Simultaneous EEG-fMRI: evaluating the effect of the cabling configuration on the gradient artefact.

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Introduction

EEG data recorded in simultaneous EEG/fMRI experiments are confounded by large gradient artefacts. The amplitude of the gradient artefact (GA) depends on the area of the wire loops formed by the EEG leads, as well as on the rate of switching of the field gradients [1]. Successful artefact correction, using average artefact subtraction (AAS), requires the artefact to be precisely sampled and highly reproducible [2, 3]. Small changes in lead positioning result in large changes in the GA amplitude [4]. The lead-paths and head position should thus remain stable during imaging. While the GA induced in the EEG cap and head has been well characterised [1], the contribution to the GA from the cabling between the EEG cap and amplifier has not previously been investigated. In this work two cable configurations were studied: i) a ribbon cable in which the wires run in parallel, effectively forming horizontal loops of large area; ii) a cable bundle consisting of wires that are twisted together thus minimising the area of the wire loops.

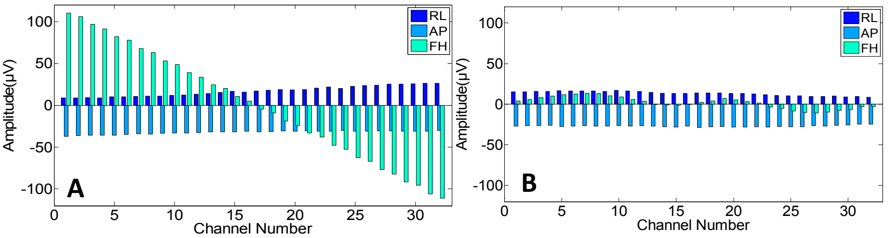

Figure 1 *GA change across channels due to a 5mm AP movement for: ribbon cable (A) and cable bundle (B).*

Methods

Combined EEG/fMRI experiments were carried out on a Philips Achieva 3T MR scanner using the BrainAmp, EEG amplifier, with 5 kHz sampling rate, Brain Vision Recorder software (Brain Products, Munich, Germany) and a 32-channel EEG cap. Trigger pulses from the MR scanner marking each slice acquisition were recorded on the EEG system. Recordings were made with cabling approximately centred in the magnet bore and running in an axial direction, as used in standard EEG/fMRI studies. The cabling was attached to a cantilevered beam to ensure it was isolated from scanner vibration. To evaluate the sensitivity of GA to cable movement, recordings were made before and after moving the cabling 5 mm in the Anterior-Posterior (AP) direction.

Study 1: EEG data were recorded during the execution of a customised EPI sequence in which gradient pulses with a slew rate of 2 $Tm^{-1}s^{-1}$ were sequentially applied in the AP, Right-Left (RL) and Foot-Head (FH) directions prior to each slice acquisition (30 repetitions) [4]. The BrainAmp system was set to record with a frequency range 0.016-1000 Hz to fully characterise the gradient pulses. The cabling was shorted using a signal tester box (Brain Products) so that the cables were the dominant source of the GA.

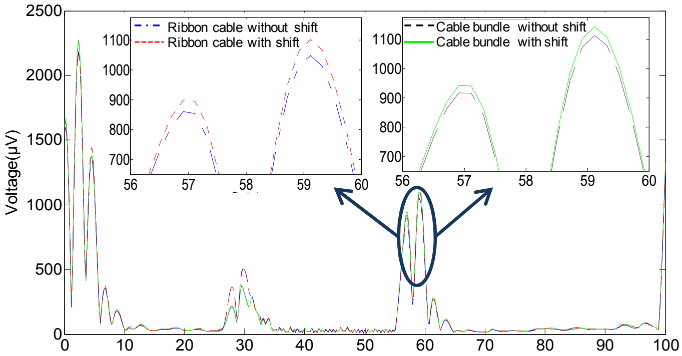

Figure 2 *RMS across leads for the average slice artefact for cable bundle and ribbon cable connected to the EEG cap before and after a 5-mm AP shift of cabling.*

Study 2: Simultaneous EEG/fMRI data were acquired on a single subject using a standard, multi-slice EPI sequence (20 slices, 64×64 matrix, 3×3×3 mm^3 voxels, TR=2s ,TE = 40ms, slice repetition frequency = 10 Hz, 40 volumes). EEG data were recorded with a frequency range of 0.016-250 Hz, as conventionally used for EEG/fMRI studies. Additionally standard EPI data were acquired using the signal tester box used in Study 1.

Results and Discussion

Study 1: The GA amplitudes (RMS across leads) at the centred position for the ribbon cable/cable bundle were found to be 83/51, 668/232 and 645/625 µV, for the RL, AP and FH gradients respectively. This indicates that, as expected the induced GA is larger for the ribbon cable than the cable bundle for all three gradients. The most distinct difference was observed for the AP gradient. This is because the greatest rate of change of flux is generated in the horizontal loops of the ribbon cable by the concomitant, vertical (B_y) field associated with the AP gradient. We also found a linear variation with channel number of the GA due to the AP gradient which results from the linear increment in loop area in the ribbon cable with channel number (the reference channel is located between channels 16 and 17). Figure 1 shows the change in the GA amplitude that was produced by a 5 mm AP shift of the cabling. The voltage differences (RMS across leads) for the ribbon cable/cable bundle were found to be 18/14, 32/27 and 67/7 µV for the RL, AP and FH gradients respectively. These results show that the GA induced in the ribbon cable is most sensitive to movement and that for a movement in the AP direction the greatest change occurs in the GA from the FH gradient. This is a consequence of the linear variation with AP position of the concomitant (B_y) field that is associated with a FH gradient.

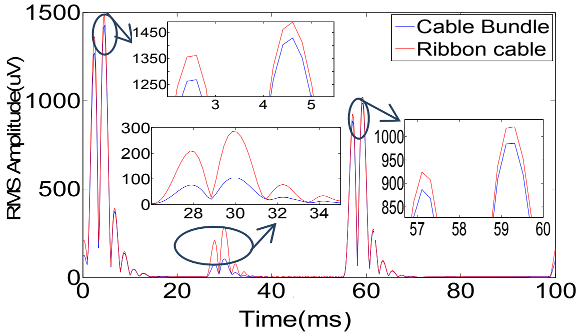

Figure 3 *RMS across leads of the average slice artefact for cable bundle and ribbon cable shorted with signal tester box.*

Study 2: Figure 2 shows the RMS over leads of the average induced GA over an EPI slice acquisition for the two AP positions of the cabling, with each cable connected to the EEG cap. The RMS of the GA summed over 100 ms of the artefact, resulted in a larger fractional change due to the 5 mm AP movement for the ribbon cable than the cable bundle (8.5 vs 4.7%). This is reflected in the zoomed views in Figure 2 which illustrate that the 5 mm AP shift produces a greater change in the amplitude of the GA in the ribbon cable than in the cable bundle for periods where the largest artefacts are induced (fat saturation, slice selection, pre-excursion pulses and post-acquisition crusher gradients). The largest changes in the GA are induced by the slice select and crusher gradients, both of which comprise a large gradient component in the FH direction. This is in line with the findings from Study 1. Figure 3 clearly shows that the GA voltage induced in the cabling by a conventional EPI sequence is smaller for the cable bundle than the ribbon cable at the periods of peak artefact generation. The RMS of the artefact over time was found to be 272/256 µV for the ribbon cable/cable bundle, further demonstrating this reduction for the cable bundle. The largest reduction occurs during the pre-excursion pulse which comprises a large gradient in the AP direction, again agreeing with the findings of Study 1.

Conclusion

The amplitude of the GA can be reduced by minimising wire loop areas in the cabling between the EEG cap and amplifier. Wire loop minimisation also increases the stability of the artefact to the effect of small movements. This is advantageous for conventional EEG-fMRI studies as the possibility of saturating channels will be reduced and the performance of artefact correction methods made more robust in the presence of small cable movements. The use of a cable bundle consisting of twisted wires is therefore recommended in future EEG/fMRI studies.

References: **(1)** W. X. Yan *et al*, *NIMG* **46**, 459 (2009); **(2)** P. J. Allen *et al*, *NIMG* **12**, 230 (2000); **(3)** M. Moosmann *et al*, *NIMG* **45**, 1144 (2009); **(4)** K. J. Mullinger *et al*, *NIMG* **54**, 1942 (2011).