High-resolution FMRI at 1.5T Using 3D BOSS

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INTRODUCTION. High resolution FMRI is of interest for the study of fine cortical architecture and localization of small gray matter nuclei [1-4]. However, high-resolution BOLD FMRI is difficult due to the coupling of BOLD contrast to sources of image artifacts. Blood oxygenation sensitive steady-state (BOSS) FMRI is a new method that obtains functional contrast based on the frequency sensitivity of refocused SSFP (Fig. 1) [5,6]. Since it is based on SSFP, BOSS has higher SNR efficiency than BOLD and does not suffer from image warping or signal dropout. These factors make BOSS ideal for high-resolution FMRI, even at low field strengths where high-resolution BOLD FMRI is difficult. We previously presented proof-of-concept data demonstrating the potential for high-resolution BOSS FMRI [7]. However, to date, BOSS FMRI has used an inefficient 2D single-slice acquisition. To realize the high SNR efficiency possible with BOSS FMRI, data must be acquired with 3D *k*-space coverage. We present an efficient 3D-EPI trajectory for BOSS FMRI, and demonstrate the ability to acquire high-resolution data (1x1x2 mm^3) at 1.5T.

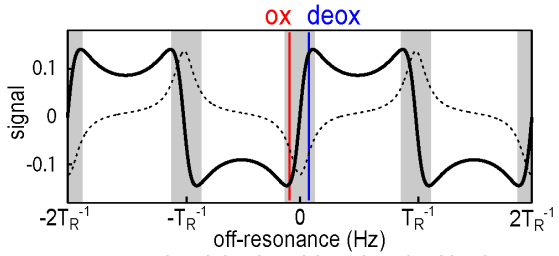

FIGURE 1. SSFP signal (real and imaginary) with placement of oxy- and deoxyHb resonance to create BOSS sensitivity to blood oxygenation.

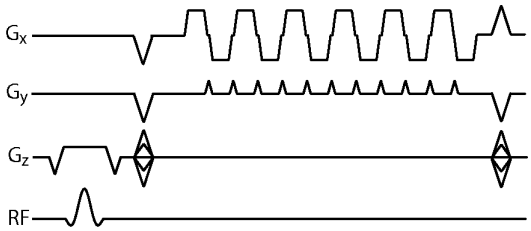

FIGURE 2. BOSS pulse sequence with a 3D stack-of-segmented EPI readout. All gradient axes have zero area.

METHODS. Refocused SSFP is characterized by high SNR efficiency, which is achieved by continually re-using signal rather than spoiling it. This signal re-use makes SSFP compatible with efficient 3D acquisitions, in which the entire volume is excited each T_R and read out in 3D *k*-space. SSFP signal fluctuations (Fig. 1) cause "banding artifacts" in the image, which are typically minimized by using a very short T_R (2-5 ms) with a 3DFT readout. In BOSS, however, these bands are the source of functional contrast and it is therefore desirable to *increase* the banding with a longer T_R (20-50ms). One consequence of a longer T_R is increased flexibility in the readout, enabling more sophisticated and efficient 3D trajectories. This work extends standard EPI to cover 3D *k*-space within a refocused SSFP sequence (Fig. 2). We acquire segmented EPI with phase encoding along the z direction, resulting in a series of segmented EPI readouts stacked along k_z. Although these readouts (20-30 ms) are longer than typically used in SSFP, they are sufficiently short to minimize off-resonance warping or T_2 blurring. This stack-of-segmented EPI readout has a high duty cycle and enables fast volumetric acquisitions.

EXPERIMENTS. 3D BOSS FMRI experiments were performed on 5 subjects (3 visual, 2 motor) on a 1.5T Siemens Sonata using a T/R birdcage head coil. Images were acquired with 3D stack-of-segmented EPI (256x256x10 matrix, 8 segments per k_z plane) with voxel size 1x1x2mm^3. The T_R (42ms) and flip angle (10^o) were chosen to maximize functional contrast and readout efficiency [6]. The stimulus was either an 8-Hz flashing checkerboard visual stimulus or a bilateral finger-tapping task in 15s on / 15s off blocks for 2 minutes (one volume every 3.6 s). This paradigm was repeated at 11 shifted center frequencies, so that tissue in a given location was matched to the region of BOSS sensitivity (central gray swath in Fig. 1) in at least one run [6]. Analysis was performed using FEAT [8] with minimal manipulation to present the data in its raw form. In particular, no spatial smoothing or cluster-based thresholding was performed. Inspection of individual runs indicated that within-run registration was not necessary. Separate runs were aligned [9] and the statistical activation maps were averaged to produce a single activation map, which was overlaid on an anatomical reference.

RESULTS. Results for 4 of 5 subjects are shown in Fig. 3. Comparing the activation patterns to the underlying anatomical map indicates that activation is largely confined to the gray matter, although there may be a bias toward the sulcal surface, as is often seen in conventional BOLD FMRI. The small voxel dimensions reduced partial volume effects relative to standard FMRI, resulting in large signal changes, as high as 35%.

DISCUSSION. 3D BOSS FMRI has several advantages for high-resolution imaging. First, image fidelity is excellent since BOSS acquires a spin echo [10] and the readouts are relatively short. Second, BOSS FMRI is extremely efficient since the majority of the T_R can be dedicated to readout (71% duty cycle in this study). Finally, true-3D readouts are a major advantage in acquiring small, isotropic voxels. One limitation of BOSS FMRI is the need for multi-frequency acquisitions, which increases brain coverage at a cost of longer experiment times. However, the experiment times used here (22 minutes) are not unreasonable for high-resolution studies, which require long scan times to increase CNR. Future work will consider methods for fast acquisition of multi-frequency data, more efficiently detecting activation and reducing sensitivity to frequency drift with prospective corrections and modeling.

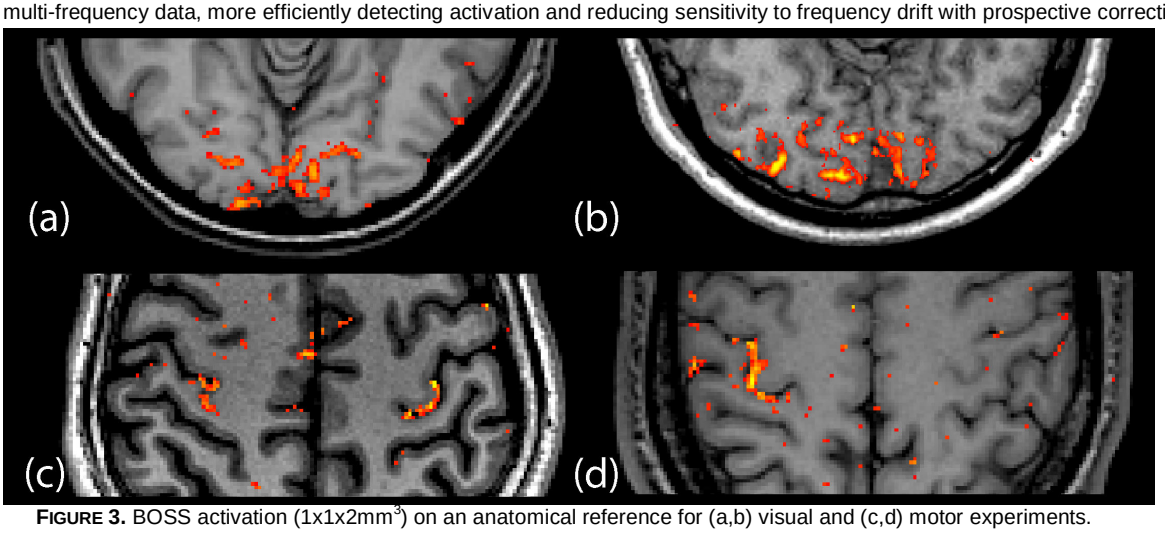

FIGURE 3. BOSS activation (1x1x2mm^3) on an anatomical reference for (a,b) visual and (c,d) motor experiments.

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