High Resolution Frequency-Modulated bSSFP fMRI

Albert Kir[1,2], Alan B. McMillan[3], Rao Gullapalli[1,2], and Joel M Morris[4]

[1]*Magnetic Resonance Research Center, University of Maryland, School of Medicine, Baltimore, MD, United States,* [2]*Diagnostic Radiology and Nuclear Medicine, University of Maryland, School of Medicine, Baltimore, MD, United States,* [3]*Radiology, University of Wisconsin Madison, School of Medicine and Public Health, Madison, WI, United States,* [4]*Communication and Signal Processing Laboratory, University of Maryland, Baltimore County, Baltimore, MD, United States*

Introduction: Echo Planar Imaging (EPI) sequences are commonly used in fMRI experiments to measure the blood oxygenation dependent (BOLD) signal. While designed to provide sufficient temporal resolution and BOLD contrast at the cost of reduced spatial resolution, such sequences are best applied to the examination of cortical regions to avoid susceptibility gradients that result in geometric distortion and signal loss around the medial temporal lobe (MTL) of a brain[1] hindering the acquisition of the BOLD signal. We have developed a banding-free balanced steady state free precession (bSSFP) technique by implementing a frequency-modulation technique[2] to manipulate the bSSFP passband/transition-band signal characteristics during an fMRI experiment.

Methods: The location of the banding artifact in bSSFP images depends on the distribution of the off-resonance frequencies, T1/T2, and the imaging parameters (RF pulse angle/phase, TR, TE)[3,4]. Fig 1(a) shows two simulated signal profiles representing the signal intensities at a range of frequencies with the same T1/T2 and imaging parameters except for different RF pulse phase schemes (solid line: 0°-0°, dashed line: 0°-180°). A smooth and flat profile, Fig 1(b), can be obtained by taking the sum-of-square (SOS) combination[5] of those in Fig 1(a). The results of the simulation imply the two phase schemes lead to two complementary patterns of the banding artifact within the image FOV, and the SOS combination of complementary images results in an image with highly uniform signal. Unfortunately, such a scheme requires two completely separate acquisitions at steady state, limiting feasibility for BOLD imaging. We propose a bSSFP technique using frequency modulation (slow quadratic phase scheme[2]) to dynamically acquire images from separate phase schemes within a single fMRI experiment without re-establishing the steady-state. Fig 1(c) and 1(d) show the corresponding simulated profiles and SOS combination of the frequency-modulated (FM) acquisition. To demonstrate the proposed FM-bSSFP acquisition for fMRI, we performed experiments targeting visual, memory retrieval and encoding functions with a block-design paradigm on Siemens 3T MR scanner. Two-dimensional functional images with high resolution (matrix size: 256 × 256, FOV: 256 × 256 mm, thickness: 5 mm) and comparable temporal resolution (FM-bSSFP: 2.95s, EPI: 3.01s) were obtained using FM-bSSFP (α: 45, TR/TE: 3.8/1.9ms, BW: 977 Hz/Pxl, 3 phase cycles) and a GRE EPI sequence (TR/TE: 3000/61ms, BW: 1148 Hz/Pxl).

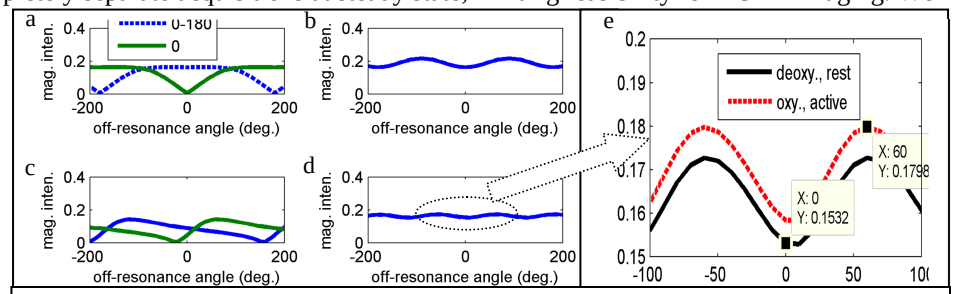

Fig 1. (a) simulated profiles for two acquisitions with differing phase schemes using bSSFP; **(b)** the SOS combination of the profiles in (a); **(c)** simulated profiles for two phase cycles of a single FM-bSSFP; **(d)** the SOS combination of the profiles in (c); **(e)** simulated BOLD contrast between the rest and active states.

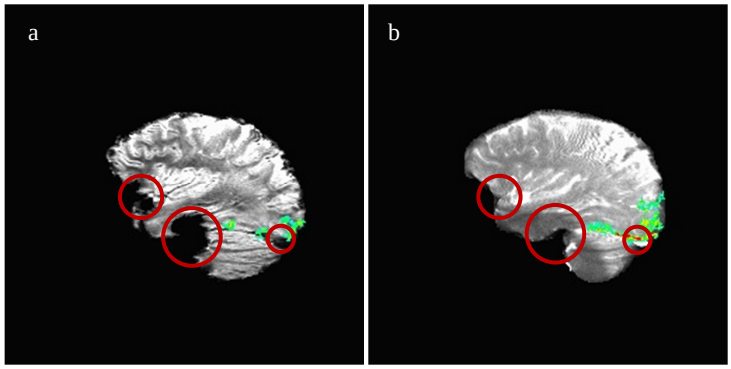

Fig 2. The activation map for GRE EPI **(a)** and FM-bSSFP **(b)**. FM-bSSFP is observed to be free of geometric distortion and signal dropout (red circles)

Results and Discussion: Fig 2(a) and (b) show images using EPI and the FM bSSFP sequence, respectively. A Gaussian kernel of 2mm FWHM was used to spatially smooth the time-series before the activation map was derived using conventional general linear model techniques. The activation maps are displayed with a *t*-statistic threshold to give a *p*-value of 0.01. The average functional contrast of all activated voxels in bSSFP acquisition is ~2.5%, compared to ~4.2% for the EPI acquisition. Per Fig 1(e), assuming frequency shift of 10 deg. and 5% change in T2 between active and resting states, the estimated signal change is approximately (0.179-0.153)/0.153×$\frac{10\ deg}{60\ deg}$ =~2.9%, which closely matches our experimental findings. Geometric distortion can be observed in the ventral part of the cerebellum and anterior part of the frontal lobe in the EPI image, and the three circles indicate regions of significant signal loss in the EPI image of 2(a) in comparison to the FM-bSSFP image of 2(b). Possible loss of functional signals in 2(a) is identified by the smallest circle while 2(b) shows strong activation from the task.

Conclusion: Comparison of the activation maps demonstrates that FM bSSFP retains the BOLD signal in the presence of significant magnetic susceptibility. For obtaining high resolution fMRI in susceptibility-artifact-prone functional areas, the proposed approach provides a viable alternative to EPI sequences. With parallel imaging and/or compressive sensing, improved temporal resolution and three-dimensional full brain coverage fMRI experiments will likely be achieved.

References: [1]Olman, et al, PLoS One 2009. [2]Foxall, MRM 2002. [3]Scheffler, et al, NMR Biomed. 2001. [4]Hinshaw, 1976. [5]Bangerter, et al, 2004.