Rapid Multiecho 3D Radial fMRI

G. R. Lee[1], J. Tkach[1], and M. Griswold[1,2]
[1]Department of Radiology, Case Western Reserve University, Cleveland, OH, United States, [2]Biomedical Engineering, Case Western Reserve University, Cleveland, OH, United States

Introduction

It is the aim of the present work to perform multi-echo GRE functional MRI [1,2] using undersampled radial acquisitions for which aliasing artifacts are incoherent (noise-like) and the central region of k-space is fully sampled in each shot. Readout durations for a single radial EPI shot are kept short (5-10 ms) to minimize susceptibility-related signal losses. Readouts are performed at multiple echo times to allow better sensitivity to tissues with a range of T2* values and to maintain a high signal-to-noise ratio (SNR) efficiency. Fig 1a demonstrates a typical BOLD acquisition with a single fully sampled readout. Fig 1b demonstrates the proposed undersampled, multiecho technique. The proposed technique allows the acquisition of full brain fMRI images at 5 separate echo times at a temporal resolution below 1 second per volume.

In the work of Poser et al. [2], multiecho GRE BOLD was performed using 2D cartesian EPI at parallel imaging acceleration factors of 2 or 3. Rather than using parallel imaging, the present work employs the UNFOLD technique [3] to remove aliasing artifacts. This allows the use of higher acceleration factors than would be possible with parallel imaging alone and has the additional advantage that there is no noise amplification due to non-ideal coil geometry (g-factor).

UNFOLD involves the acquisition of a periodic series of undersampled images. The resulting aliasing artifacts are periodic in time and can be removed by means of a temporal filter. For fMRI applications, relatively large UNFOLD factors of 6 or more are possible. This is because the majority of the aliasing energy is due to the static brain tissue and can be removed by very narrow notch filters (often only a single frequency sample wide). In addition, the bandwidth of the BOLD response itself has most of its energy below 0.2 Hz due to convolution of the underlying neuronal activity with a relatively slow hemodynamic response (time-to-peak is on the order of 6 seconds). For fMRI applications, the loss in SNR due to undersampling is largely compensated for by the increased number of observations available during data analysis.

Methods

A 2D radial EPI trajectory [4] consisting of 16 projections per shot was used to progressively fill in 3D k-space. This was done by applying rotations of this single pattern about both the k_z axis and the k_y axis as demonstrated in Fig. 2 (for the multishot cases, points on the surface of the sphere indicate projection locations). After 14 rotations about k_z, an undersampled 3D k-space has been acquired. In total, 224 unique shots were used. For all subsets of 14, 28, 56, or 112 shots the projections are equidistantly spaced (aside from the increase in sampling density near the poles of the sphere). After the k-space data has been acquired, one can determine how many shots to use when reconstructing each image. For instance; if 224 shots/image are used, the images will have minimal aliasing artifacts, but temporal resolution will be poor. If only 14 shots/image are used to improve temporal resolution, substantial aliasing will occur, but this aliasing will have a periodicity of 224/14=16 and can be removed via temporal filtering using the UNFOLD technique. Alternatively, view sharing reconstructions such as sliding window or KWIC [5] can be used.

The proposed trajectory was employed for a simultaneous motor/visual paradigm in 6 human subjects. Subjects were scanned in accordance with IRB regulations on a 4T Siemens/Bruker system (single channel birdcage head coil). The paradigm consisted of bilateral finger tapping [32 s TAP, 32 s REST by 4 repetitions] with simultaneous 8 Hz flashing checkerboard stimulus [16 s OFF, 16s ON by 8 repetitions]. The total experimental duration was 243 s. Scan parameters were: 3D FLASH acquisition, matrix=64x64x42, ellipsoidal FOV (24 cm in A/P and R/L, 16 cm in S/I), TR = 57 ms, flip angle=15, 16-projection radial EPI readouts (8.4 ms duration) were centered at TE=7.3, 16.1, 24.9,33.6 and 42.4 ms. The same shot was always used for all readouts within a single TR. The center of k-space was used for self-navigation [6] in order to improve shot-to-shot consistency. Weighted summation of the separate echoes was performed using the method of Poser et al. [2]. fMRI analysis was performed (after UNFOLD filtering of the timeseries) via a standard GLM analysis using the FSL software package. No spatial smoothing was used during the analysis.

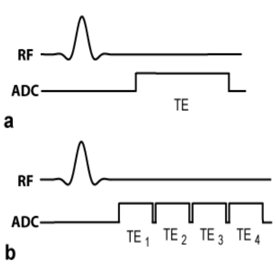

Fig. 1

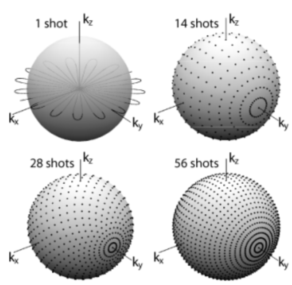

Fig. 2

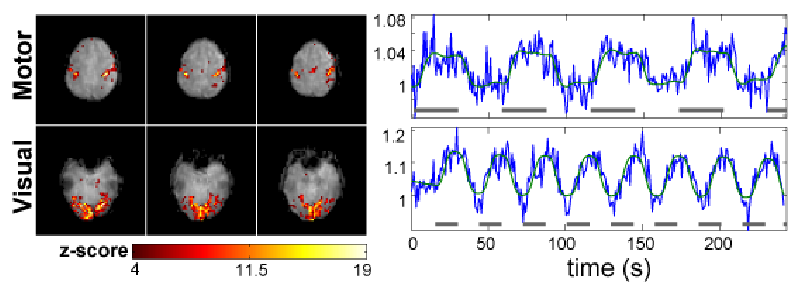

Fig. 3

Results and Discussion

Fig. 3 shows z-score maps and single-voxel timeseries for representative slices displaying either motor or visual activation. These maps correspond to the weighted summation of the separate echoes. The timeseries plotted correspond to the single voxel displaying the highest z-score for each task. Only 14 shots/image (16 radial lines/shot) were used, resulting in a temporal resolution of 0.798 seconds per volume.

In addition to using weighted summation for increasing fMRI sensitivity, the multiple echoes can also be used to quantify T2*, calculate dynamic field map information, and/or differentiate BOLD-related signal changes from inflow effects. Although multishot radial EPI was used in the present work, other trajectories such as rosettes or variable density spirals can be employed using the same series of rotations. The spiral-based trajectories do not cross themselves and would experience less signal loss due to off-resonance for a given readout duration. The proposed 3D radial view ordering enables the acquisition of images at multiple TE values while maintaining good temporal resolution and sensitivity.

References: 1. Posse et al. MRM 1999;42(1):87-97 2. Poser et al. MRM 2006;55(6):1227-1235 3. Madore et al., MRM 1999;42(5):813-828
4. Silva et al. JMR 1998;135(1):242-247 5. Song et al. MRM 2002;52(4):815-824 6. Wowk et al. MRM 1997;38(6):1029-1034
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