Reducing the Gradient Artefact in Simultaneous EEG-fMRI by Adjusting the Subject's Axial Position.

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Introduction

EEG data recorded simultaneously with fMRI acquisition are contaminated by large voltages generated by the time-varying magnetic field gradients. The resulting gradient artefact (GA) can be more than 3 orders of magnitude larger than signals of interest from the brain. Correction of the GA generally relies on the use of low-pass filtering to attenuate the large, high-frequency voltage fluctuations produced by the gradient waveforms, followed by subtraction of a GA template produced by averaging over many repeats of the artefact waveforms [1]. The average artefact subtraction (AAS) process relies on the EEG system having a dynamic range great enough to characterise the artefact voltages and also on invariance of the artefact waveform over multiple image acquisitions. Saturation of the amplifiers, changes in subject position or variation in the timing of the gradient waveforms cause these conditions to be violated, leaving unwanted residual GA after AAS. Recently described simulations [2] have shown that the GA amplitude can potentially be reduced by adjusting the axial position of the subject relative to the scanner's iso-centre (i.e. the centre of the gradient coils). Here, we describe an experimental investigation of the effect of adjusting the subject's axial position on the magnitude of the GA and on the residual artefact after AAS.

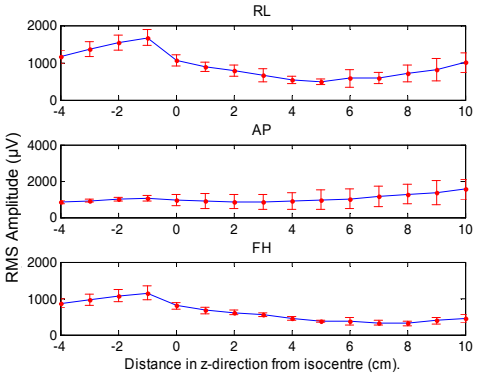

Figure 1: *Variation of the average GA (RMS value over electrodes) with subject's axial position for gradients applied in RL, FH & AP directions (0 cm = nasion at iso-centre). Error bars show std across subjects.*

Methods

EEG Data were recorded at 3T using a 32-electrode EEG cap, a BrainAmp MR-plus EEG amplifier and Brain Vision Recorder software (Brain Products, Munich). Four subjects took part in each study.

Study 1 To identify how axial repositioning of the subject affected the magnitude of the GA produced by the three orthogonal gradients, EEG recordings were made during execution of a sequence in which gradient pulses with a slew rate of 2 $Tm^{-1}s^{-1}$ were sequentially applied in the Anterior-Posterior (AP), Right-Left (RL) and Foot-Head (FH) directions. Recordings were made with the subject at 15 different axial positions, characterised using the z-co-ordinate of the nasion. This ranged in 1cm steps from -4cm to +10cm with positive values corresponding to an axial shift towards the feet. Artefacts from 30 pulses applied along the three gradient axes were recorded at each position using a low-pass filter cut-off of 1000Hz. The range and root-mean-square amplitude of the artefacts across electrodes were calculated for each position and gradient direction.

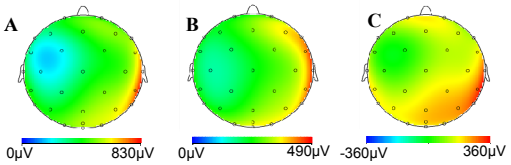

Figure 2: *Maps of the RMS (over time) of the average GA produced by a multi-slice EPI acquisition with the nasion at: **A)** iso-centre; **B)** +4cm. **C)** shows the difference, **A)-B).***

Study 2 Experiments were carried out with the nasion at iso-centre (conventional subject position) and at the optimal *z*-offset identified from Study 1. EEG data were recorded over an 8 minute period whilst a standard axial, multi-slice EPI sequence was executed (84×84×32 matrix, 3×3×4 mm^3 voxels) with TR/TE =2.5s/40ms. During the scanning, subjects were cued to move their feet for 5s every 30s. Foot motion generated cumulative head movements of less than 1mm in amplitude, mimicking the position changes which may occur during fMRI sessions. A low-pass filter cut-off of 250Hz was used in this case to avoid saturating the EEG amplifiers at the z=0 subject position. Data were exported to Matlab both before and after AAS had been carried out in Brain Vision Analyzer2.

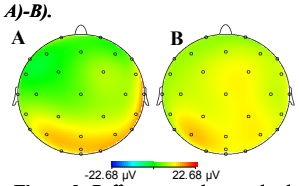

Figure 3: *Difference in the standard deviation of the residual GA (0cm-+4cm). **A**: average over subjects and **B**: standard deviation over subjects.*

Results

Study 1 Figure 1 shows that shifting the subject's axial position towards the feet (starting with the nasion at iso-centre) produces a significant decrease in the RMS amplitude of the GA for the RL and FH gradients, although the artefact produced by the AP gradient is increased. For minimising the overall artefact amplitude a sensible compromise is to adopt a +4cm shift for which the range/RMS of the GA is decreased by 55/43% and 51/41% for the RL and FH gradients respectively, with only a 14/14% increase for the AP gradient. A shift of +4cm was therefore used in Study 2.

Study 2 Figure 2 shows the map of the RMS value of the GA prior to application of AAS produced by averaging over the slice acquisitions of the axial multi-slice EPI sequence, with the subject at iso-centre and shifted by +4cm. The difference of these two maps (Fig. 2C) shows that the GA is significantly reduced by axial repositioning and that the greatest reduction occurs in the posterior electrodes. When averaged over electrodes, a +4 cm axial shift produced a 28/36% reduction in the range/RMS value of the GA. Figure 3A demonstrates that the residual GA after AAS can also be reduced by adjusting the subject's axial position. It displays the difference in the standard deviation of the residual GA recorded at the two subject positions (averaged over subjects and calculated only using data from the 25-s-periods of no movement, thus avoiding the effect of artefact voltages due to head motion in the static field). The positive values indicate that the residual GA is larger at the z = 0cm position. Figure 3B shows the standard deviation of the difference over subjects, indicating that there is significant variation of the difference measure from subject to subject, probably due to differences in the amount of movement, and also due to the contribution of other sources of signal variance, including the pulse artefact and brain signals. A clearer measure of the reduction of the residual GA produced by shifting the subject's axial position is provided by Fig. 4, which focuses on signals occurring at multiples of the 12.6Hz slice repetition frequency that are dominated by residual GA. It indicates that the signal power at these frequencies is reduced at the +4cm position, with the most significant reduction occurring at the higher frequencies where the residual GA power tends to be higher.

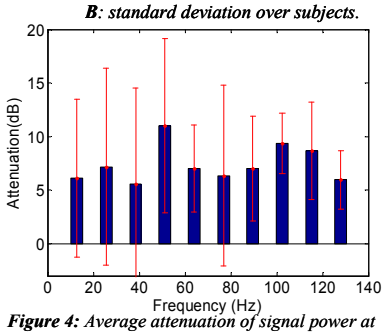

Figure 4: *Average attenuation of signal power at optimal position compared to isocentre after GA correction for harmonics of the slice frequency over all channels and subjects. Error bars: standard deviation over all subjects.*

Discussion

The results presented here indicate that a simple adjustment of the axial position of the subject so that the nasion is moved +4 cm from iso-centre towards the subject's feet produces a significant reduction in the size of the voltages produced by time-varying gradients applied in the RL and FH directions, and that this can be translated into a reduction of the GA produced in a conventional EPI acquisition. Such a reduction would allow the use of larger gradients and/or a higher EEG bandwidth before data are corrupted by EEG amplifier saturation. An increased bandwidth would be particularly beneficial for recording high frequency signals in combined EEG/fMRI experiments [4]. Further work is needed to understand why the GA produced by an AP gradient is larger at the z=+4cm position. The results also indicate that adjustment of the subject's axial position produces a significant reduction of the residual GA after correction by AAS in fMRI experiments in which movements of order 1 mm occur. Residual GA can easily swamp brain signals and any reduction in the residual artefact is advantageous. The +4cm shift needed to produce these benefits does not affect the quality of the MR data, since the head remains within the homogeneous volume of the magnet and gradients.

References [1] Allen *et al*. Neuroimage 12:230,2000 **[2]** Yan *et al* Neuroimage 46:459,2009 **[3]** Moosmann *et al* Neuroimage 45:1144, 2009 **[4]** Freyer *et al* Neuroimage 48:94, 2009.