Enhancement of Temporal Resolution and BOLD Sensitivity in Real-Time fMRI using Multi-Slab Echo-Volumar Imaging

Stefan Posse[1,2], and Elena Ackley[1]

[1]Neurology, University of New Mexico, Albuquerque, NM, United States, [2]Electrical and Computer Engineering, Physics and Astronomy, University of New Mexico, Albuquerque, NM, United States

Objective Echo volumar imaging (EVI) improves temporal resolution in fMRI to resolve regional onset latencies, to improve deconvolution of physiological noise and to reduce motion sensitivity. Integration of parallel imaging has led to considerable improvement in image quality as demonstrated in several recent studies (1-3). We recently introduced EVI with sequential multi-slab excitation and 4-fold GRAPPA acceleration to further reduce geometrical distortion and reported preliminary accounts of increased BOLD sensitivity (4). Here we provide a quantitative comparison of BOLD sensitivity between multi-slab EVI acquisitions with TR: 286 ms and TR: 136 ms, and EPI with TR: 2000 ms.

Methods FMRI data were acquired using a Siemens 3 T scanner equipped with a 12-channel head array coil. Whole-brain EVI was performed in 4 subjects using: TR: 286 ms, TE_{eff}: 28 ms, α: 10^{o}, 4 slabs in AC/PC orientation, slab thickness: 24 mm, inter-slab gap=10%, FOV: 256 mm, 4-fold GRAPPA acceleration in the readout direction, reconstructed image matrix per slab: 64x64x8, isotropic voxel dimensions: 4 mm, no. measurements: 600. EPI data acquisition was additionally performed using identical acquisition parameters, except: TR: 2000 ms, 32 slices, no. measurements: 84 (**Figure 1**). Multiple EVI and EPI scans were collected in randomized order. Partial brain EVI using TR: 136 ms was performed in 3 subjects using identical acquisition parameters as whole brain EVI except: 2 slabs, slab thickness: 42 mm, voxel dimensions: 4x4x6 mm^3, no. measurements: 1100. Real-time in-plane EVI image reconstruction was performed on the scanner. EVI image reconstruction in the 3^{rd} dimension and fMRI analysis were performed with time delays of less than one TR using real-time fMRI TurboFIRE software [5]. A block-design auditory-gated visual-motor paradigm, which consisted of 5 blocks of simultaneous 2 Hz right index finger tapping and eyes open (4 s duration) versus rest and eyes closed (19 s duration), was employed. EVI and EPI scans were collected in randomized order. EVI images were spatially normalizated into MNI space and segmented into 144 functional brain regions using the Talairach Daemon database (6). Cumulative General-Linear-Model (GLM) analysis was performed in batch mode. The percent signal change, t-score, and extent of activation were measured in visual cortex (BA17-19) with t-scores greater than 5.0 and in extended motor cortex (BA1-6) with t-scores greater than 3.0. Only voxels that were consistently activated in all 4-slab EVI and EPI scans of a given subject were selected for measuring percent signal change and t-scores to ensure identical VOI selection. 2-slab EVI was analyzed in subject space. Temporal SNR (7) was computed in left Brodmann Area 10 for non-activated voxels with t-scores less than 1.0.

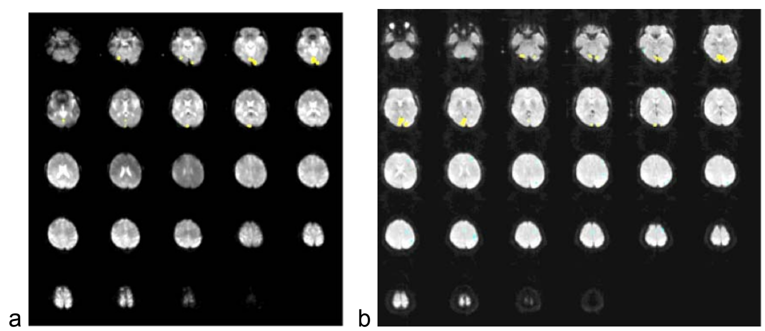

Figure 1: Whole brain (a) EVI and (b) EPI raw data with overlaid activation maps.

Results BOLD signal changes and t-scores in visual cortex (Brodman areas 17-19) were significantly larger with 4-slab EVI compared with conventional EPI (**Table 1** showing means and (SD) across subjects). The average temporal signal-to-noise ratio was 76.6 +/- 4.9 using 4-slab EVI and 159.8 +/- 24.6 using EPI (p < 0.00008). Similar mean percent signal changes in Brodmann areas 17-19 and in Brodmann areas 1-6, and smaller extent of activation, and mean and maximum t-scores in these areas, were measured with 2-slab EVI. The average temporal signal-to-noise ratio was 55.8 +/- 11.1.

	VISUAL CORTEX (BA17-19)						MOTOR CORTEX (BA1-6)					
	4-slab EVI		EPI		2-slab EVI		4-slab EVI		EPI		2-slab EVI	
	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max	Mean	Max
t-score	15.3 (2.2)	38.3 (4.7)	7.8 (0.9)	11.2 (1.4)	9.7 (1.3)	23.4 (6.6)	8.8 (3.5)	18.6 (9.4)	5.0 (0.7)	7.3 (1.5)	5.4 (0.7)	13.2 (2.8)
% Signal Change	4.2 (0.4)	12.8 (2.2)	2.6 (0.5)	10.1 (2.5)	3.9 (0.7)	8.9 (1.6)	3.6 (0.3)	7.5 (3.0)	1.5 (0.3)	4.1 (1.5)	4.4 (0.7)	8.1 (2.0)
Extent [cc]		58 (20.4)		46.3 (21.7)		24 (8.5)		26.9 (10.8)		21.3 (9.2)		20.4 (9.7)

Discussion The high BOLD contrast in multi-slab EVI is in part due to the readout duration of 1.3 * T2* that provides close to maximum BOLD sensitivity as previously shown for multi-echo EPI (8) and enhanced BOLD contrast from tissue compartments with long T2* values, such as CSF filled spaces (9). The high temporal resolution of multi-slab EVI improves the Nyquist sampling of heart-beat related signal fluctuation and increases the statistical power by almost sqrt($TR_{EPI}/TR_{multi-slab-EVI}$), which more than compensates the moderate 51% reduction in temporal SNR compared to EPI. We are currently studying serial correlations in multi-slab EVI data in the context of univariate autoregressive (AR) models to determine the appropriate model order for GLM analysis.

Conclusion Multiple-slab EVI provides considerable improvement in temporal resolution and fMRI sensitivity compared to EPI. However, improvements in spatial resolution, quantification of contrast mechanisms and statistical modeling are required to make this new methodology a viable alternative to EPI.

References 1. Rabrait C, et al. J Magn Reson Imag. 2008 27(4):744. 2. van der Zwaag W, et al. Magn Reson Med. 2006 56(6):1320. 3. Witzel, T, et al. Proc ISMRM 2008; 1387 4. Posse, S., et al. Proc ISMRM 2011; 3583 5. Posse S., *Human Brain Mapp* 12:1 (2001) 25. 6. Gao and Posse, Neuroimage 19 (2), 838, 2003 7. Murphy K, et al.. Neuroimage. 2007 Jan 15;34(2):565-74... 8. Posse, S., et al, Magnetic. Resonance. Med., 42 (1): 87-97, 1999 9. Fera F, et al. J Magn Reson Imaging. 2004 Jan;19(1):19-26