Charlestown, MA USA; [2]University of New South Wales, School of Electrical Engineering and Telecommunications, Sydney, NSW Australia; [3]Massachusetts General Hospital, Department of Anesthesia and Critical Care, Boston, MA USA;

Introduction

Simultaneous recording of EEG and fMRI is an important, emerging tool in functional neuroimaging that combines the high spatial resolution of fMRI with the high temporal resolution of EEG [1]. A fundamental limitation in this technique is the noise introduced in the EEG due to motion within the magnetic field, either from cardiac pulsation (ballistocardiogram) or from head movements. The ballistocardiogram noise obscures EEG activity at alpha frequencies (8-13 Hz) and below, with amplitudes often in excess of 150 mV, larger than the alpha waves seen in most patients. Head rotations and translations, present in longer recordings or in recordings of patients with certain neurological disorders, result in even larger disturbances to the EEG. A popular method for removing the ballistocardiogram noise is to subtract an average ballistocardiogram waveform created from the EEG data itself [2]. Because of variations in heart rate and blood pressure, both on a beat-to-beat basis and over larger time scales, such as in sleep studies, the amplitude and form of the ballistocardiogram artifact can vary over time. Under such circumstances, simply subtracting an average waveform can introduce systematic errors into the processed EEG. Furthermore, the "average-waveform" method cannot remove motion artifacts, and would be cumbersome to implement in real-time, which limits its potential usefulness in EEG-triggered MRI applications. In this abstract we present a method that is capable of removing both ballistocardiogram and motion-induced noise simultaneously in a way that lends itself naturally to real-time implementation. We demonstrate its efficacy in recordings of alpha waves, visual evoked potentials (VEPs), and head motion.

Methods

The method we present is an application of adaptive noise cancellation [3], where a reference signal related to the noise source is used to adaptively estimate the noise signal and remove it. In this case, for the reference signal, we use a small, piezo-electric motion sensor placed over the subject's temporal artery to record both ballistocardiogram and head motion signals. The noise signal is estimated using a FIR filter on the reference signal whose weights are adaptively updated with a Kalman filter. In five subjects, we recorded alpha waves and VEPs in the magnet. To obtain the alpha waves, subjects were instructed to rest with eyes open for 10 seconds, followed by 20 seconds with eyes closed, repeated over a 3-minute interval. Alpha waves should be present when eyes are closed. For the VEPs, subjects were presented a full-field flickering checkerboard reversing at 2 Hz for 15 seconds followed by 15 seconds of fixation (gray background) to collect ~500 epochs per trial, with three trials per subject. To create motion data, one subject was asked to nod his head slightly once every 10 to 20 seconds over a five-minute period while resting inside the magnet and recording EEG. Simulated epileptic spikes were added to this data to determine if the adaptive noise cancellation could improve detection of spikes. T1 and T2*-weighted EPI structural images were taken to confirm that the motion sensor did not interfere with MRI imaging.

Results and Discussion

Upon visual inspection, the algorithm yielded vast improvement in observation of alpha waves for three of the five subjects (Fig. 1), with the remaining two subjects showing no evidence of alpha waves. VEPs were detected in four of the five subjects, showing strong agreement, both in terms of temporal waveforms and spatial distribution, between recordings done inside and outside the magnet. The motion epochs produced EEG deflections in excess of 300 uV. Adaptive noise cancellation reduced these deflections to below 100 uV and improved observation of simulated spikes. The T1 and T2* structural images showed no reduction in quality when taken with the motion sensor present.

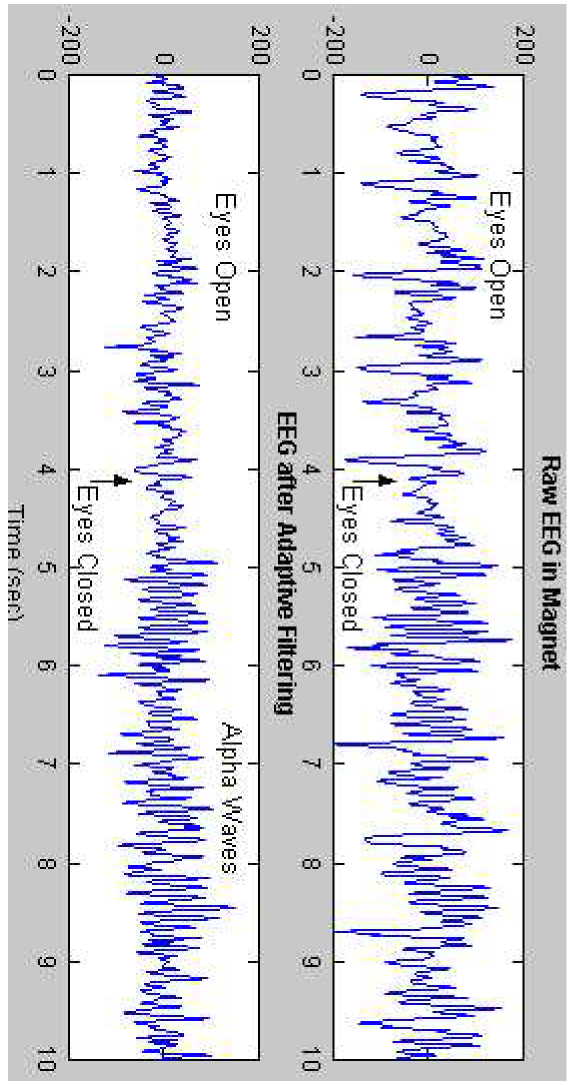

Figure 1

Conclusions

We have developed a method based on adaptive noise cancellation for removing ballistocardiogram and motion artifacts from EEG collected in the magnet. This method allows for improved observation of activity at alpha frequencies and below, improved evoked-potential recordings, and the ability to reduce motion artifacts. This method can be implemented naturally in real-time, which will make it useful in EEG-triggered fMRI applications.

References

[1] Schomer DL, et al., 2000, J Clin Neurophysiol. 17(1):43-58.
[2] Allen PJ, et al., 1998, Neuroimage 8:229-239.
[3] Haykin SS, Adaptive Filter Theory, Prentice Hall, 1995.