3D Radial GRE-EPI with up to 8-fold acceleration for functional imaging at 9.4T

Philipp Ehses[1,2], G. Shajan[1], and Klaus Scheffler[1,2]

[1]*High-Field MR Center, Max Planck Institute for Biological Cybernetics, Tübingen, Germany,* [2]*Dept. of Biomedical Magnetic Resonance, University of Tübingen, Tübingen, Germany*

Introduction: Accelerating the acquisition of individual time frames is beneficial in fMRI since it increases statistical power[1] and allows the separation of physiological noise components from the time series[2]. An effective means to achieve this speed is to combine EPI with parallel imaging techniques. This combination offers the additional advantage of reduced distortion artifacts and T_2^*-related blurring in the phase-encoding direction of the EPI sequence. Depending on the coil setup, the move from 2D to 3D EPI can allow higher parallel imaging acceleration factors, since acceleration can now be performed in both phase-encoding directions[3]. In order to allow even higher acceleration factors by exploiting coil sensitivity variations in all three dimensions, it is necessary to move to a non-Cartesian trajectory. To this end, a 3D EPI sequence was developed that combines an in-plane radial with a through-plane EPI readout. We present first results with up to 8-fold radial undersampling from finger tapping experiments at 9.4 T.

Methods: All experiments were performed at 9.4 T on a healthy volunteer with informed consent and approval by the local ethics committee. A custom-built head coil[4] was used for signal transmission/reception (16 transmit / 31 receive channels).

A 3D radial stack-of-stars GRE-EPI sequence was developed analog to a recent publication[5]. Due to an imperfect slice excitation profile and the additional problem of EPI distortions/chemical shift artifacts, it was necessary to use a high slice oversampling factor (50%) to prevent fold-over artifacts in the outer slices. Thus, 24 phase-encoding steps were necessary for the acquisition of 16 slices. EPI echo spacing was 1 ms, resulting in an echo train length of 24 ms. Two 3D radial EPI fMRI experiments were performed, with and without GRAPPA acceleration (TR=32 ms, TE=18 ms, FA=12°, 1.5 mm isotropic resolution, projections = 128/32 (4-fold acceleration), TA per volume = 4.096/1.024 [s]). Furthermore, an 8-fold accelerated dataset was artificially generated from the 4-fold accelerated data by removing every other projection. The fMRI paradigm consisted of finger tapping with both hands: 20s of rest were followed by 20s of tapping in 5 min functional scans (80/320 volumes).

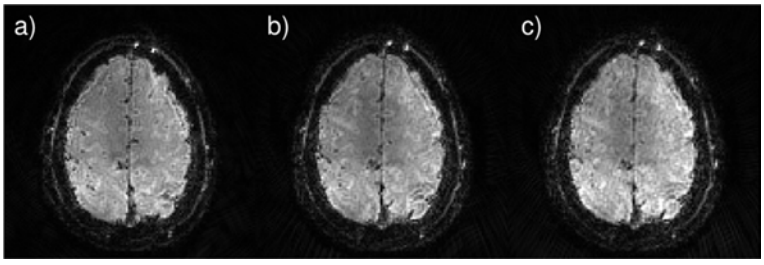

Fig 1: Representative time frames (central slice) of the 3D Radial EPI experiments with acceleration factor of a) R = 1, b) R = 4, and c) R = 8.

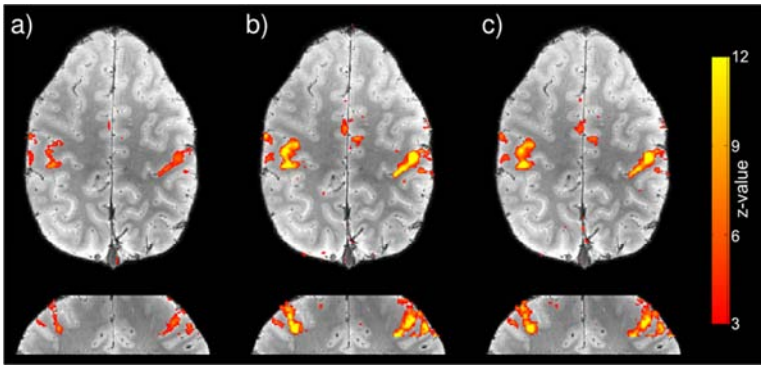

Fig 2: Overlay of reference image with activation maps (top: axial, bottom: coronal view) for acceleration factors of a) R=1 (4.1s/vol.), b) R=4 (1s/vol.), and c) R=8 (simulated from b).

Image reconstruction was performed in multiple steps: First, gradient delays were corrected for by using phase-correction scans that were acquired before each EPI echo train. Missing projections in the accelerated datasets were then reconstructed using radial GRAPPA[6]. To this end, GRAPPA calibration was performed using a hybrid through-k-space/through-time calibration approach[7] (32 calibration time frames, 8 partitions, segment size in read/proj. = 12/3). After 1D Fourier transform, oversampled slices were removed from the dataset. Finally, the radial and ramp sampled data were convolution gridded, 2D Fourier transformed, and individual coil data were combined using the adaptive combine technique[8].

For analysis, the data were processed with FSL FEAT after brain extraction, using a standard hemodynamic response function and temporal filtering (no spatial smoothing). Resulting activation maps were registered to a T_2^*-weighted anatomical image.

Results: Fig. 1 shows representative time frames from all three datasets. Resulting activation maps are presented in Fig. 2. Increasing the temporal resolution by 4-fold acceleration results in much higher statistical significance (Fig. 2ab), while each individual image suffers from increased noise (Fig. 1ab). Although the temporal resolution in the simulated 8-fold accelerated dataset is not increased compared to its 4-fold accelerated counterpart and despite increased image noise (Fig. 1bc), statistical significance is only slightly affected (Fig. 2bc).

Conclusion: The presented results show that 3D radial GRE-EPI with up to 8-fold acceleration is viable for high-resolution fMRI at 9.4T. Future work aims at even higher acceleration by also undersampling in the partition encoding direction. Radial view-sharing[5] and partial Fourier in slice direction may lead to further speed gains.

References: [1] Feinberg et al, Neuroimage 2012;62:720-5. [2] Hu et al, MRM 1995;34:201-12. [3] Poser et al, Neuroimage 2010;51:261-6. [4] Shajan et al, ISMRM 2012;20:308. [5] Jonathan et al, ISMRM 2013;21:582. [6] Griswold et al, ISMRM 2003;11:2349. [7] Seiberlich et al, MRM 2010;65:492-505. [8] Walsh et al, MRM 2000;43:682–90.