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500 ms temporal and 750 µm spatial inplane resolution for whole-brain fMRI applications in the macaque at 7T

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Target audience: Researchers interested in advanced preclinical neuroimaging applications and method development

Purpose: Advanced fMRI applications targeting changes in neural networks usually need full brain coverage and high spatio-temporal resolution, otherwise the statistical analysis relying on signal decomposition is unreliable or requires a great amount of data to show significant changes. Our aim was to achieve 500 ms volume repetition time and a real 0.75x0.75x2 mm³ voxel size over the entire macaque brain for fMRI concurrent with electrophysiological recordings in the hippocampus during spontaneous activity [1]. We demonstrate here the applicability of our methods and hardware using results of a simple visual stimulation paradigm.

Methods: Hardware: Experiments were performed using a 7T/60cm vertical bore Bruker magnet equipped with 85mT/m imaging gradients (type S380). 8-channel RF phased arrays for reception and a separable volume coil for transmission were used. Rx-helmets were built and optimized for every subject (n=4 Macaca mulatta), taking into account the position of chronic implants (fixation chambers for recording electrodes) on the skull of the animals (n=2 animals with implant). The separable Tx-coil was optimized for handling and provided in situ access to the electrode positioning drive. Acquisition: Resolution loss in the EPI readout dimension due to sampling on the gradient ramps was compensated using an adapted oversampling and Bruker's trajectory measurement. Relative to the "Ramp Sampling Compensation" in the EPI method we sampled just enough points to encode the full readout FOV. We rotated the imaging slices of the EPI around the axis parallel to B0, because the gradient coils of the S380 system are cooled separately and allow for an up to 100% higher duty cycle, if the readout loads at least two gradients (100% for 45°). Blipped CAIPIRINHA type k-space sampling [2] was implemented for EPI on the Bruker console, allowing for accelerating the acquisition in phase encoding and slice dimensions. To save time during functional series, a separate calibration scan was performed using full k-space sampling. Point spread function mapping for EPI [3] was also implemented in order to correct for distortions due to long echo trains. Stimulation under anesthesia (see [1] for the protocol): Uniform light flashes (32 Hz) through the closed eye lids, 20 times 10s – 6s – 14s (off – on – off).

Results: The spatial resolution and echo time were fixed to 0.75x0.75x2 mm³ and TE=18 ms, respectively. The sequence parameters were optimized empirically until the minimum repetition time was found. In the single shot, full k-space sampling, case (Fig.1), TR was limited to 1.3s by gradient duty cycle constraints. PSF-correction was applied to the series before statistical mapping. The negative BOLD responses by the applied stimulus were observed mainly in the V2/V3 regions. The average time-course of all activated voxels shown in diagram 1 presents the expected shape with peaks generated by stimulus onset and offset. Fig. 2 shows the results of a blipped CAIPI acquisition with TR=0.5 s and acceleration factors of 2 in phase encoding and 2 in slice direction. Due to relatively minor distortion artifacts (x2 acceleration in PE-direction), PSF-correction was not applied for the images shown in Fig.2. The small additional peaks of variable amplitude superimposed on the averaged BOLD curve in diagram 2 most likely reflect the arterial pulse which is not synchronized to sensory stimulation.

Conclusion: Relative to the state of the art for whole-brain fMRI on macaque in our lab (nominal 1x1x2 mm³, 2 segments needed to reduce distortions, volume TR=2 s), we improved the effective spatial resolution by a factor of 2.8 and temporal resolution by a factor of 1.5 without parallel imaging. With parallel imaging, using the signal from 8 channels, these factors are 2.8 in spatial and 4.0 in temporal dimension.

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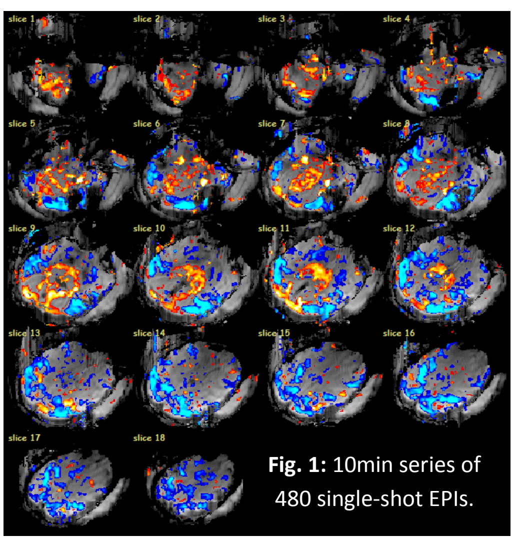
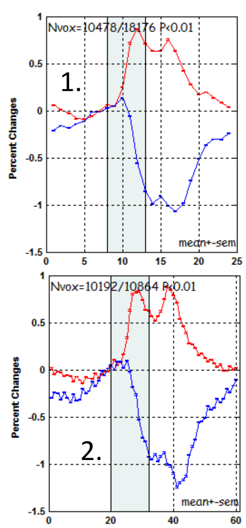


Fig. 1: 10min series of 480 single-shot EPIs.



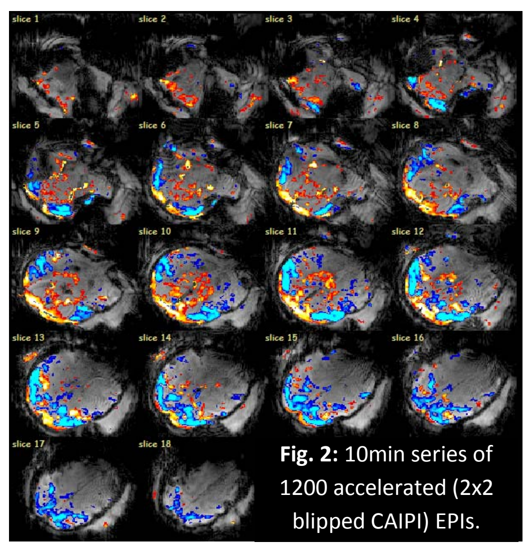


Fig. 2: 10min series of 1200 accelerated (2x2 blipped CAIPI) EPIs.