

High field balanced-SSFP fMRI: Examining a diffusion contrast mechanism using varied flip-angles

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Introduction

Although T2*-weighted gradient echo based fMRI has become a standard acquisition tool for neuro-scientific investigation, many questions still exist as to the spatial specificity of the functional patterns observed relative to neuronal activity. Two main problems persist with T2* weighted fMRI: (i) an oversensitivity to oxygenation changes in large draining veins located distal to the site of activation; and (ii) an inability to perform robust T2* fMRI analysis in regions of strong field inhomogeneity like the frontal and temporal lobes. Alternative approaches, such as spin-echo or other T2 based methods, have been proposed to alleviate the issues associated with T2* approaches. However, a strong reduction of sensitivity to BOLD contrast prevents the practical implementation of these approaches. Recently, balanced SSFP (b-SSFP) (also TrueFISP or FIESTA) has been proposed as a BOLD sensitive approach that relies on the inherent sensitivity of b-SSFP to off-resonance signal changes [1]. Although possessing spin-echo like properties [2], fMRI acquisition with b-SSFP has relied on careful shimming of specific regions to within a few Hz of the critical transition bands [1], or to the acquisition of multiple off-resonance images with image recombination strategies that limit temporal resolution [3].

This paper proposes the use of b-SSFP at high field (4T) using on-resonance acquisitions without shimming in regions of interest to the edge of the b-SSFP transition band. We have previously shown on-resonance b-SSFP acquisitions to have far greater BOLD sensitivity than gradient-echo acquisitions with matched TE/TR, and to have comparable sensitivity as standard EPI-gradient echo acquisitions. In this work, we demonstrate that BOLD-based fractional signal changes for b-SSFP acquisitions increase by more than twofold within tissue for flip angles varying from 20° to 65°, while large draining veins often show a negative fractional signal response that increases in magnitude over the same flip angle range. The increased sensitivity of the BOLD response in tissue for larger flip angles is consistent with the known enhancement of diffusion sensitivity for b-SSFP acquisitions with increased flip angle [5]. This suggests increased diffusion sensitivity to microscopic field inhomogeneities surrounding the micro-vasculature of the cerebral cortex as a possible mechanism for observed BOLD contrast in b-SSFP acquisitions.

Methods

Experiments were performed at 4T on a whole body Varian/Siemens system using a transmit-receive, 2-element, quadrature surface coil (7"element) placed posteriorly to the head of the volunteers. Three oblique slices were prescribed from a sagittal scout (4 mm each, 1 mm gap) oriented in a plane through and parallel to the calcarine sulcus. During the visual stimulation paradigm, a series of 63 b-SSFP images (19.2x14.4 cm fov, 128x96, 8.0/4.0 ms TR/TE) were acquired at flip angles (α) of 20, 35, 50 and 65 degrees. A reference set of EPI images (19.2x19.2 cm fov, 128x128, 4 shot, 750/15 ms TR/TE, $\alpha=40$) were acquired to evaluate functionally related signal changes in the primary visual cortex. A block stimulation paradigm was used alternating between 25 seconds of fixation and 25 seconds of a reversing checkerboard repeated for 3.0 minutes. Each data set was analyzed using a pixel wise cross-correlation (Stimulate; CMRR, UMN) at a conservative threshold value of .20 and mapped as the percentage signal change onto a T1-weighted anatomical reference. During each session, a corresponding high resolution GRE venogram (19.2x14.4 cm fov, 256x192, 50/30 ms TR/TE, $\alpha=25$) was collected to evaluate the origin of functional signal changes.

Results

The images in Fig. 1 show functionally related activity in human visual cortex using b-SSFP acquisitions over a range of flip angles. A high resolution T1-weighted anatomic is shown to illustrate the origin of functional activation (on right). Superimposed black lines correspond to venous vessels, as selected from the venogram, to highlight obvious large vessel signal. The colorbar shows the relative percent signal change in significantly activated voxels as assessed through cross-correlation analysis. One clear observation is the appearance of negative signal changes upon activation for larger flip angles, particularly in the indicated regions (on right) corresponding to draining veins. A second observation is increased map sensitivity in grey matter tissue as a function of flip angle. Fig. 2 illustrates the b-SSFP functional signal dependence (in percent averaged over 2 subjects) as a function of flip angle in regions defined as tissue (using T1-weighted image) and large venous vessels (using venogram) in the area of primary visual cortex. Tissue regions demonstrate a nearly linear increase in percent activation by more than a factor of 2 over the flip angle range investigated, while activation induced negative signal changes within obvious draining veins increase in magnitude for larger flip angles. Corresponding maps generated from T2*-weighted EPI acquisitions demonstrate comparable signal changes within tissue (3.25% averaged over 2 subjects) to that of high flip angle b-SSFP, and strong overlap of positive signal changes with b-SSFP maps (not shown).

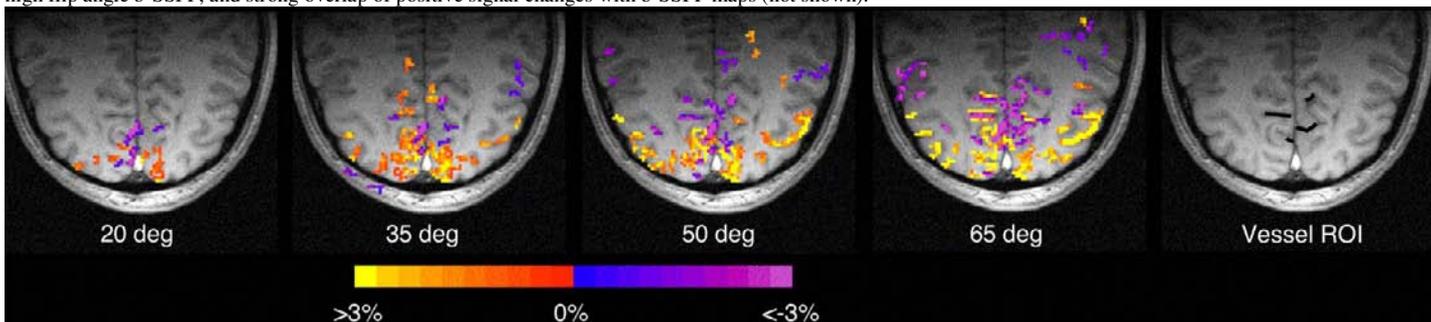


Figure 1: b-SSFP Activation Patterns versus Flip Angle

Discussion

BOLD based fMRI activation maps obtained with high flip angle balanced-SSFP demonstrate excellent sensitivity in active brain regions, with comparable signal changes to widely accepted T2*-EPI techniques. The BOLD based fractional signal changes in tissue were observed to scale with flip angle, in qualitative agreement with theoretical predictions of the diffusion sensitivity through a linear field gradient for b-SSFP measurements [5]. Previous work by our group using low flip-angle (25°) b-SSFP acquisitions [4] demonstrated an inherent insensitivity to BOLD signal changes in large draining vessels relative to T2*-EPI. In this work, a negative signal response with increased magnitude for larger flip angles was observed in vessels, indicating the potential for suppression of large vessel activation relative to T2*-weighted EPI. We believe that the b-SSFP method possesses adequate BOLD sensitivity, possibly a result of inherent sensitivity of b-SSFP to diffusion surrounding tissue micro-vessels, and may provide an alternative tool for neuro-scientific investigation.

References

[1] Scheffler K, Seifritz E, Bilecen D, Venkatesan R, Hennig J, Deimling M, Haacke EM, MRM Biomed 2001;14:490-6. [2] Scheffler K, Hennig J., MRM 2003;49:395-7. [3] Miller KL, Hargreaves BA, Lee J, Ress D, Pauly JM, MRM 2003;50:675-83. [4] Bowen CV, Menon RS, Gati JS, Proc. 13th ISMRM (Miami 2005):119. [5] Freed DE, Scheven UM, Zielinski LJ, Sen PN, Hurlimann MD, J. Chem. Phys. 2001;115:4249.

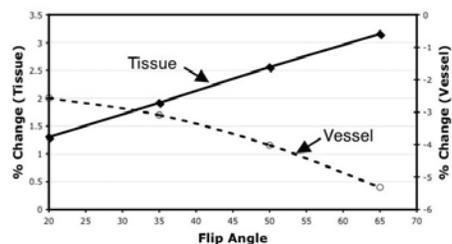


Figure 2: b-SSFP BOLD Sensitivity