75 µm High-Resolution Parallel Imaging GE-EPI BOLD fMRI in rats at 11.7 Tesla: New Insights into Cortical and Thalamic Micro-Structures

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Introduction: It is well known that Parallel Imaging allows higher temporal and higher spatial resolution with SNR sufficient for conventional imaging. However, for EPI with long TR (around 3 seconds) no reduction in scan time is achieved and the increase of SNR in the phased array mode (sum of squares) for 4 element surface coils is only marginal compared to quadrature surface coils. Furthermore k-space undersampling in EPI, allowing shorter echo times and higher matrices, decreases the SNR to even less than that of quadrature surface coils. Here we show BOLD response of Parallel Imaging with high matrix size, leading to 75 µm in-plane resolution in single-shot GE-EPI with still high SNR due to short TE and low partial Fourier acceleration with only minor distortions. BOLD activation was detected in coronal and horizontal imaging planes, showing detailed structures in S1 and thalamus, confirmed by repetitive scans.

Methods: MRI Bruker BioSpec 117/16 USR/TT. Magnet 11.7 Tesla, Gradient 750 mT/m and 100 µs ramp time. AVANCE II electronics. Coils: 72 mm quadrature resonator, 4 element surface array coil, size 32 x 35 mm², 115 repetitions, 5 min 45 sec scan time. Protocol: GE-EPI, matrix (256)², FOV (19.2 mm)², resolution (75 µm)² x 1mm, 9 slices, TR/TE 3000/16 ms, FA 90°, bandwidth 555kHz. Parallel Imaging: GRAPPA, acceleration R=2, overscans 50, partial Fourier acceleration 1.44 → Parallel Imaging matrix 256 x 89.
Animals + Stimulation 8 male Wistar rats, repetitive studies, 300 – 450 g, medetomidine (Domitor) sedation after initial isoflurane [1]. Electrical forepaw stimulation, I = 2 mA, f = 6 Hz with block diagram: 5 sec rest + 15 sec stimulation, 5 repetitions, additional 5 min rest.
Analysis Motion correction (FSL). Gauss filtering (64), Student's t-test, confidence level 99%, PVMZ baseline correction (STIMULATE).

Results: Parallel Imaging (R=2) allowed temporally stable and high-resolution images (matrix 256, resolution 75 µm) with low partial Fourier acceleration (1.44) and short TE (16 ms) for high SNR, good image quality and only minor distortions. BOLD response was observed in all fMRI high-resolution GE-EPI scans. BOLD activation in the somatosensory cortex S1 (2.7%) and S2 (1.6%) as well as in the thalamus (3.4%) was clearly detected in adjacent slices (Fig. 1A). Structures in S1 revealed clear differentiation between cortical layers, but also a trace of cortical columns (Fig. 1B). Thalamus activation also arose to a spatial structure (Fig. 1C). Repetitive scans showed continuous activation and uncovered areas of stable activation (Fig. 1D, red pattern) and areas of no activation at all (black pattern) within the center of the S1 area.
BOLD was also observed in high-resolution horizontal slices, however, images are somewhat distorted (Fig. 2). Also, high-resolution SE-EPI provided bad image quality (not shown) due lower SNR and strong reconstruction artifacts. An optimization of these protocols is currently underway. The position of the array coil over the animal's head was found to have a strong influence on SNR and image quality, which resulted in dramatic decrease of BOLD analysis confidence, due to the design of the 2 x 2 element coil. Coronal slices (Fig. 1) under the center of the surface coil received 25% less SNR compared to slices directly under coil pairs. In horizontal slices this loss in SNR was not observed.

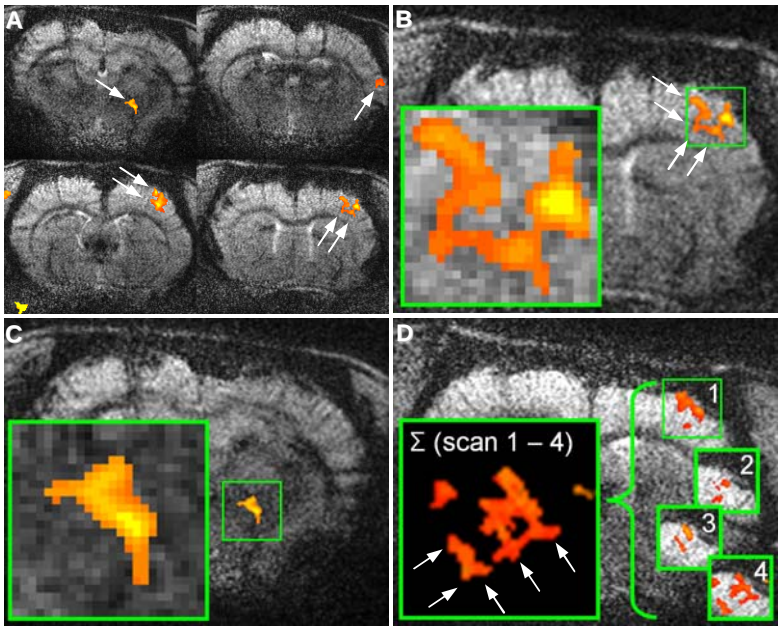

Figure 1: Adjacent slices showed activation in thalamus, S2 and S1 (A). Enlarged view of structures in S1 (B) and thalamus (C). Repetitive scans (1–4) show areas of (red) and without (black) activation (D). (A)–(D) Arrows: activation. Colors (red–yellow): 0 – 5% BOLD contrast.

Conclusions: Parallel Imaging allowed fast BOLD image acquisition with little distortions and high spatial resolution within the same scan time. GE-EPI high-resolution fMRI revealed structure in both, S1 and thalamus activation, which had been detected before as homogeneous regions with lower resolutions. GE-EPI BOLD was able to detect columnar structures which were found by task-related early negative BOLD dip [2], hemodynamic CBF [3] and GE-EPI BOLD [4] in animals and humans [5]. The activation pattern in dependence of stimulation conditions has to be studied.

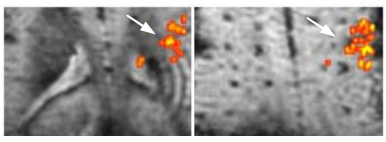

Figure 2: Two adjacent horizontal slices showing S1 BOLD activation.

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