Sensitivity and Specificity Enhancement in High-Speed FMRI using Multi-Echo Echo-Volumar Imaging

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Objective Several studies have demonstrated that multi-echo EPI (MEPI) is advantageous for increasing BOLD sensitivity compared to EPI, for reducing signal losses in areas with magnetic field inhomogeneity and for characterizing contrast mechanisms in fMRI (1-3). However, applications of MEPI have been limited by reduced volume coverage and/or elongated TR due to the long readout. Our recently developed multi-slab echo volumar imaging method (EVI) provides considerably improved temporal resolution and strongly increases BOLD sensitivity compared to EPI (4). Here we introduce high-speed multi-echo EVI with 241 ms temporal resolution and investigate the BOLD contrast characteristics of parametric EVI images during visual and motor tasks.

Methods The multi-echo EVI (MEVI) pulse sequence was implemented on a Siemens 3 T scanner equipped with a 12-channel head array coil. Two consecutive EVI readout modules were implemented to sample 2 echo times in a single shot. Partial brain data were acquired using: TR: 241 ms, TE_{eff}: 28 and 75 ms, α: 10°, 2 slabs in AC/PC orientation, slab thickness: 36 mm, inter-slab gap=10%, FOV: 256 mm, 4-fold GRAPPA acceleration in the readout direction, reconstructed image matrix per slab: 64x64x8, voxel dimensions: 4x4x6 mm^3. Real-time in-plane image reconstruction was performed on the scanner. Reconstruction in the third dimension, multi-echo preprocessing and fMRI analysis were performed on an external workstation 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. Data were acquired with 689 scan repetitions, corresponding to 3 min scan time. The following were generated from the MEVI data: first echo, second echo, T_2* using exponential fitting, initial signal intensity of the exponential fit (S_0), weighted echo average using voxel-wise weights based on the intrinsic T_2* value. MEVI images were spatially normalized into MNI space based on a coregistered EPI scan and segmented into 144 functional brain regions using the Talairach Daemon database (6). Cumulative General-Linear-Model (GLM) analysis was performed to detect task activation. The percent signal change, t-score, and extent of activation were measured in visual cortex (BA17-19) (t>5.0) and in extended motor cortex (BA1-6) (t>3.0). Temporal SNR (7) was computed in left Brodmann Area 10 for non-activated voxels (t<1.0).

Results Average T_2* values in cortical areas ranged from 30 ms in motor cortex, 41 ms in visual cortex, 43 ms in auditory cortex and 52 ms in anterior cingulate cortex to 60 ms in medial frontal cortex, consistent with T_2* values measured using MEPI. In CSF a T_2* value of 300 ms was measured. First and second echo images, and weighted echo average maps showed strong BOLD activation in visual and motor cortex and supplementary motor area with 3.5 to 4.2% average signal change and high t-scores consistent with EVI (4) (**Fig.1**). Strong activation was also present in the T_2* maps, albeit with lower t-scores due to the noise sensitivity of the exponential fit. The S_0 maps showed much smaller activation, consistent with localized in-flow effects in larger blood vessels.

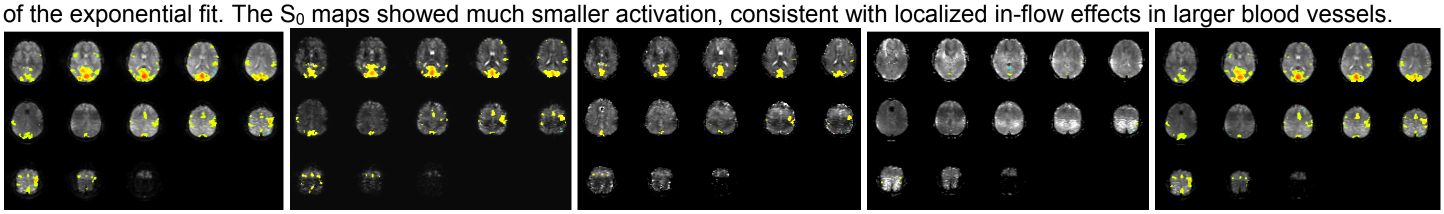

Figure 1: Partial brain MEVI with overlaid activation map showing activation in visual cortex (BA17-19) and motor activation (M1-4 and SMA). (a) first echo (b) second echo, (c) T_2*, (d) S_0, (e) weighted echo average.

a

Type	VISUAL			MOTOR		
	Extent [voxels]	t-scores Mean	t-scores Max	Extent [voxels]	t-scores Mean	t-scores Max
TE1	612	13.1	51.2	285	7.9	24.8
TE2	597	14.9	52.5	96	7.3	19.1
T_2*	273	9.229	21.9	94	5.4	12.3
S_0	25	7.4	13.0	25	5.2	10.6
WgtAvg	548	12.8	46.9	258	7.4	20.0

b

Type	VISUAL % Signal Change		MOTOR % Signal Change	
	Mean	Max	Mean	Max
TE1	0.037	0.135	0.036	0.060
TE2	0.042	0.172	0.041	0.071
T_2*	0.082	0.208	*	*
S_0	0.064	0.107	*	*
WgtAvg	0.038	0.132	0.035	0.060

c

Type	tSNR Mean	tSNR SD
TE1	76.3	17.5
TE2	34.0	6.0
T_2*	25.9	6.1
S_0	35.9	14.8
WgtAvg	69.2	20.9

Table 1: (a) Spatial extents and t-scores in BA17-19 and BA1-6, (b) Percent signal change in BA17-19 and BA1-6, (c) Temporal signal to noise ratio in BA 10. * = unreliable fit results in isolated voxels.

Discussion Dual-echo EVI shows fMRI contrast characteristics that are consistent with previous studies using multi-echo EPI while providing almost an order of magnitude faster temporal resolution and much higher t-scores than multi-echo EPI. Strong BOLD contrast was measured at long TE, consistent with the BOLD contrast model, and minor in-flow effects were observed in S_0 maps in the vicinity of large blood vessels. The recently introduced combination of parallel imaging with compressed sensing, which exploits the sparsity of the signal decay in the echo time domain (8), has the potential to shorten inter-echo spacing and to increase spatial resolution, thus improving T_2* fitting and enabling characterization of non-exponential signal decay.

Conclusion Multi-echo multi-slab EVI enables rapid mapping of T_2* in human brain and sensitive detection of brain activation and in-flow effects in different tissue compartments.

References 1. Posse, S., et al, Magnetic. Resonance. Med., 42 (1): 87-97, 1999 2. Poser BA, et al. Magn Reson Med. 2006 Jun;55(6):1227-35. 3. Glover GH and Law CS. Magn Reson Med. 2001 Sep;46(3):515-22. 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. Fera F, et al. J Magn Reson Imaging. 2004 Jan;19(1):19-26