MR-encephalography: Fast Volumetric Imaging of Brain Physiology using Rosette Trajectories

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MR-Encephalography (MREG) [1] is an extremely fast technique to monitor physiological changes in the brain by use of simultaneous readout with multiple small RF-coils. Recently a radial sampling scheme with very low number of projections using the COBRA(Constrained reconstruction Based on Regularization using Arbitrary projections) technique) was proposed in order to improve spatial localization of activation at the cost of temporal resolution [2]. In its generic form COBRA acquires one projection per TR and thus covers only one linear k-space line per acquisition.

In this work we have investigated a more efficient sampling strategy by implementing curved trajectories to cover a larger part of k-space per acquisition interval. Amongst known options (spirals, rosettes…) we have chosen a single shot rosette trajectory with dominant movement in radial direction and low circular frequency [3]. Rosettes offer several k-space zero crossings per trajectory and thus appear to be more versatile with respect to T2*-sensitivity compared to spirals. On the downside, rosettes are known to show a more complex off-resonance behavior which requires multi-frequency reconstruction with a linear phase correction for each receiver coil estimated from an acquired field map prior to image reconstruction.

Materials and methods:

All experiments were performed on a 3T scanner (Trio, Siemens). Signal was acquired with a custom built 8-channel surface array head coil placed above the region of the visual cortex. The stimulation paradigm was a checkerboard task consisting of 3 rest periods (black screen) and 3 activation periods (flickering checkerboard) each 15s long. Areas of visual activation were determined by running a conventional reference EPI-BOLD experiment (TR 2s) in advance. Rosette trajectories were implemented for 2D- and 3D-acquisitions. 2D-versions were used to elucidate basic signal behavior especially with respact to off-resonance effects and optimization of reconstruction algorithms. For the 2D-case the implemented rosette trajectory $k(t) = k_x(t) + ik_y(t)$ with 2n petals is described by $k(t)=k_{max} \cos(\omega_1 t) \exp(i\omega_2 t)$. The radial frequency ω_1 and the circular frequency ω_2 are related by $\omega_2 = \omega_1/2n$. The radial frequency was chosen to satisfy given amplitude and slew rate limits (G_{max} = 30mT/m, $Slew_{max}$ = 150T/ms). The acquisition time for a full turn is therefore $T_{acq}= 2\pi/\omega_2$ and the number of acquired samples was 2048 for all trajectories. The remaining parameters were: slice thickness 5mm, FOV = 250mm, TR 50ms, flip angle 15°, and k_{max} was calculated for a nominal resolution of 128 pixel. For 3D-acquisition the planar rosette trajectories were continuously rotated with azimuthal frequency ω_3 selected to ensure symmetrical k-space undersampling.

Image reconstruction:

Offline image reconstruction was performed using MatLab (MatLab Inc.). Images were reconstructed by using experimentally measured k-space trajectories, which have been determined previously on a phantom. To account for off-resonance effects leading to signal loss caused by field inhomogeneities, the raw data for each channel were multiplied with a linear increasing phase with the average local off-resonance frequency estimated from the field map. The actual image reconstruction is based on solving the inverse problem given by $Ax = b$ where x is the unknown image, b is the measured data and A describes the forward operation of the measurement including the coil sensitivity weights from the fully encoded reference scan. A solution for the inverse problem is found by applying Thikonov-regularization that means minimizing the function $f(x)=||Ax-b||^2 + \lambda||x||^2$ with respect to x, where the image smoothness is controlled by the regularization parameter λ.

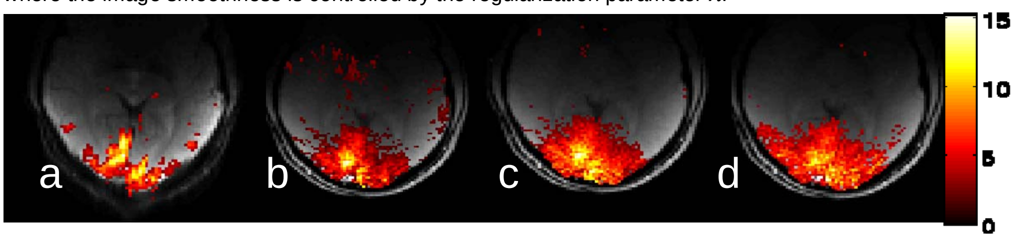

Fig.1: Activation maps (t-values from colorbar) calculated from reconstructed Rosette-MREG images overlying anatomical image. a)EPI reference activation; b)16 petal rosette single coil reconstruction; c) 16 petals constraint reconstruction, T_{acq}=10ms; d)12 petals constraint reconstruction, T_{acq}=8ms;

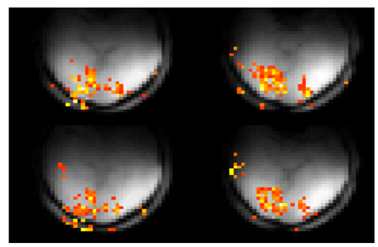

Fig.2: Activation maps from volumetric 3D-rosette acquisition (T_{acq}=27ms).

Results:

Activation maps (t-maps, t >3) calculated from a 16-petal rosette image acquired in 10ms are shown in Fig.1 b) and c). Single coil reconstruction without any prior knowledge and SoS-combination is displayed in b). Multicoil reconstruction with acquired anatomical coil images as a constraint are shown in c) and d). Although the unconstrained reconstruction in b) suffers from false activations outside the visual cortex the shape of the EPI activation pattern is reproduced. For the constraint reconstruction in c) and d) the activation is restricted to the region of the visual cortex showing a higher number of activated pixels compared to the EPI reference. Areas with high t-values in the rosette reconstruction correspond well to the EPI reference both for the 16 and the 12 petal rosette acquisition. Results from functional studies using 3D-acquisition (T_{acq}=27ms) are shown in Fig.2 with four central slices selected.

Discussion:

The results demonstrate that single shot rosette MREG is able to detect activation with very high temporal and reasonable spatial resolution. It can be seen as an accelerated extension to the proposed COBRA approach with more efficient k-space sampling. Straightforward reconstruction with unconstrained reconstruction already produces reasonable results. As expected, 3D-acquisition requires additional phase and offresonance correction especially with respect to respiratory- and ecg- induced phase modulations.

References:

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This work is part of the INUMAC project supported by the German Federal Ministry of Education and Research, grant #13N9208 and through grant 1.02.1/04/006 by the Hertie Foundation