Comparison of the location and extent of BOLD activation in high spatial resolution SE and GE fMRI of the Motor Cortex at 7T

J. Harmer[1], R. M. Sanchez-Panchuelo[1], R. W. Bowtell[1], and S. T. Francis[1]
[1]Sir Peter Mansfield Magnetic Resonance Centre, The University of Nottingham, Nottingham, Nottinghamshire, United Kingdom

Introduction: fMRI studies generally employ gradient-echo (GE) BOLD contrast due to the limited signal change and signal-to-noise ratio (SNR) of spin echo (SE) BOLD contrast at standard field strength. Ultra-high field (7T) provides increased BOLD contrast-to-noise ratio (CNR) and decreases the contribution that large vessels make to GE BOLD contrast, due to higher capillary contribution and the suppression of intravascular BOLD signal as a result of shortened blood T_2 [1]. However, the extravascular venous signal will still contribute to GE BOLD maps at 7T. In SE BOLD contrast, extravascular static dephasing effects around large vessels are refocused causing the SE signal to arise mainly due to microvascular effects [2, 3]. A limited number of studies have compared GE and SE BOLD contrast, and these have generally been restricted to the visual cortex (due to its large response) with data being acquired at relatively coarse spatial resolution [4]. Here, the increased BOLD CNR at 7T is exploited to assess GE- and SE-BOLD responses to a simple motor task at high (1.5 mm isotropic) spatial resolution. We investigate CNR, fractional signal change as a function of echo time, spatial specificity of SE BOLD and the localisation of GE and SE activation in relation to underlying venous blood vessels.

Methods: Six subjects participated in the study. Scanning was performed on a 7T Philips Achieva System with a 16-channel array coil. *Protocol:* 1.5 mm isotropic resolution, axial, multi-slice, single shot spin echo EPI data were acquired using SENSE 2 with a field of view (FOV) of 192 x 72 mm^2 (AP x RL) and image based shimming. Volumes comprising 16 contiguous axial slices spanning the right primary motor cortex were acquired in a TR of 2.4 s. An outer-volume suppression slab was used to prevent signal fold-over in the phase encode (RL) direction and Slice Selective Gradient Reversal (SSGR) [5] used to suppress the fat signal. In addition, a high-resolution, T_2^*-weighted image (0.25x0.25x1.5 mm^3) was acquired to identify large veins. *Paradigm*: A block motor paradigm was performed. This consisted of a 16.8 s rest period followed by 14.4 s of finger tapping with the left hand, repeated for 6 cycles. The motor task was repeated for SE echo times of 30, 35, 40, 45, 50 and 55 ms, and for a single GE-BOLD scan at TE 25 ms. Following functional scans, GE- and SE-EPI measurements were acquired at a range of echo times to form T_2 and T_2* maps. *Analysis*: Data were realigned using AFNI (http://afni.nimh.nih.gov/afni) and analyzed using a general linear model in FEAT (FSL, Oxford, UK). Z-statistic maps were obtained for each echo time. An average Z-map based on SE data from all TE's was formed. Threshold-free cluster enhancement (TFCE) [6] was then applied to the Z-score statistical maps. TFCE maps were threshold at the 95th percentile to form a SE-ROI and a GE-ROI. The cluster size and T_2 distribution were determined for each ROI, and the CNR, number of active voxels, and the fractional signal change ($\Delta S/S$) at each echo time also measured. ΔR_2 was estimated assuming a linear relation between ($\Delta S/S$) and TE. Venous vessel masks were generated for four subjects by thresholding the phase data from the high resolution T_2^*-weighted image. Masks were registered to the functional data and used to determine the fraction of active voxels common to veins.

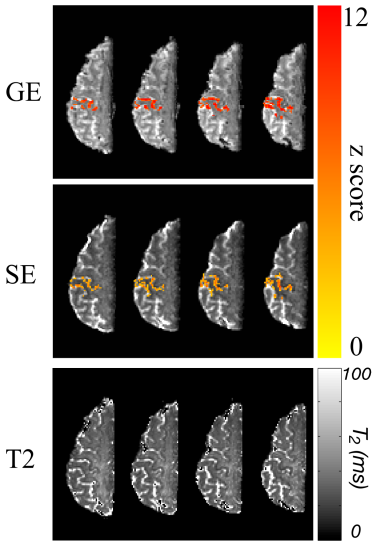

Figure 1: *Top: GE-ROI overlaid on GE EPI image, Middle: SE-ROI overlaid on SE EPI image (TE=45ms). SE-ROI contains 777 voxels and GE-ROI 843 voxels, with 365 common. Bottom: T_2 map illustrating low T_2 band along the motor cortex.*

Results: Significant activation was found for all subjects across all echo times. Figure 1 shows the average SE-ROI and GE-ROI for a representative subject. The T_2 map shows a clear band of low T_2 values (~ 25 ms) along the motor cortex. The number of active voxels for this subject was largest for TE = 30 ms. Figure 2 shows the percentage signal change in the SE-ROI (mean across cycles) for SE data at each echo time and for the GE data. Figure 3 shows the SE percentage signal change as a function of TE for both the SE-ROI (blue) and GE-ROI (red). Assuming a linear relation, the mean ΔR_2 for the SE-ROI was $-1.59 \pm 0.05\ s^{-1}$ and $-0.74 \pm 0.06\ s^{-1}$ for the GE-ROI. The CNR for GE data was 20.1±2.4 (mean ± stderr) compared to 7.8±1.9 for SE (TE=45ms) in the SE-ROI. Figure 4 shows an example of the phase data used to create the venous masks. Results in Table 1 show that 22% more voxels overlap the venous mask for the GE versus SE ROI when the whole ROI is considered, and 52% more when analysing the voxels which did not overlap in SE and GE ROIs.

	Whole ROI		Non-overlapping ROI	
	SE	**GE**	**SE**	**GE**
Subject 1	0.22	0.36	0.14	0.24
Subject 2	0.23	0.25	0.22	0.25
Subject 3	0.32	0.39	0.16	0.36
Subject 4	0.18	0.24	0.25	0.75
mean	**0.24**	**0.31**	**0.19**	**0.40**
std err	0.03	0.04	0.03	0.14
Diff (%)	**22 ± 1**		**51 ± 7**	

Table 1: *Fraction of voxels common to the venous mask in the SE/GE ROIs, and fraction in the region of the SE/GE ROIs that were non-overlapping. The percentage increase in voxels for GE data is provided.*

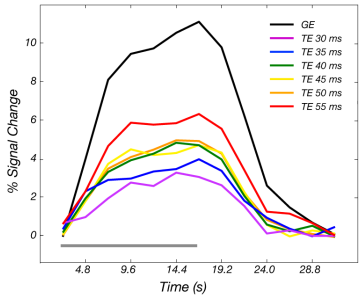

Figure 2: *Percentage signal change averaged, across cycles, for SE and GE data. The ON period is represented by the grey bar.*

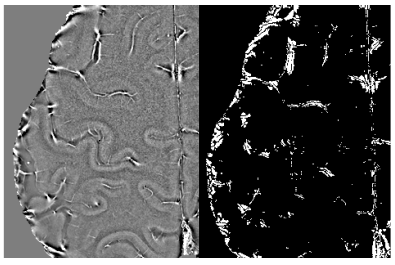

Figure 4: *Left: High resolution phase map from a high resolution T_2^*-weighted image. Right: Venous mask created by inverting the phase and thresholding the data. Clustering was used to reduce the effects of noise*

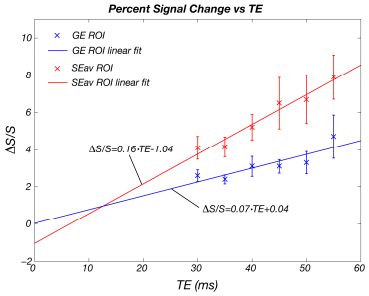

Figure 3: *Fractional signal change versus echo time (TE) for SE ROI (blue) and GE ROI (red) (n =4). Data fit to a linear regression. Error bars show standard deviation across subjects*

Discussion: The mode and median of the T_2 distribution (averaged across subjects) in the SE-ROI were 34 ± 5 ms and 43 ± 7 ms. The low T_2 values reflect the dark band seen in the motor strip on the T_2 map, and agrees with low signal in this area reported by others [7]. ΔR_2 changes were similar to previous studies for the GE-ROI [8], but greater for the SE-ROI. This difference is likely due to reduced partial volume effects at high resolution and is also influenced by the size of the ROI. A higher proportion of GE activation was found to occur in voxels classified to have a high venous contribution than for SE. Robust BOLD responses can be detected with SE fMRI at high resolution at 7T.

References: [1] Thulborn et al., Biochem. Biophys. Acat. 714, 1982. [2] Boxerman et al., MRM., 34, 1995. [3] Yacoub et al., MRM, 49, 2003. [4] Duong et al., MRM., 49, 2003. [5] Park et al., MRM, 4, 2005 [6] Smith et al., Neuroimage, 44, 2009. [7] Haacke, MRI, 23, 2005. [8] Schafer et al., Magn. Reson. Mater. Phy., 21, 2008.