T2- prepared blood-oxygenation-level-dependent (BOLD) fMRI using single-shot 3D fast gradient echo (GRE) sequence with whole brain coverage at 7T

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TARGET AUDIENCE: MR physicists and clinicians who are interested in fMRI acquisition methods.

PURPOSE: To date, the majority of blood-oxygenation-level-dependent (BOLD) fMRI experiments are performed using 2D gradient echo (GRE) echo-planar-imaging (EPI). While they provide excellent sensitivity to signal changes during functional stimulation with high acquisition efficiency, they often suffer from geometric distortions and signal dropouts in regions near air cavities. These problems are aggravated with long readout echo trains, making whole brain fMRI at common spatial (~3mm) and temporal (2-4s) resolution quite challenging. High field (7T) human MRI scanners have become available in recent years with the promise of approximately linear increase of signal-to-noise ratio (SNR) with field strength. In addition, high field is particularly attractive to BOLD fMRI as the BOLD contrast shows a beyond linear increase with field (1). However, geometric distortion and signal dropouts are also exacerbated at high field, which hampers the application of BOLD fMRI especially when whole brain coverage is desired, or for brain regions such as the orbitofrontal cortex and temporal lobes. 2D spin echo (SE) EPI is a useful alternative approach to alleviate these problems. It has also been shown that the T2-weighted contrast in SE EPI is more specific to the site of neuronal activity at high field than the T2*-weighted contrast in GRE EPI (2). The main constraint for SE EPI is its high power deposition, which unfortunately scales with the square of the field strength. In this study, we propose a new acquisition scheme for T2-weighted BOLD fMRI. It employs a 3D fast GRE (also known as turbo field echo, TFE, or TurboFLASH) sequence as the readout, which has much less geometric distortion, signal dropouts and lower power deposition, and is commonly used in high resolution anatomical scans such as MPRAGE (3). The T2 contrast is induced with a T2 preparation module (4-7) applied immediately before the readout train, similar to the T2-MPRAGE (8) and 3D T2prep-EPI (9) sequences. fMRI experiments with simultaneous flashing checkerboard and finger tapping were performed to evaluate this 3D T2prep-GRE approach and compare it with the conventional 2D SE EPI sequence.

METHODS: Three subjects were scanned on a 7T Philips MRI scanner. A 32-channel phased-array head coil (Nova Medical) was used for RF reception and a head-only quadrature coil for transmit. Visual stimulation was performed using flashing checkerboard (42s off/31.5s on, 4 repetitions). The subjects are instructed to perform bilateral finger tapping during the flashing periods. Two fMRI scans were performed on each subject: (a) 3D T2prep-GRE, 55 slices, voxel=2.5mm isotropic, TR=3.5s, single shot 3D spoiled fast GRE readout, FA=1º, turbo direction=radial, SENSE=3x2(APxFH), centric phase encoding. A T2 preparation module (90ºx–180º–180º–90º-x, effective TE=50ms, adiabatic pulses used for 180º) was applied immediately before the readout. (b) 2D SE EPI, 23 slices, voxel=2.5mm isotropic, TR=3.5s, TE=50ms, single-shot multi-slice SE EPI, FA=80º (Ernst angle), SENSE=3, partial Fourier fraction=0.6, fat suppression. First order volume shim was applied in both scans. Note that due to the specific absorption rate (SAR) limit, 2D SE EPI can only accommodate less than half of the slices allowed in 3D T2prep-GRE. To compare image quality in the whole brain, another 2D SE EPI scan was performed without functional stimulation: 55 slices, voxel=2.5mm isotropic, TR=9s, TE=50ms, other parameters the same. Anatomical images are acquired using MPRAGE (voxel=1mm isotropic, TR/TE/TI=4.7/2.1/446ms). All fMRI analysis was carried out with SPM8 and Matlab6 (general linear model for activation detection, P<0.01, cluster size ≥4). fMRI images were co-registered with anatomical images. Temporal SNR (tSNR) was calculated as the signal divided by standard deviation along the time course in each voxel. Contrast-to-noise ratio (CNR) was defined as: relative signal change between activation and rest (ΔS/S) x tSNR x square root of number of image volumes acquired during the entire scan.

RESULTS & DISCUSSION: Fig. 1 compares the images from MP-RAGE (anatomical), 3D T2prep-GRE (fMRI scan a, 55 slices) and SE EPI (55 slices, no stimulation). Sagittal, coronal and 3 axial slices at different locations (slice number 12, 26 and 47) are shown. Geometric distortion and signal dropouts are visible in SE EPI images, especially in the frontal and temporal lobes (red arrows), but are quite minimal in 3D T2prep-GRE images. Note that this was achieved with only linear shim to ensure a relatively homogeneous B0 across the entire brain. The readout in 3D T2prep-GRE is similar to that in MP-RAGE, resulting in fMRI images that resemble anatomical images, which would help to minimize problems in image registration. The fMRI results with 3D T2prep-GRE in Fig. 2 show robust activation in both visual and motor cortex, while the single-shot SE EPI sequence (scan b, TR=3.5s, 23 slices) was not able to cover both visual and motor cortex. The average time courses (Fig. 2b) over common activated voxels from the two scans were comparable, and consistent with SE BOLD responses in the literature with a typical post-stimulus undershoot. Quantitative results (all common voxels) are summarized in Table 1. The numbers of activated voxels and relative signal changes (ΔS/S) were comparable (P>0.1) between 3D T2prep-GRE and SE EPI, whereas average t-score, tSNR and CNR were slightly higher (P<0.1) in SE EPI. Note that this is based on a SE EPI sequence that can only cover 23 slices as compared to 55 slices in 3D T2prep-GRE within the same TR. While the major factor that limits spatial coverage in SE EPI is power deposition, it is not the bottleneck for 3D T2prep-GRE (half SAR level for twice as many slices with the same TR), mainly due to the small FA. In addition, the 3D readout in T2prep-GRE permits parallel imaging in two phase encoding directions, rather than one in the case of 2D SE EPI, which can be employed to further improve acquisition efficiency.

Fig. 1

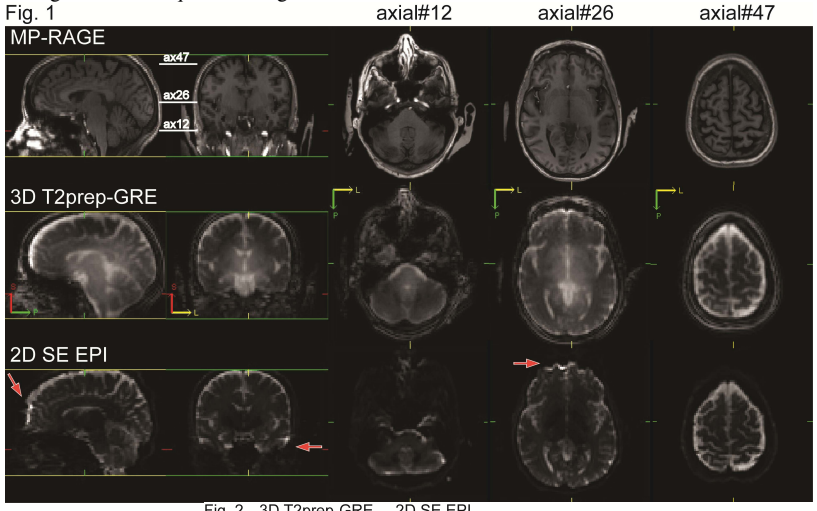
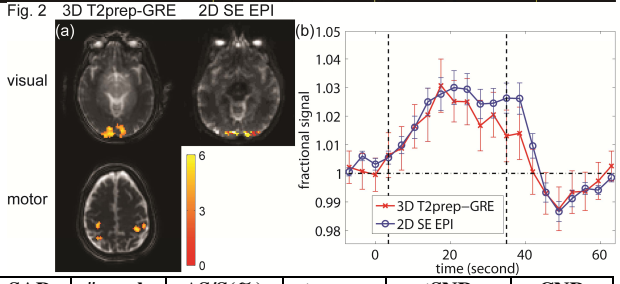


Fig. 2 3D T2prep-GRE 2D SE EPI



CONCLUSION: We have demonstrated a new T2-weighted BOLD fMRI pulse sequence, 3D T2prep-GRE, which can achieve sensitivity comparable to the conventional 2D SE EPI, but with minimal geometric distortion and signal dropout, lower SAR and greater spatial coverage. This approach is expected to be useful for fMRI scans of the whole brain, or high resolution scans focusing on regions near air cavities where conventional EPI fails to produce faithful images. The concept of using T2 preparation to generate BOLD contrast is certainly not limited to EPI (9) and 3D fast GRE, but can be combined with any other fast readout sequence. Although this technique is demonstrated here at 7T, it is readily transferable to any other field strengths.

Table 1.	TR(s)	#slices	SAR	#voxels	ΔS/S(%)	t-score	tSNR	CNR
3D T2prep-GRE	3.5	55	42%	415±91	2.2±0.7	3.0±0.4	41.1±13.2	6.9±3.1
2D SE EPI	3.5	23	81%	384±88	2.5±0.6	3.8±0.7	51.6±18.9	8.8±4.1

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