High Spatial High Temporal Resolution MR-Encephalography using Constraint Reconstruction based on Regularization with Arbitrary Projections (COBRA)

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Introduction: MR-Encephalography (MREG) [1] or inverse imaging [2] has been introduced as an extremely fast technique for the measurement of brain physiology. In the original implementation spatial encoding is achieved based on the sensitivity profiles of small coils of a multi-array coil array only. Additional spatial resolution can be achieved by signal readout under one-dimensional readout gradient. The purpose of this paper is to explore the possibility of further improvement of spatial localization using a radial sampling scheme with a very low number of projections (2, 3, 4, ..). Image reconstruction is performed using constraint reconstruction based on regularization with arbitrary projections (COBRA). As a constraint a separately acquired reference image for each coil is used.

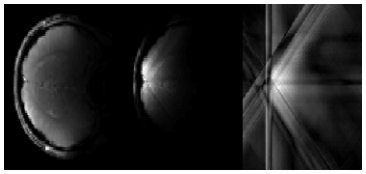

Fig.1: Reconstructed image for one coil from 4 projections without constraint (right), with constraint (middle), SoS-reference image (left).

Methods: All experiments were performed on a 3T Tim Trio (Siemens). A custom made 8 channel head coil array (MGH, L. Wald) was used for data reception. The single coil elements are aligned in a half circle around the visual cortex. A gradient-spoiled FLASH sequence (TE=10ms, TR=20ms) was used for data acquisition as described in [1]. Data from each coil are saved separately. Image reconstruction is performed using MatLab (MatLab Inc.). ECG- and Respiration-signals were also recorded to correct the data for physiological noise. For visual stimulation a checkerboard paradigm was used. The stimulus presentation followed a block design with 3 periods containing 20s of activation followed by 20s of rest. Experiments were performed with 2 (orthogonal), 3 and 4 projection-angles. Slice selection was performed to select a 5mm slice through the visual cortex.

Image reconstruction is based on the solution of the inverse problem specified by the algebraic equation $Ax = b$. Here x is a vector containing the unknown image that will be reconstructed and b contains all projections for all coils that are acquired after each TR_{eff} in a single vector. The matrix A can be written as a matrix multiplication $A = P \cdot C$, where P performs the projection operation and C introduces the reference coil image weighting, which is gained from a full k-space reference scan performed before the measurement. Since the size of A increases quadratically with the number of image voxels, the acquired projections were also sampled down to 128 bins. A solution for the inverse problem was calculated by Tikhonov-regularization, that is minimizing the function $f(x) = \|Ax - b\|^2 + \lambda \|x\|^2$, with respect to x, where λ is the regularization parameter controlling the "roughness" of the solution. The image reconstruction was performed for every time-frame to produce a time series of 3000, 2000 and 1500 images along the total acquisition time of 120 s for COBRA-measurements with 2,3 and 4 projections respectively. SPM5 was used to identify activated voxels. In order to test for the influence of physiological noise, SPM analysis was performed with and without correction for physiological noise using a RETROICOR approach [3].

Results: Fig. 1 shows an image for one coil from 4 projections versus the sum-of-squares reference image. Although the data is heavily undersampled with only 2 projections, good image quality can be achieved, due to the constraint. Fig. 2 shows the activation maps from the SPM analysis for the reconstructed time series for 2, 3 and 4 projections without physiological correction. The number of identified voxels increases with the number of projections (329 for 2 up to 461 for 4 projections). Fig. 3 demonstrates the activation map for an EPI measurement with the same visual stimulation for comparison. More activated voxels are found in the reconstructed time series compared to the EPI measurement. Fig. 4 displays the signal time course of a voxel in the activated region of the visual cortex with and without physiological correction. The reconstructed time series shows a BOLD-response on the order of 2%. The effect of the noise correction on the statistics is shown above, where the activation map from data which was corrected for physiological noise (394 activated voxels) is compared to data without correction (162 activated voxels). At identical t-value threshold more activated voxels are found.

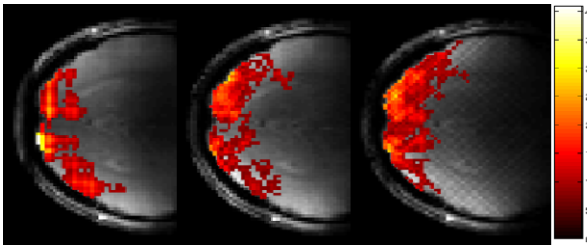

Fig.2: Reconstructed time-frame for 2,3 and 4 projections with t-value map overlay from SPM (t-threshold=6).

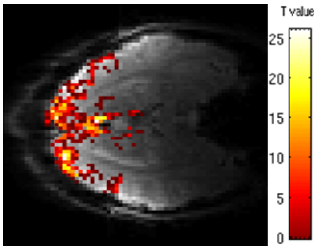

Fig.3: SPM of the same fMRI experiment performed with EPI (TR=2s)

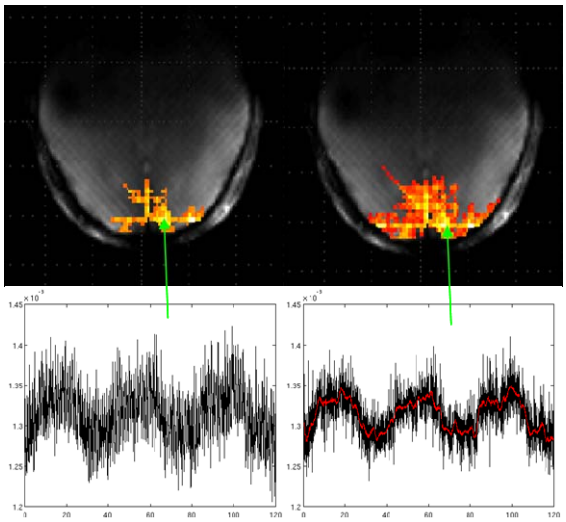

Fig.4: SPMs and exemplary time courses without (left) and with (right) physiological correction before data analysis and additional mean filtering (red curve).(same t-threshold of 10)

Discussion: The results demonstrate that COBRA with very low number of projections can be used to acquire activation maps with reasonable spatial resolution at very high temporal resolution. Signal time courses show excellent contrast-to-noise for the observed BOLD response. Physiological effects (ECG and breathing pulsatility) are directly measured and can therefore be removed to further increase the sensitivity to BOLD-activation. The reconstruction algorithm can be extended to 3-dimensional encoding offering the potential for full brain coverage with a suitable multi-array head coil. Further measurements as well as data simulation are required to establish the 'true' spatial resolution of the experiment.

References:
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