A Quantitative Analysis of fMRI Induced Phase Changes Using Averaged-BOSS (A-BOSS)

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Introduction: Due to the mechanism of contrast origin in BOLD fMRI, generally only the magnitude data is used for activation detection. Through the use of SSFP sequences, we are able to detect fMRI activation directly based on phase variation induced by frequency shift. BOSS fMRI utilizes this phase information in addition to magnitude changes for activation detection[1, 2]. The contribution of phase, however, is highly dependent on the position of the center frequency on the SSFP profile[2] and therefore may not be quantified accurately. Averaged-BOSS (A-BOSS)[3], which has recently been introduced for fMRI by compressing the SSFP profile into a single voxel, also indicates that activation patterns should exist in both phase and magnitude images. Figure 1 graphically shows this concept. Because of its averaging nature, this method provides a novel approach for quantitative analysis of fMRI induced phase changes while removing its sensitivity to the off-resonance frequency.

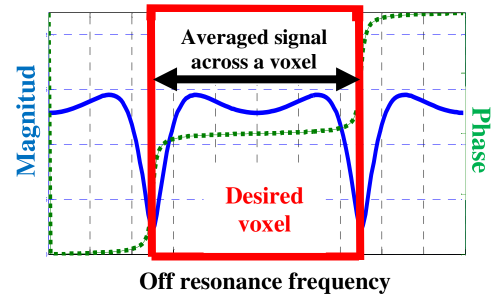


***Figure 1**. A-BOSS is based on compressing the SSFP profile to the size of each voxel. Total signal of each voxel is a complex average of SSFP profile.*

Method: A-BOSS signal is essentially similar to BOSS, but the SSFP profile is averaged across each single voxel. In this context fMRI activation is a change of the voxel signal in the complex domain. Figure 2 shows this idea. Here S and θ show the fMRI magnitude and phase change due to activation, respectively.

Bloch equation simulation was performed for a voxel inside the blood veins where an oxygenation change from 70% to 85% results in about 5 Hz shift in frequency[4]. In vivo A-BOSS fMRI data was acquired from a single subject on a 3T Siemens TIM Trio scanner. Data was collected during a right-hand finger tapping experiment with a block design of 3 cycles of on\off (30s\30s), TR\TE= 9.8ms\4.9ms, FA=20°, matrix size 128x128 and resolution 2x2x5 mm^3. Four axial slices and a total of 30 volumes were collected in 3 minutes. Both magnitude and phase images were acquired from scanner. Preprocessing was performed using SPM 8 including head motion correction, slice timing correction and smoothing with a Gaussian kernel of twice the voxel size. Activation detection was performed for magnitude and phase data separately, based on the cross correlation of amplitude and phase time series with the temporal pattern of task paradigm. The cross correlation values were then converted to z-score.

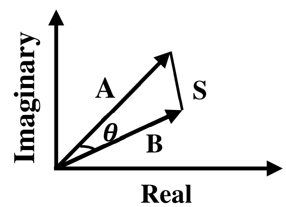
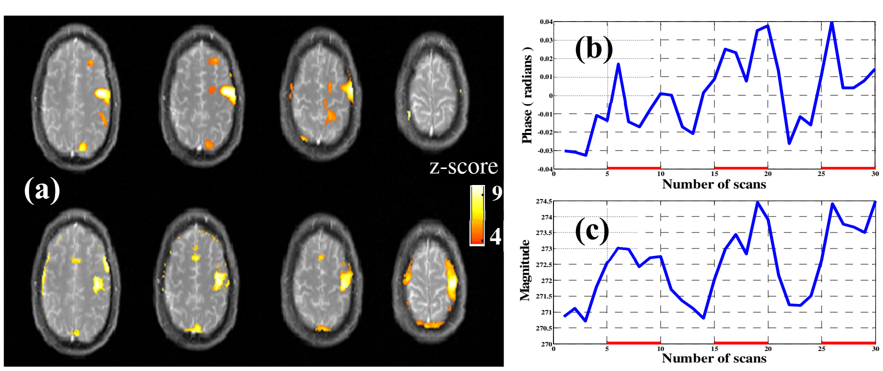


***Figure 2**. Phasor diagram of fMRI activation*

Results: According to Bloch equation simulations for the specified imaging parameters as well as oxygenation change, we obtained an expected activity for a blood filled voxel about 0.1 radian change in phase, and about 5% for magnitude signal variations from base line. In the in vivo experiment, for the threshold value of z-score = 4.4 ($p < 0.001$) a total number of 1391 voxels were detected, 593 (42%) voxels showed phase activation (maximum z-score=8.8), 935 (67%) voxels showed magnitude activation (maximum z-score=9), and 136 (10%) voxels showed both phase and magnitude activation. Figure 3 shows the activation maps for magnitude and phase without any thresholding on spatial extent of active clusters. This figure also shows the mean time courses of phase and magnitude of active voxels in each case. An obvious localized activity is seen in phase map (Figure 3-a, top row) in Brodmann's areas 4 and 6 related to finger tapping experiment. It is also the case for magnitude activation maps (Figure 3-a, bottom row). Phase time courses showed about 0.07 radian mean activation signal change and magnitude time courses showed 1.5% increase from baseline. These results are in general agreement with simulations.

Discussion & Conclusion: A-BOSS is a new method for steady state fMRI that provides images free of banding artifact. It does not require adjusting center frequency as in BOSS fMRI to improve spatial coverage. One advantage of A-BOSS is that the phase information is not dependent on the center frequency which makes it suitable to infer phase changes with intra voxel origin. It is worth mentioning that the sequence parameters were not perfectly optimized for this preliminary data and computer simulation shows that longer TR would result in a better functional contrast, also by increasing the TR value, the pattern of phase variation in profile will approach a linear shape which increases the contribution of phase in active voxels. Here we investigated the phase activation patterns using A-BOSS and showed a mean phase change of 0.07 radian induced by activation. About 42% of active voxels showed localized phase activation which could not be detected just based on magnitude data. These results suggest that A-BOSS may provide both magnitude and phase information in the complex domain for fMRI.



References:

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***Figure 3**. (a) fMRI activation map for phase (top row) and magnitude (bottom row),(b) mean phase time course of active voxels, (c) mean magnitude time course of active voxels. (Threshold = z-score 4.4)*