Functional Magnetic Resonance Imaging with Undersampled Projection-Reconstruction

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INTRODUCTION

Image acquisition for fMRI is conflicted between two important parameters: (1) long echo times required for T2* contrast; (2) fast image acquisition and extended readout window width. By using methods such as parallel imaging or filtering techniques such as UNFOLD, the readout window width can be reduced which reduces off-resonance distortion and blurring and increases temporal resolution. Presented in this work is a technique to acquire fMRI data with a reduced readout window width using a multi-echo undersampled projection-reconstruction acquisition. Using the described acquisition, the fMRI BOLD response can be measured with good fidelity, with a technique that offers much potential for significant improvements in acquisition speed for fMRI and similar experiments.

MATERIALS AND METHODS

A multi-echo gradient echo projection-reconstruction pulse sequence was designed and implemented on GE Signa LX 1.5T MRI scanner. Because eddy currents, gradient non-linearities, and timing errors can distort the *k*-space trajectory, the gradient waveforms and resultant trajectory were mapped using the technique described by Duyn (1998). Images were acquired with 90 readout points along 8 maximally-spaced projections with the resultant measured gradient waveforms and *k*-space trajectory as shown in Figure 1. The readout window width was approximately 8 ms and centered about an echo time of 40 ms, where each slice was imaged in 50 ms across 20 slices with 4 mm thickness and 240 mm field of view.

The experimental paradigm was right-hand finger tapping to elicit a motor response with 8 on-off blocks where finger tapping was "on" for 13 seconds and "off" for 13 seconds. The total time of the experiment was 3 minutes and 41 seconds. Images were reconstructed using convolution regridding and Voronoi diagram sampling density compensation with subsequent inverse Fourier transform. To control aliasing due to undersampling as seen in Figure 2a, the UNFOLD technique (Madore 1999) was used. After all slices were acquired, each set of 8 sparse projections were periodically rotated between 13 evenly spaced intervals. A FIR low-pass filter was then used to remove the temporally varying aliasing with the resultant image as shown in Figure 2b. Image volumes were smoothed with a 5.5 mm FWHM Gaussian kernel and Pearson's correlation coefficient was calculated for each voxel compared to the expected timecourse (the boxcar activation function convolved with the hemodynamic impulse response function from SPM (Wellcome Department of Cognitive Neurology, London, UK).

RESULTS AND DISCUSSION

As shown in Figure 2c, the BOLD response can readily be measured using undersampled projection-reconstruction imaging. The highest correlations map spatially to both the primary motor area and supplementary motor area indicating that the expected BOLD signal is indeed present in the acquired data in the expected regions. Implemented as described, 71% of the 142 Nyquist dictated projections are acquired with no aliasing visually apparent in the filtered image (Figure 2b). Note that the "halo" around the brain is due to subcutaneous fat present around the skull that has not been suppressed. Additionally, the short readout time (8 ms) is desirable in that it limits off-resonance blurring and distortion.

Empirical results have provided good quality single-shot images (without the use of UNFOLD) with as few as 20% of the required number of projections acquired within a readout window of 25 ms; however, off-resonance blurring attenuates BOLD sensitivity. Work is ongoing to implement a simultaneous data and field map acquisition to improve blurring and distortions due to off-resonance and further analyze the potential of undersampled projection-reconstruction images for acquiring fMRI data sets, particularly with single-shot acquisitions.

CONCLUSION

fMRI data can be obtained using undersampled projection-reconstruction. Additionally, projection-reconstruction offers the potential for increased temporal resolution in for fMRI and other imaging methods, such as perfusion imaging, while being compatible with parallel imaging and filtering methods such as UNFOLD. The short readout time is also advantageous in limiting blurring and distorting due to off-resonance.

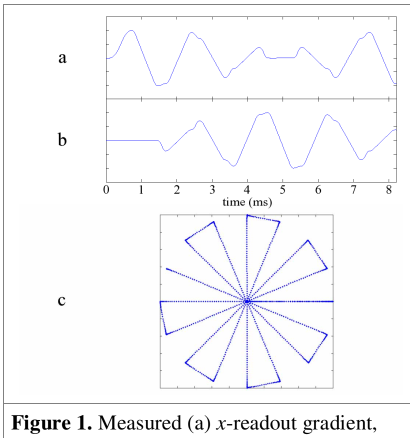

Figure 1. Measured (a) *x*-readout gradient, (b) *y*-readout gradient, (c) *k*-space trajectory.

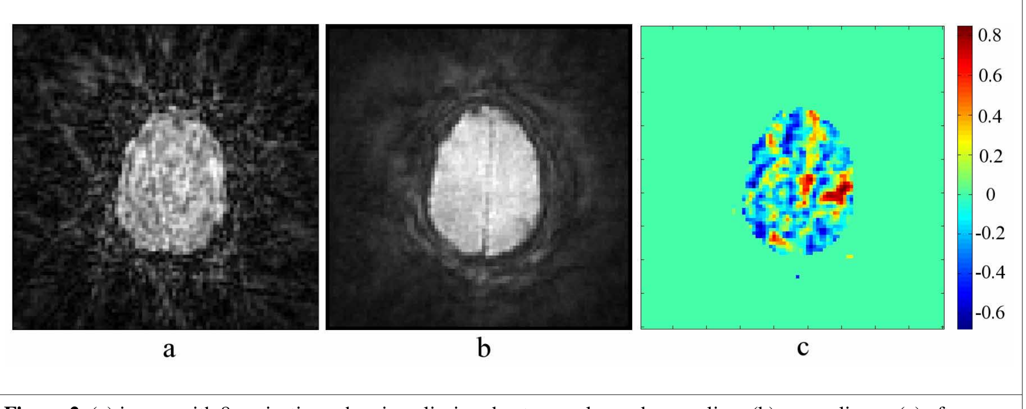

Figure 2. (a) image with 8 projections showing aliasing due to angular undersampling. (b) same slice as (a) after restoration using the proposed filter and UNFOLD. (c) correlation map to expected BOLD response.

REFERENCES:

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