Reference Layer Artefact Subtraction (RLAS): A novel method of minimizing EEG artefacts during simultaneous fMRI.

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Introduction

The large artefact voltages produced in EEG recordings made during concurrent fMRI pose heavy demands on the bandwidth and dynamic range of EEG amplifiers, and mean that even small fractional variations in the artefact voltages give rise to significant residual artefacts after average artefact subtraction (AAS). Since these effects currently limit the utility of simultaneous EEG-fMRI, alternative approaches for reducing the magnitude and variability of the artefacts are required. One such approach that has been used with limited success to attenuate the pulse (PA) and motion (MA) artefacts is to record signals from wire loops attached to the subject's head and then to subtract these signals from the scalp EEG [1]. This approach has recently been extended [2, 3] by use of an EEG cap that incorporates a reference layer with similar conductivity to tissue, which is electrically isolated from the scalp. The reference layer carries a set of electrodes and leads that precisely overlay those attached to the scalp, such that similar voltages will be induced in associated reference and scalp leads by switched magnetic field gradients or head rotation in the static magnetic field. Since the reference layer is isolated from neuronal signals, subtraction of the voltages in reference and scalp channels greatly reduces the magnitude of gradient artefacts (GA), and also attenuates the PA and MAs, without affecting sensitivity to neuronal signals. Here, we investigate the artefacts induced on the reference layer and scalp and evaluate the attenuation of artefacts which can be achieved by using Reference Layer Artefact Subtraction (RLAS).

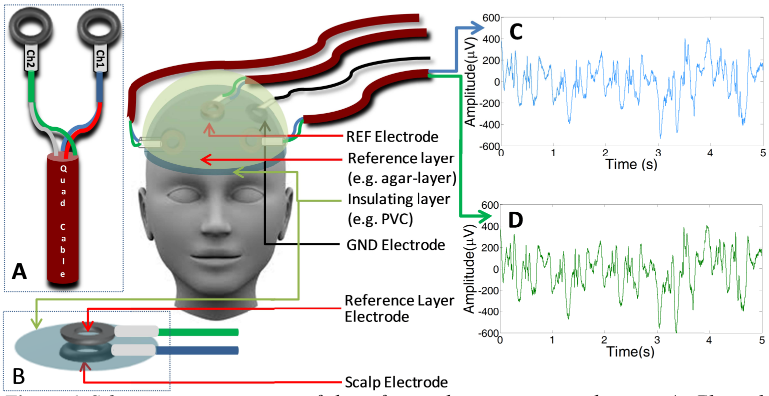

Figure 1 *Schematic representation of the reference layer experimental setup.* ***A:*** *Electrode connection with star-quad cable;* ***B:*** *Electrode set-up on scalp and reference layer; EEG traces recorded from* ***(C)*** *scalp and* ***(D)*** *reference channels from subject during head movement.*

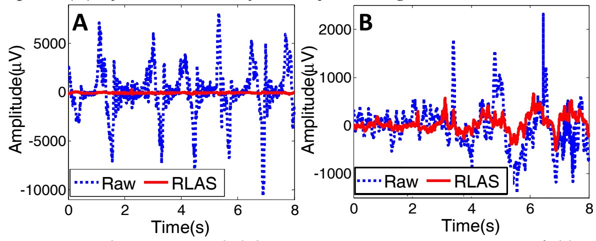

Figure 2 *Scalp EEG recorded during movement in static magnetic field (blue) and after RLAS (red) for phantom* ***(A)*** *and subject* ***(B)****.*

Methods

Cap construction: Electrode pairs were constructed by attaching each Ag/AgCl ring electrode to a pair of wires in a star-quad cable (Fig 1A). The electrode pairs were attached to the scalp with a thin insulating layer separating the electrodes from one another (Fig, 1B). In these experiments, using a prototype system, three electrode pairs were positioned approximately equidistant from the reference electrode pair, in which the electrode employed as the amplifier's reference input (REF) was attached to the scalp. A 5-mm-thick, hemispherical, conducting agar reference layer (agar made according to [4]) was placed on the phantom/head (Fig. 1). The ground (GND) electrode was attached to the scalp, but also shorted to the reference layer using conductive gel to so as to provide a common ground. *Data acquisition:* EEG data were acquired in a 3T MR scanner using a BrainAmp MRplus amplifier (5 kHz sampling rate and 0.016-250 Hz frequency range). Data were acquired on a spherical, agar phantom (containing a small dipole) [4] and on a human subject whilst: i) the phantom/head underwent small movements in the static magnetic field to allow assessment of MA attenuation; ii) EPI (5 slices, 36×36 matrix, 7 mm resolution, TR/TE = 2000/35ms, 70 volumes) was executed and the phantom/head moved, thus changing the form of the GA on each lead and producing an MA. Artefact attenuation was assessed for small and large movements (made once or three times). By applying an 11 Hz signal to the dipole embedded in the phantom we also tested the fidelity of recording of brain-like signals after RLAS.

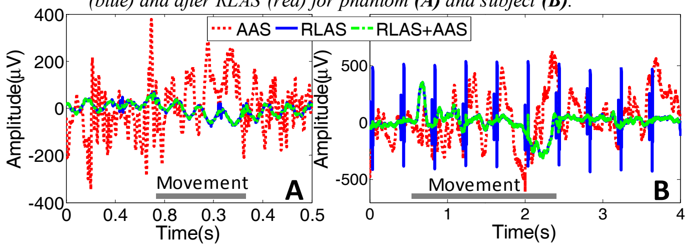

Figure 3 *EEG corrected using AAS (red), RLAS (blue) and RLAS+AAS (green) for data acquired during movement and EPI on: phantom (A) and subject* ***(B)****.*

Analysis

To implement RLAS, the reference layer voltages were re-referenced to the channel in the reference layer which overlaid the REF channel on the scalp. The signal from each reference layer electrode was then subtracted from the corresponding scalp electrode signal. AAS was carried out on the raw scalp recordings and on the data produced after RLAS. In both cases, all 350 slice repetitions were used to form the average artefact template. To evaluate the efficacy of correction the RMS magnitude of the artefact voltages over time was calculated for the raw data and then for data that had been subjected to: (i) AAS, (ii) RLAS and (iii) RLAS+AAS. Results were converted to attenuation relative to the raw signal for each channel and the mean, maximum and minimum attenuation over channels was evaluated for each data set.

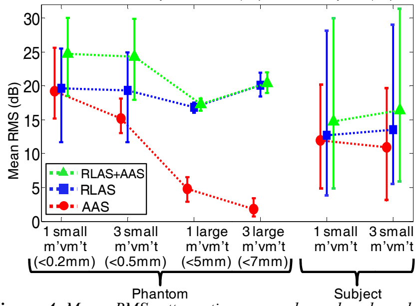

Figure 4 *Mean RMS attenuation over channels when data corrected with AAS (red), RLAS (blue) and RLAS +AAS (green) for varying degree of movement (m'vm't). Error bars denote the range of attenuation values across channels (max – min).*

Results and Discussion

Figure 1C&D show example traces recorded from a reference layer electrode and associated scalp electrode on the head while the subject executed small movements in the scanner. The strong similarity of the artefact voltages in the two traces, which forms the basis of RLAS, is evident. Figure 2 shows further recordings made on the moving phantom (A) and head (B), before and after RLAS. In these data, the RMS artefact voltage was attenuated by 35/10 dB (phantom/head) after RLAS. Figure 3 shows data that were recorded from the phantom (A) and head (B) during EPI acquisition and movement, and then corrected using AAS, RLAS or RLAS+AAS. The maximum RMS artefact voltage generated in the raw data from the phantom/head was 988/1587 μV. The 11 Hz signal from the dipole embedded in the phantom is clearly recovered after RLAS and RLAS+AAS, but not when AAS alone is used (Fig. 3A), demonstrating the benefits of RLAS. For these particular phantom/head data, the RMS artefact voltages were attenuated by 15/20, 25/29 and 25/31 dB by AAS, RLAS and RLAS+AAS respectively. Figure 4 shows the mean, max. and min. artefact attenuation measured across leads in the different phantom/head experiments. It indicates that RLAS outperforms AAS in all experiments and that implementing AAS after RLAS provides further attenuation of artefacts. It also shows that the efficacy of RLAS is relatively independent of the number or magnitude of the movements, while AAS performance is compromised by large or numerous movements. The significant variation of artefact attenuation across channels when RLAS is used is believed to be due to small differences in the electrode pair wiring in our prototype system. The slightly poorer RLAS performance on the subject is most likely due to the reference layer slipping and thus not following head movement. The significant benefits of RLAS demonstrated on our simple prototype, which in addition to the presented results also include a significant potential reduction of the required EEG amplifier dynamic range and attenuation of the PA, mean that development of a more robust reference layer system is well worth pursuing.

References [1]. R. Masterton *et al NeuroImage* **37**:p202 (2007). [2]. F. McGlone *et al Epilepsy and Behavior* **16**:p6 (2009). [3]. R. Dunseath *et al. Patent # US 0099473* (2009). [4]. W.X. Yan *et al*, *Neuroimage* **46**:p 459 (2009).