Echo-Shifted Multi-Slice EPI compared with GE-EPI in Median Nerve Stimulation at 7T

G. B. Grimnisdottir[1], N. Petridou[1,2], and R. Bowtell[1]
[1]Sir Peter Mansfield MR Centre, Physics and Astronomy, The University of Nottingham, Nottingham, Nottinghamshire, United Kingdom, [2]UMC, Utrecht, Netherlands

Introduction Faster sampling is one way to obtain more sensitive fMRI measurements and better characterisation of the timing of responses in event-related experiments. PRESTO [1] uses echo shifting to facilitate the rapid acquisition of T2*-weighted images with echo times that are optimal for BOLD contrast. The combination of PRESTO with parallel imaging [2] makes ultrafast 3D T2*-weighted imaging of large volumes a possibility, as well as enabling increased resolution with faster scanning over smaller volumes [3]. Echo-Shifted Multi-Slice (ES-MS) EPI [4] offers similar rates of volume acquisition, but does not require maintenance of transverse coherences over many excitations. Here, the performance of ES-MS-EPI and conventional GE-EPI is compared in fMRI during median nerve stimulation at 7T.

Methods Five, right-handed volunteers were studied. A pair of electrodes was positioned on the proximal-distal axis of the lower medial forearm, and a constant current stimulator (Digitimeter) was used to stimulate the median nerve so as to elicit involuntary flexion of a single finger. In subjects 1 and 4 this produced movement, of the index finger, in 2 and 3, the middle finger, and in 5, the thumb. Stimulation was applied at 1.87Hz (in 250ms bursts) during a 5s on-period, followed by 20s of rest over 12 cycles. Ten contiguous, ascending axial slices were acquired at 2mm isotropic resolution with SENSE factor 3 using a 16 channel receiver coil on a Philips Achieva 7T system. Two scans with different parameters were acquired for each sequence. ES-MS-EPI: TR=330/526ms, effective TE=43/63ms, 1024/620 volumes. GE-EPI: TR=2000/526; 170/620 volumes, TE=27ms. At this resolution and number of slices, the minimum TR obtainable with GE-EPI was 526 ms. The Ernst angle was used, assuming T1=1800ms for grey matter at 7T. Additional one-minute scans were acquired at rest, to evaluate the temporal SNR (tSNR). ES-MS-EPI images were reordered in FSL [5], and functional data processed in AFNI [6]. RETROICOR [7] was used to reduce the effect of cardiac and respiratory fluctuations. 4th order Legendre polynomial detrending was used to filter out low frequency signal variation.

Results Figure 1 shows thresholded T-statistic maps (A: GE-EPI, B: MS-ES-EPI) of the BOLD response to median nerve stimulation for one subject, $p \leq 3.6 \cdot 10^{-6}$, Bonferroni corrected, cluster size thresholded at 20 voxels. The largest and most significant area of activation, was in the left central sulcus, spanning the motor and somatosensory regions, as would be expected for stimulation of the right hand. Similar results were obtained for all subjects. Activation was also observed near the supplementary motor area in some scans (Figure 1). The number of active voxels in the thresholded T-maps ranged from 49 to 177 for the GE-EPI, and 722 to 1163 for the ES-MS-EPI across subjects. Figure 2 depicts the BOLD time courses for a single voxel selected in the same location for both sequences. Approximate fMRI signal change in these two time-courses is 7% in GE-EPI and 12% in ES-MS-EPI. Representative tSNR maps can be seen in Figure 3. Table 1 summarises the mean tSNR values for all subjects, along with average values scaled with sqrt(TR) to account for the sampling rate, and by the reciprocal of the transverse signal decay, assuming T2*=27ms.

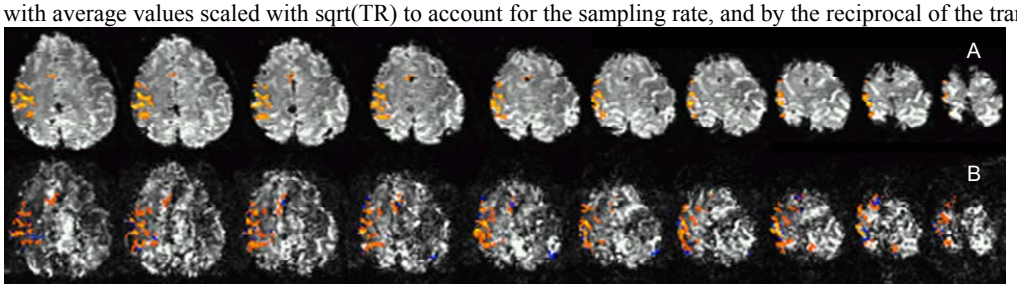

Figure 1: *Thresholded T-maps for subject 1, index finger. A: GE-EPI TR=2000ms. B: ES-MS-EPI TR=330ms.*

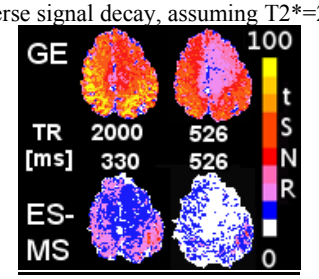

Figure 3: *tSNR maps, slice 3.*

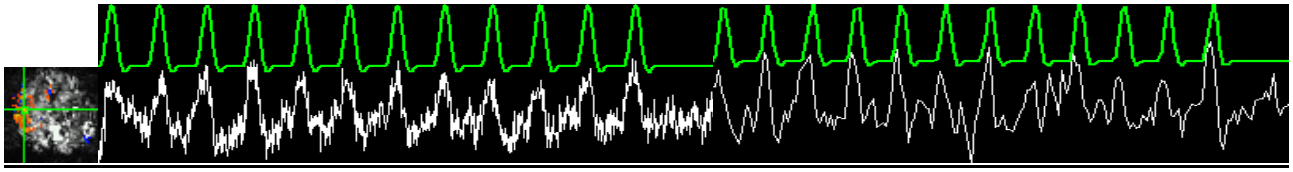

Figure 2: *Single voxel time courses (white) compared with an ideal response (green) for ES-MS, TR=330ms, and GE-EPI TR=2000ms.*

Table 1*: Mean whole brain tSNR values, and their scaled counterparts*	**TR [ms]**	**TE [ms]**	**Mean, whole brain tSNR 1 2 3 4 5**	**Average all =A**	**A/sqrt(TR) =B**	**B·exp(TE/27) =C**
GE-EPI	2000	27	55 48 49 48 47	49±3	35±5	95±25
ES-MS-EPI	330	43	17 14 18 18 16	17±6	29±4	142±11
GE-EPI	526	27	39 35 na 38 35	37±2	51±3	138±8
ES-MS-EPI	526	63	9 10 na 11 10	10±1	14±1	142±10

Conclusions In fMRI experiments of fixed duration employing median nerve stimulation, the number of active voxels was found to be greater in short TR ES-MS-EPI data, compared with data acquired using standard GE EPI with a long (2s) TR. The time-course of the ES-MS-EPI data shows finer sampling of the hemodynamic response than in the standard GE-EPI data and could be used to capture transient features of the fMRI signal.
The nearly two-fold increase in percentage signal change is due to the longer TE, which is a feature of the echo shifting. Poorer tSNR in ES-MS-EPI is made up for by the increased number of samples, and the tSNR values are similar for all the short TR scans, when both temporal efficiency (B in Table 1) and the different TE (C) are taken into account. ES-MS-EPI enables fMRI measurements with better coverage than GE-EPI of the same TR can offer, and can also provide higher temporal resolution and increased sensitivity.

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