Encoding of EEG in MR images

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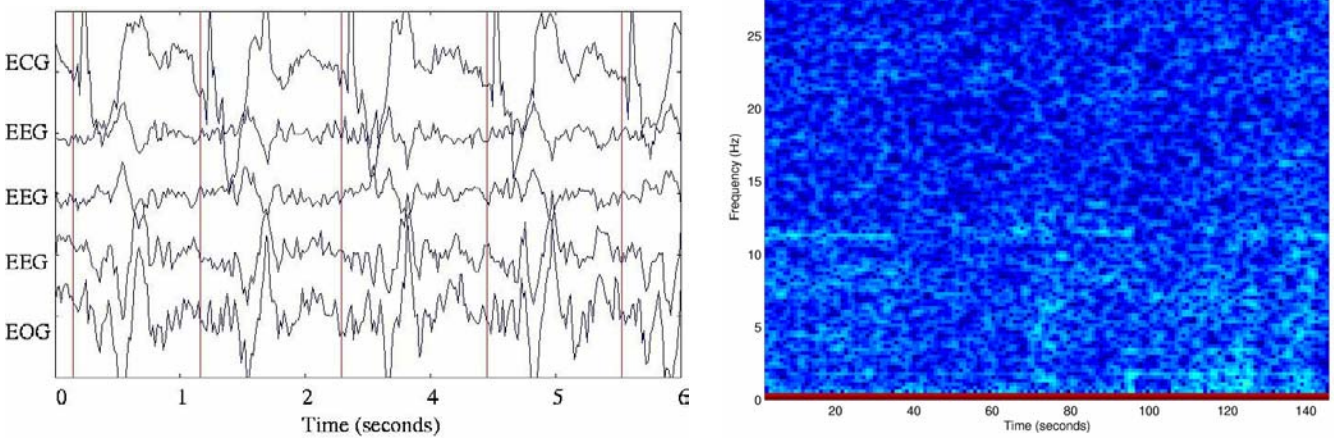
Introduction: It was shown in [1] that electrophysiology and other non-MR signals can be measured by MR equipment after modulation to frequencies close to those of the MR-signals. After wireless transmission to the scanner, MR and and non-MR signals were recorded together. The technique is somewhat similar to the "mag stripe" technique used for encoding soundtracks in movies: The signals are encoded in the oversampled region just outside the field-of-view. Here we demonstrate 6 channel simultaneous ECG, EOG and alpha-EEG, all recorded by the scanner during fast echo planar imaging at 3 tesla.

Methods: A tailored programmable 8-channel modulator for encoding of electrical signals in MRI was used [2]. Filters, gains, trigger timings and frequencies are controlled via an optical PC-link. This link also provides a view of the recordings independent of those made by the scanner (lower quality, but adequate for verifying EEG quality ahead of scanning and for monitoring the recordings real-time during scanning). A gradient activity sensor implemented with a simple coil near the opening of the scanner triggers a sample-hold circuit, thus largely eliminating gradient noise in the electrophysiological recordings [3]. These are modulated onto RF carriers at different frequencies near the Larmor frequency. The high-frequency output is amplified and emitted into the scanner room by a simple aerial. It is detected by the RF coil of the scanner and is extracted from the MR raw data. For demonstration, ECG, EEG and EOG was recorded during fast ramp sampling EPI on a Siemens Trio 3T MR system. Matrix 64x64, 10 slices, TE/TR=41/607ms, 220 mm FOV, echo spacing 560 microseconds, gradient plateau 300 microseconds, line sampling time 512 microseconds. A healthy volunteer was verbally instructed to open and close the eyes every thirty seconds during a 145 second scanning period. Six twisted carbon electrode pairs were used to record ECG, 2xEOG and 3xEEG (electrodes placed at forehead and behind ears). Two channels were used to record the same EEG signal with opposite polarity (pads with dual leads, Ambu, DK) in order to evaluate system noise common between channels. An additional channel was used to record a known 30 Hz calibration signal. The electrophysiological recordings were reconstructed to 1.7 kHz bandwidth after lowpass filtering to 1.5 kHz bandwidth in the modulator. Gradient artefact template subtraction was performed k-space-line- and slice-wise (median over whole period). A further reduction to 60 Hz was performed after reconstruction and gridding. Pulse artifact subtraction was performed with the FMRIB EEGlab plugin [4].

Results: With proper carrier frequency selection and reconstruction, the MR images are unaffected by the encoded signals. The gradient artefacts in the electrophysiological recordings are comparable in size to the ECG artefacts and are easily removed by template subtraction due to the intrinsic perfect synchronization between noise generator and sampling equipment [5]. Their limited size allows for crude real-time visual evaluation even without gradient artefact filtering. Cardiac pulsation artefacts were adequately removed using software made for “normal” EEG recording. The figures show data before and after pulse artefact subtraction.

Discussion and conclusion.]. ECGs, EOGs and EEG in good quality can be recorded by the scanner during fast MR imaging. Gradient artefacts are largely avoided and residuals easily filtered. The developed battery-driven 8-channel modulator fits in a lunchbox and is modular so that many-channel recordings can also be made. Surplus sampling and storage capacity of scanner is exploited.



Figures: Left figure shows example signals before pulse artifact subtraction during the first few seconds of the scan (rest). Right figure shows a corresponding EEG spectrogram demonstrating alpha activity only in the resting periods, especially the first one ending after 30 seconds.

[1] Hanson LG et al, Proc Human Brain Mapping 2005. [2] Hanson CH et al, Proc Int Soc Magn Reson Med, 2006. [3] Anami K et al, Neuroimage, 19:281, 2003. [4] Nieazy et al, NeuroImage 28:720,2005. [5] Cohen MS et al, Proc Human Brain Mapping 2001.