# Pushing the limits: Ultrafast 2D accelerated High Resolution Whole-Head Volumetric Functional Imaging at 7 Tesla

**T. Nguyen[1], S. Moeller[2], U. Goerke[2], E. Yacoub[2], and K. Ugurbil[2]**

[1]High-Field Magnetic Resonance Center, Max-Planck Institute for Biological Cybernetics, Tübingen, Germany, [2]Center for Magnetic Resonance Research, Minneapolis, Minnesota, United States

**Introduction:** In functional imaging (fMRI), high spatial resolution and whole-head coverage at a temporal resolution of a few seconds is difficult to achieve. Three-dimensional (3D) acquisition offers many well-known benefits for large volume coverage in MRI, e.g. [1]-[2], but has temporal constraints and increased temporal noise. Hence, multi-slice 2D-EPI acquisition remains the predominant method in fMRI. However, with the extension to a 3D approach, the 2D phase-encoding features of a hybrid 3D-EPI sequence [3] can be exploited with parallel imaging along with the higher encoding capability at high-field to overcome inherent limitations [4]. The motivation is to gain the full potential of such a hybrid 3D-EPI scheme, making it feasible in routine settings with enhanced fMRI performance at high magnetic fields. This study demonstrates that.

**Methods:** Acquisition: Data were collected on a 7T Siemens system using a 16-channel Tx/Rx head coil. Four human volunteers were scanned using a hybrid 3D-EPI scheme that was based on a segmented EPI sequence modified to facilitate acceleration along two phase-encoding directions. Three accelerated schemes were compared: 2D-EPI (R=1x4), hybrid 3D-EPI (R=1x4), and hybrid 3D-EPI (R=4x4). Protocols for the former two were selected to be as consistent as possible, with the same temporal resolution per volume as the latter. The acquired volumes were consequently 30, 44, and 176 slices, respectively. Hence, full-head coverage was only achieved in the 3D-4x4 scheme. Parameters were optimized for BOLD fMRI with TE=30 ms, a TR for slab-to-slab excitation (3D) or slice-to-same-slice excitation (2D): TR(3D volume)=82 ms (x 44=3.6 s); TR(2D volume)=3.6 s, flip-angle=17° (81° for 2D), and matrix=200x200 for an isotropic nominal spatial resolution of 1 $mm^3$ for 3D-4x4 (1x4 schemes: 1x1x2 $mm^3$). RF-spoiling and fat saturation was applied for all, and further scans included scans with no RF pulse for noise quantification, both a full calibration scan without phase-encoding and segment-wise navigators for phase-corrections, plus a full FOV reference scan for image reconstruction. Functional studies: fMRI time-series of 50 volumes with activation/rest blocks of 10 image volumes each, alternating between visual stimulus with flickering checkerboards and simultaneous unilateral sequential finger tapping for activation and static checkerboards and no motor task for resting states. Additional resting state baseline time-series were acquired for subsequent signal and noise analysis. Data processing: All raw data handling was offline in Matlab. For the more artifact-prone segmented EPI data acquired at high-field, proper EPI corrections are more demanding and crucial. An essential part of the work was then to implement optimal procedures for the EPI corrections, from ramp re-interpolation to phase discrepancy corrections, in integration with data unfolding using a 1D GRAPPA reconstruction algorithm. Baseline temporal signal fluctuations and *t*-score activation maps for the functional data were calculated.

**Results:** With an optimized choice and order of phase-correction and reconstruction procedures, the 4x4-fold accelerated hybrid 3D-EPI scheme provided reproducible data of high image quality with very little apparent ghosting artifacts or loss in image contrast due to aliasing (Fig.1). Whole-head volume data with isotropic nominal spatial resolution of 1 mm were achieved at a 16-fold reduced temporal resolution of 3.6 s/vol. Preliminary analyses showed general higher temporal voxel signal instability in the 4x4 compared to the 1x4-fold schemes with concomitant general slight reduction in max *t*-score (in visual cortex ROI) (Fig.2). Nonetheless, the 3D-4x4 method exhibited a detected 5-10% BOLD signal change with no blurring of the activated voxel clusters in stimulated brain areas (Fig.2-bottom right).

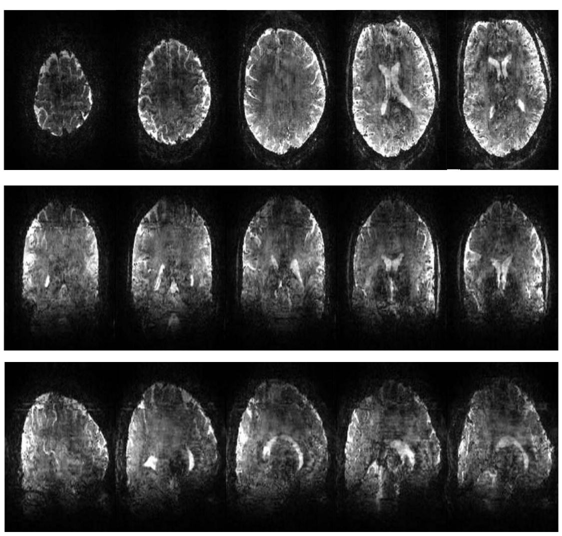


**Fig. 1:** *GRAPPA-reconstructed 16-fold (4x4) accelerated whole-head coverage 3D-EPI volume scan acquired with isotropic 1 mm nominal spatial resolution in 3.6 s/vol. Shown are samples of axial, coronal, and sagittal slices from a single volume (no averaging), demonstrating the data quality and spatial coverage.*

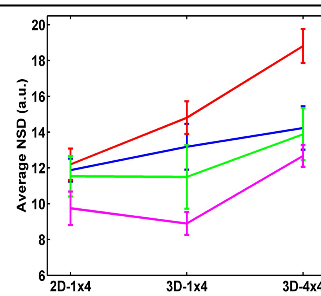
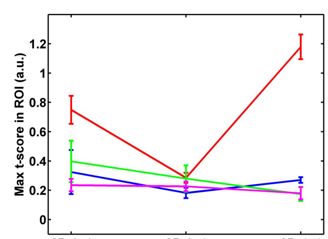
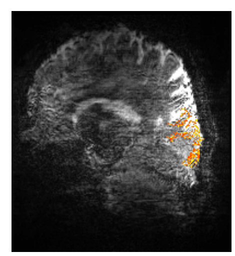



**Fig. 2:** *(Top) Slice-averaged normalized standard deviation of temporal signal fluctuations (NSD) was higher for 3D- 4x4 in the 4 subjects with general reduced ROI max t-score, but results yielded high quality activation maps (bottom row).*



**Conclusion:** The highly accelerated hybrid 3D-EPI method has proved feasible at high magnetic fields by taking advantage of the increased signal- and contrast-to-noise ratio and improved parallel imaging capabilities at high-fields. It was demonstrated that despite the increased temporal signal instability and reduced max *t*-score, the acquisition scheme combined with an optimized reconstruction provides high quality activation maps. This pushes the current imaging limits and opens up new options for fMRI by achieving ultrafast whole-head coverage, high spatial resolution, and increased fMRI performance at ultrahigh fields.

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**References:** [1] Yang, Y. *et al.*, (1999), *NeuroImage* **9**, 446-451. [2] van der Zwaag, W. *et al.*, (2006), *Magn Reson Med.* **56**, 1320-1327. [3] Muftuler, LT. *et al.*, (2000), *Magn Reson Med.* **44**, 485-490. [4] Golay, X. *et al.*, (2004), *Top Magn Reson Imaging.* **15**, 255-265.