Parallel imaging accelerated multi-echo fMRI at 7T

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Introduction: BOLD fMRI at 7T is promising due to the short T2* of blood, which leads to much less vessel contamination of the fMRI signal compared to 3T. Moreover, there is plenty of baseline SNR due to a higher polarization of the main magnetic field. However, there are many challenges for BOLD fMRI at 7T, which make fast imaging techniques highly desirable to achieve reasonable spatial and temporal resolution. Due to strong B0 and B1 field inhomogeneities at ultra-high field, EPI-based image acquisition suffers from severe image distortions and signal dropouts, which ultimately result in images of limited quality. However, if appropriate pulse sequences are used in concert with the correct scan parameters, these distortions and dropouts can be reduced substantially. Parallel imaging (PI) becomes particularly interesting at 7T as it successfully reduces in-plane distortions due to faster k-space sampling in phase-encoding direction. PI also leads to smaller signal dropouts caused by through-plane dephasing. The reasons for the latter are shorter possible echo times (TE's) compared to non-accelerated acquisitions. Nevertheless, the use of parallel imaging for fMRI can be problematic – in particular at lower field strengths – due to a lower overall SNR compared to fully sampled images. However, the possibility to combine multiple echoes following a single excitation pulse – afforded by the much shorter EPI trains –partially restores the loss in SNR ([1],[2]), without any time penalty. fMRI experiments benefit from PI-accelerated multi-echo sequences regarding both SNR and distortion reduction. In this study, we applied PERMEATE [3] – a multi-shot multi-echo EPI acquisition technique – to 7T. In particular, we performed a comparative evaluation of a 3-echo acquisition with a 3-fold undersampling in k-space and a fully sampled single-echo scan. Specifically, comparisons of distortions, temporal SNR, and fMRI activation were made.

Methods: A 7T GE Signa MRI unit and a 16-channel parallel imaging array (Nova Medical, Inc.) were used to perform our experiments. With a spectral-spatial excitation pulse to suppress the fat signal, the shortest possible TE for fully sampled measurements (R=1) on our system was 22.1 ms for a resolution of 66x66 voxels. If parallel imaging with a reduction factor of 3 (R=3) is used, three EPI echo trains can be fitted into the same acquisition window used for R=1, with TE's of 11.7 ms, 23.5 ms, and 35.3 ms. The three echo images for each slice were later combined to one single image using T2*-weighted summation [4]. Prior to the actual experiment, higher-order shimming was performed to reduce off-resonance effects. The shimming values were kept constant for all subsequent measurements. Further scan parameters were: TR = 1500 ms, flip angle = 60°, slice thickness = 4.5 mm, FOV = 24 cm. 25 adjacent slices were acquired covering the whole brain. For R=3, parallel imaging reconstruction was performed using GRAPPA with a 2D kernel size of $2k_y$ x $5k_x$ [5]. The first 3 EPI interleaves were combined to form a fully sampled k-space to calculate GRAPPA-weights for all subsequent undersampled images. Brain activation was measured from a bilateral finger-tapping experiment. Finger-tapping was alternated with baseline for a total of 6 cycles. Each on-/off-cycle was 36 seconds long (18 sec on/18 sec off), resulting in a total scan time of 3:36 min. The correlation of the experiment with a sinusoid function [6] was calculated for fMRI analysis. The correlation threshold above which a voxel was considered activated was set to 0.5.

Results: Fig.1 shows BOLD activation maps of the fMRI time series acquired with R=1 (Fig.1a-e) and R=3 (Fig.1f-j), overlaid onto the time averaged EPI images of the experiments. In-plane image distortions were greatly reduced using parallel imaging with a reduction factor of 3. This can be seen easily by comparing Fig.1b to Fig.1g. In particular, frontal areas of the brain suffered from severe distortions in the fully sampled images. Furthermore, residual ghosting artifacts remained significant in R=1 images, possibly leading to false activation in dropout regions in the lower frontal cortex shown in Fig.1a. The temporal SNR of the T2*-weighted images derived from R=3 was 20% higher compared to the single-echo acquisitions in the R=1 measurements. Parallel imaging accelerated acquisitions also resulted in a higher total number of activated voxels (Table 1) as well as more distinct activation patterns.

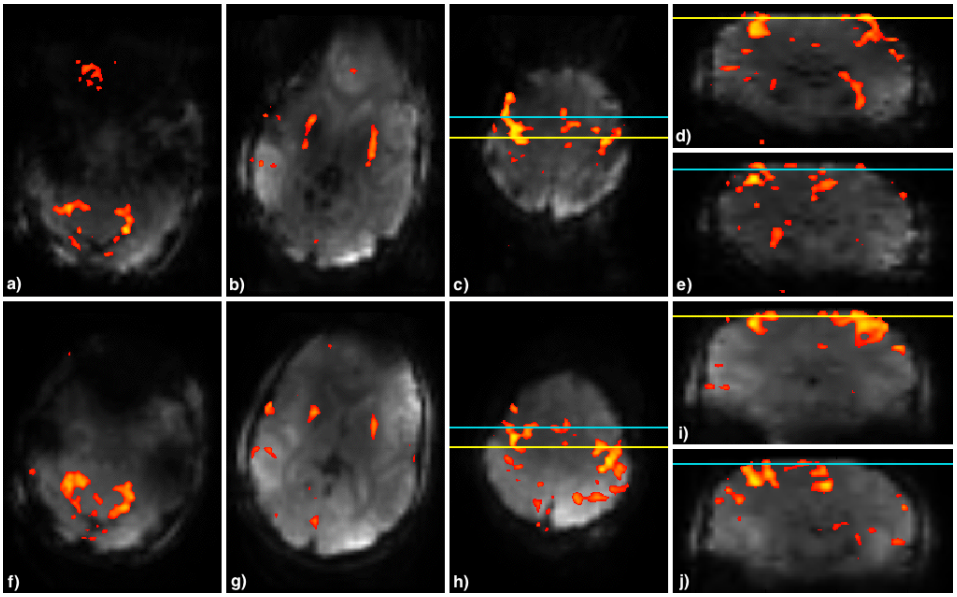

Fig.1. a-e: non-accelerated acquisition, f-j: acquisition with PI acceleration factor R=3. The coronal slices in d, e, i and j were produced by reshaping the axially acquired images. The colored lines in d, e, i and j represent the locations of corresponding slices.

Table 1: Temporal SNR and activation volume

	Temporal SNR *	Activation **
R=1	1	788
R=3	1.20	1254

** Temporal SNR was derived from a ROI within the slice in Fig.1c (R=1) and Fig.1h (R=3), normalized to R=1*

*** Number of activated voxels within the brain*

Discussion: The present study demonstrated highly reduced image distortions at 7T using parallel imaging compared to fully sampling acquisitions. Non-accelerated measurements suffered from severe distortion artifacts which could alter the patterns of functional activation, resulting in activation at spatially wrong locations due to image deformation and residual ghosts. Lower SNR – resulting from PI – could be compensated by the acquisition of multiple echoes per excitation. The fMRI activation was considerably lower for fully sampled acquisitions when compared to PI-accelerated multi-echo measurements (Table 1). Although the difference in activation was quite big, one must be careful interpreting activation as it highly depends on the subject's level of attention to the task. However, the obtained results indicate higher BOLD sensitivity using R=3. In addition, PI mapped activation to more accurate locations. In order to reasonably use 7T scanners for fMRI, geometric distortions must be compensated for. Parallel imaging has shown great utility to counteract these image distortions. Furthermore, fMRI benefits from multi-echo acquisitions to restore the loss in SNR using PI as well as to reduce through-plane dephasing by acquiring images at shorter echo times. For regions of considerable changes of the underlying T2*, the multi-echo approach offers the ability to provide echoes that match closer to the echo time which leads to the optimal fMRI sensitivity.

References: [1] Poser *et al*, MRM 55:1227-1235, 2006; [2] Schmiedeskamp *et al*, Proc. ISMRM 2007, p1925; [3] Newbould *et al*, MRM 58:70-81, 2007; [4] Posse *et al*, MRM 42:87-97, 1999; [5] Qu *et al*, J Magn Reson 174:60-67, 2005; [6] Lee *et al*, MRM 33:745-754, 1995

Acknowledgements: NIH (2R01EB002711, 1R21EB006860), Center of Advanced MR Technology at Stanford (P41RR09784), Lucas Foundation, Oak Foundation.