Frequency stabilization using finite impulse response filtering for BOSS fMRI at 3T

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Introduction

Blood Oxygenation Sensitive Steady State (BOSS) functional MRI (fMRI) has been demonstrated in 1.5 Tesla systems [1]. Based on balanced SSFP imaging with a small flip angle, whose magnitude peaks at the narrow band of phase transition [1], BOSS imaging is suitable for detecting small functional changes in blood oxygenation, which however also leads to native sensitivity to field instability during consecutive scans. At higher fields, frequency drifts resulted from heating of high order shimming can be more prominent [2]. Therefore, signal fluctuations caused by frequency drifts on high field systems can impede the observation of activation signal with BOSS fMRI. In this study, we examined the signal change due to field fluctuations and implemented frequency stabilization methods based on finite impulse response (FIR) filtering on 3 Tesla MRI. BOSS fMRI was performed for comparison.

Material and Method

[Imaging] Six sets of BOSS images were obtained from each of our seven subjects with 64x64 matrix to demonstrate the effects of stabilization methods. Three sets contained 100 blank scans without stimulus. The other three sets were performed with 5Hz checkerboard visual stimulus within 75 time frames (2 on, 3 off, 15 frames/block, 2 sec/frame). One subject underwent three trials of high resolution BOSS fMRI (matrix 256x256, 2 slices, voxel size $0.75x0.75x3mm^3$, frequency stabilization with FIR filtering; see below) with frequency shift of -7Hz, 0Hz, 7Hz, separately. Visual stimulus (4 on, 5 off, 8 frames/block, 4 sec/frame) was given in 72 dynamic scans. All images were acquired on Philips Achieva 3 Tesla system using an 8-channel head coil (TR/TE/flip angle: 8ms/4ms/5^o) with high order shimming covering occipital lobe.

[Frequency Stabilization] Frequency drift estimation was done by applying an RF pulse with a small flip angle right before each dynamic scan. Thereupon frequency was adjusted accordingly in each scan. To further improve signal stabilization and reduce oscillation, a real-time three point FIR filter, with empirically selected weighting of 1-2-1, was applied to update central reference frequency.

[Data Analysis] In blank scans, mean signal fluctuation was calculated from a selected ROI of 8x10 voxels and then normalized by first 10 time points. For BOSS fMRI, data were analyzed by ICA included in fMRLAB [3]. In each trial, activated voxels were selected with a threshold of Z>1.5 and normalized mean time curve were therefore calculated from raw data.

Results

Figure 1 showed results from blank scans. Note that without frequency stabilization (red), signal dropped over 15% in 100 dynamic scans. While both stabilization methods maintained relatively flat curves, filtered frequency stabilization method further lowered the signal standard deviation from 2.33% (green) to 1.13% (blue). Fig.2 plotted activation curves from three BOSS fMRI trials with different stabilization conditions. Activation curve was distorted and drifted in the trial without stabilization (red). With FIR filter applied (blue), the oscillation of time curve was reduced, compared with regular frequency stabilization method (green). Fig.3 showed results of high resolution BOSS fMRI. Fig.3a was the activation map obtained by combining Z-maps from three trials with maximum intensity projection (MIP) method. Most activated voxels accorded nicely with gray matter region of underlying T1 images. Fig.3b plotted activation curves of each trial. With filtered frequency stabilization, baseline drift was observed in none of the trials. In addition, due to reduced partial volume effect, activation signal was at a high level of 15%.

Discussion

BOSS technique provides a distortion-free option for fMRI [1], which is beneficial at high fields. However, due to unfavorable sensitivity to minute field drifts, frequency stabilization plays a key role for feasible BOSS fMRI on high field systems. Without frequency stabilization, activation signal can be overwhelmed by large baseline fluctuation. Field drift estimation with small angle RF pulses partially inhibit the baseline fluctuation, but still prone to estimation errors due to low SNR. The utilization of FIR filter enables a flat baseline with low oscillation, which would otherwise render impossible high resolution BOSS fMRI with longer scan time. Our results demonstrate that with good FIR frequency stabilization, BOSS has strong potential for high resolution distortion-free fMRI studies.

References [1] Karla LM. *MR M* 2003;50:675 [2] Pierre-Gilles H. *MRM* 1999;42:636 [3] McKeown MJ. HBM 1998;6:160

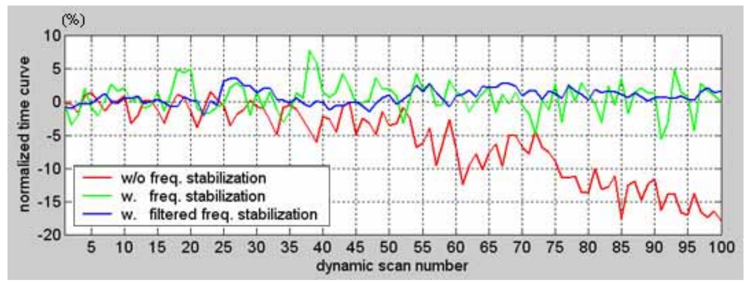

Figure 1. Results of stability test with 100 continuous scans. Mean time curves were calculated from a selected ROI of 80 voxels and then normalized by the average of first 10 time points. Without frequency stabilization (red), signal dropped over 15% within 100 dynamic scans. Signal stability improved when both frequency stabilization methods were applied (green and blue). Filtered frequency stabilization method further lowered the signal standard deviation from 2.33% (green) to 1.13% (blue).

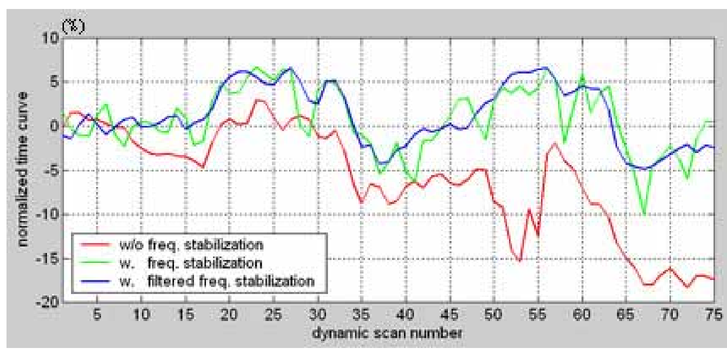

Figure 2. Three visual BOSS fMRI trials were acquired with different stabilization conditions. Without frequency stabilization (red), activation curve was distorted and drifted. Filtered frequency stabilization (blue) further reduced the oscillation of time curve in regular frequency stabilization method (green).

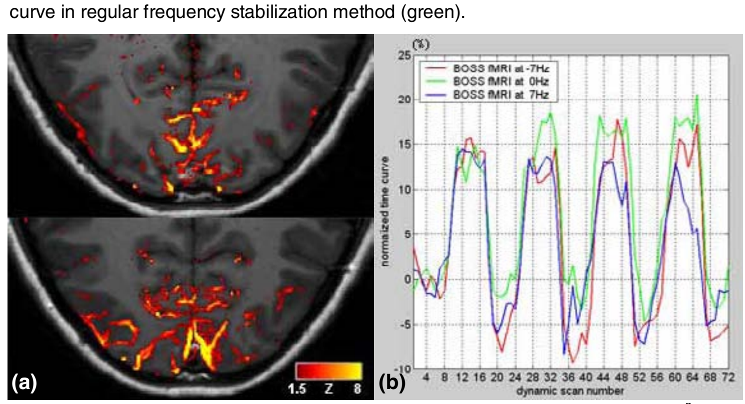

Figure 3. High resolution BOSS fMRI experiments, with voxel of $0.75x0.75x3mm^3$, were performed with frequency shift of -7Hz, 0Hz, and 7Hz. (a) Activation map obtained by combining Zmaps from three trials with MIP method. Note that most activated voxels accorded nicely with gray matter region of underlying T1 images. (b) Normalized mean time curves from three trials. Due to reduced partial volume effect, activation signal was at a higher level of 15%.