Isotropic Sub-Millimeter fMRI in Humans at 7T

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Introduction: Ultra-high field MR scanners are used to perform brain functional MRI with a very high in-plane resolution [1,2]. Since the human cortex is convoluted in 3D, the use of isotropic voxels with high resolution is essential for fMRI to avoid partial volume effects. With higher field strength and resolution, susceptibility effects and T2* decay cause increased distortions, drop-outs and image degradation. It has been recently shown that isotropic sub-millimeter fMRI can be achieved by combining zoomed imaging (reduced FOV in PE direction) with parallel imaging [3]. In the current study we used this approach to obtain high acceleration factors of up to 5.5, which significantly improves the spatial precision of fMRI at ultra-high field strength, while avoiding the head motion artifacts of segmented acquisitions.

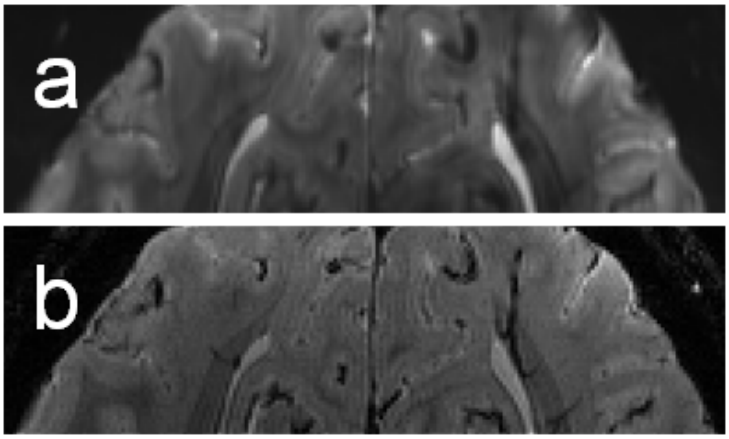

Fig 1: Comparison between zoomed GRAPPA EPI with 0.65 mm isotropic resolution (a) and an anatomical FLASH image with 0.6 mm isotropic resolution (b).

Methods: All experiments were performed on a 7T whole-body MR scanner (MAGNETOM 7T, Siemens Healthcare Sector, Erlangen, Germany) with a 24-element phased array head coil (Nova Medical, Wilmington, MA, USA). Scans were performed on four healthy volunteers, and informed consent was obtained before each study. Since the visual stimulation set up for this coil was not yet completed, a very simple functional paradigm with blocks of 28 s stimulus-on and 28 s stimulus-off was used, with 15 epochs for a total acquisition time of 14 min. For stimulus-on a bright light was presented within the inner bore of the scanner, while for stimulus-off the light was turned off. The experiments were performed with a zoomed EPI sequence (TR = 3500 ms, TE = 27 ms, FOV = 109x156 mm^2, 30 slices, voxel size = 0.65x0.65x0.65 mm^3) with OVS using a SKEWED pulse as proposed in [1]. GRAPPA with an acceleration factor of three was used. Reconstruction was performed with a 2D convolution kernel [4] using three source points along the readout direction (RO) and two source points along phase encoding direction (PE). SPM5 was used for data analysis. Functional scans were corrected for slice timing and motion. No spatial smoothing was applied. The activation maps were corrected for multiple comparisons with a $p<0.05$ (FDR) and a minimum cluster size of two voxels leading to a t-score threshold of 2.8. The mean EPI image was used to co-register the activation map to the additionally acquired anatomical FLASH image.

Results and Discussion: PE direction was chosen A-P to obtain less pronounced, symmetric distortions. For the head geometry of the volunteers examined in this study it would require a FOV of 200 mm to avoid aliasing in PE direction. With the zoomed approach we could use a reduced FOV of 109x156 mm^2, with an image matrix of 169x240. The resulting FOV in PE direction corresponds to an acceleration factor of 1.83. The combination of OVS and GRAPPA resulted in a total acceleration factor of 5.5. Figure1a shows a mean EPI image with an isotropic resolution of 0.65 mm, while Fig. 1b shows a transverse view of a coronal FLASH acquisition with 0.6 mm isotropic resolution. Obviously, there is close correspondence between the EPI images and the anatomical FLASH. The EPI image quality enables identification of very small anatomical structures, such as the stria of Gennari. In Fig. 2 the activation map is overlaid on the anatomy. The activation pattern along the calcarine sulcus is nicely presented.

Conclusion: This combination of zoomed imaging with parallel imaging facilitated the very high acceleration factors required to address problems of distortion and blurring in fMRI at ultra-high field strength with high resolution. The resulting accelerated zoomed EPI images can provide fMRI data with isotropic sub-millimeter resolution. Further studies will address intra-cortical and layer-specific fMRI activations.

References: [1] Pfeuffer, et al. NeuroImage 2002;17:272-86. [2] Yacoub, et al. MRM 2003;49:655-64. [3] Heidemann, et al. ISMRM 2009 #2442. [4] Griswold, 2nd Workshop on Parallel Imaging 2004; p. 16-18.

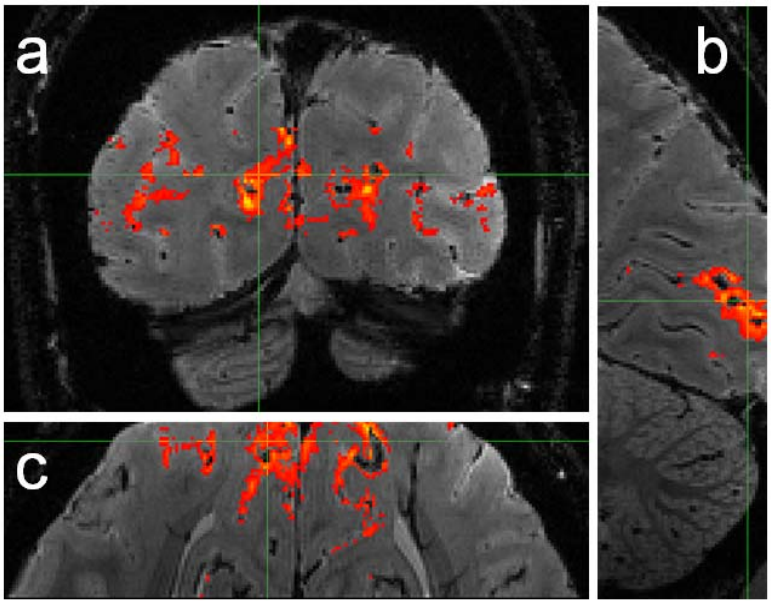

Fig 2: Activation map with 0.65 mm isotropic resolution overlaid onto the anatomy with 0.6 mm isotropic resolution: (a) Coronal, (b) sagittal and (c) transverse view.