Safety in EEG-MRI: Heating beneath EEG scalp electrodes for different RF transmit coils

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Introduction

In neuroscience, the simultaneous data acquisition of different modalities such as EEG and (f)MRI is of increasing interest as it yields over-additive information compared to separate data acquisition with posthoc combination. However, simultaneous EEG-MRI acquisition is challenged by various difficulties, like degradation of MR data quality, artefacts in EEG data from gradient switching and RF transmission, and in particular safety related issues: the transmitted RF field can induce currents in the conducting electrodes and leads, resulting in heating and potentially injuries to subjects or patients. The purpose of this study was (1) to monitor *in vivo* the frequency and intensity of the heating beneath various ECG, EMG, and EEG scalp electrodes for several sequences covering a wide range of SAR values and (2) to compare the results for two types of RF transmit coils, a body coil and a head coil, as previous phantom studies on intracranial EEG electrodes and deep brain stimulators reported stronger heating for body coils [1, 2].

Materials and Methods

In vivo MRI measurements were performed on a 3 Tesla whole body scanner on three healthy volunteers. Sequences routinely used in clinical and research applications covering a wide range of SAR values were tested: a GE-EPI sequence used for functional studies, T1-weighted anatomical sequences (FLASH, MDEFT, MPRAGE, T1-SE), and T2-weighted anatomical sequences used for the detection of lesions (T2-FLAIR, T2-TSE). EEG, EMG, and ECG measurements were performed with commercially available MR compatible EEG equipment with a 32-channel EEG cap connected by a 10 cm flat ribbon cable with a unipolar amplifier positioned within the scanner bore above the subject's head. In addition, the ECG and the EMG channels were recorded by means of a second bipolar amplifier placed on the scanner table next to the subject's feet. Each amplifier was powered by a rechargeable battery pack. Data were transmitted from the amplifiers via fibre optic cables through a wave guide to the USB interface at the control computer outside the scanner room. Electrodes consisted of a ring shaped plate of sintered Ag/AgCl, covered by epoxy resin on the top, and were mounted on the cap by means of plastic holders which prevented direct contact between the electrodes and the skin, i.e. electrical contact was only mediated by the electrolyte gel. Eight fibre optic temperature probes with GaAs tips were positioned in the gel at the following sites: ECG (lead and electrode), chin (EMG), clavicle, Fz, P3, Cz, and T8. Temperatures were monitored online and stored with 1 Hz sampling rate using commercial software. Whenever temperature increases exceeded 0.5°C, the equilibrium temperature was fitted exponentially.

Results

Only temperature increases of at least 0.5°C were considered. Head coil: In five cases, temperature increases below 1°C could be observed; however, increases between 1.1°C and 4.6°C were found beneath the clavicle electrode in one subject (m90, male, 90 kg) only, a region with high local SAR values [3]. Body coil: Heating was stronger and more frequent over subjects and electrodes with temperature increases mostly below 2°C (39 cases); however, under the T8 and Cz electrodes, increases of more than 2°C were found in 8 cases, reaching values of up to 6.9°C. Fig. 1 shows the temperature-time curve for the Cz (left) and T8 (right) electrodes for subject m85 (male, 85 kg) when using the body coil. In general, fitted equilibrium temperatures increased with the scanner-calculated SAR.

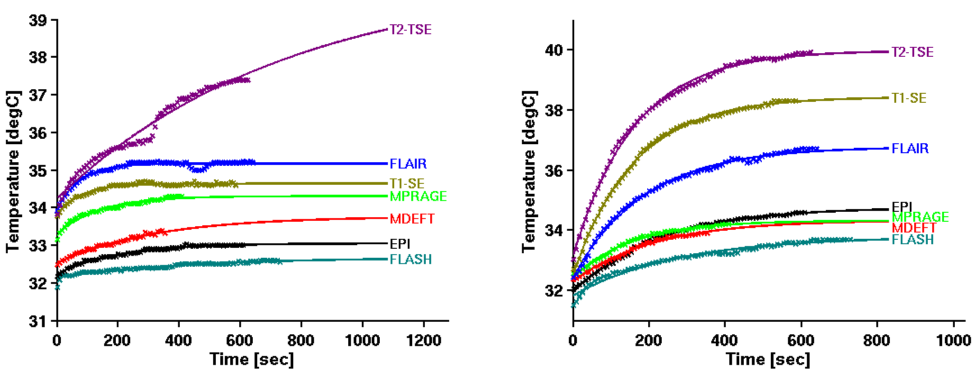

Figure 1: Measured (x) and fitted (-) temperature-time data for all seven sequences tested. Shown are the Cz (left) and T8 (right) electrodes on subject m85 when using the body coil.

Discussion and Conclusion

Data confirm theoretical predictions and results from previous phantom studies [1, 2] that heating is stronger for body coil transmission, showing that restrictions to very low SAR sequences are required in this case. This is probably due to the larger coil size, requiring more energy to produce the B1 field and exposing a larger part of the EEG equipment to RF. For the head coil, fitted equilibrium temperatures remained below 39°C, whereas for the body coil values above 40°C were fitted for high SAR sequences, reaching the critical level of 41°C [4]. However, for the GE-EPI sequence, fitted equilibrium temperatures were below 35°C for both coil types. In general, in simultaneous EEG-(f)MRI, a head transmit coil should be used; however, the strong heating of the clavicle electrode when using the head coil shows that even in this case high SAR sequences should be avoided unless temperature measurements are performed for safety. In case a body transmit coil has to be used, GE-EPI sequences seem to be safe at least for the setup used in this study, but high SAR sequences must not be used as there is a high risk of injuries due to electrode heating. These findings are of high relevance as many scanners are not routinely equipped with head transmit coils and the number of simultaneous EEG-MRI studies is increasing.

References

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