A low-power multi-slice sequence using stimulated echoes for T_2-sensitized fMRI at high magnetic fields

U. Goerke[1], P-F. van de Moortele[1], M. Steen[1], K. Ugurbil[1]
[1]CMRR/University of Minnesota, Minneapolis, Minnesota, United States

Introduction:

It has previously been shown that, at high fields, the signal changes of spin-echoes (SE) related to the BOLD effect are more specific to capillaries and, therefore, more confined to the site of neuronal activity than the ones observed with gradient-echo (GE) EPI [1]. However, the SAR limit is quickly reached using multi-slice SE-EPI with a short repetition time at high field strength since the power deposition increases with the square of the pulse amplitude. In order to avoid pulses with large flip angles, a multi-slice T_2-sensitized stimulated echo (STE) sequence is suggested. In the presented fMRI study, the contrast-to-noise is compared for SE-EPI and STE-EPI at the same level of power deposition.

Methods:

One female and two male volunteers participated in the study. The paradigm consisted of two blocks presenting a red flashing checker board for 30 s followed by a resting period of 39 s. Breaks of at least one minute were made between the functional experiments. The experiments were performed on a Varian 7T scanner. A 15 channel open-face multi-line radio-frequency coil with multi-channel acquisition was used [2]. Anatomical images were acquired using an inversion-recovery Turbo-Flash sequence. The final image is reconstructed from a "square-root of the sum of squares" of the images of the individual channels. The slices were oriented along the calcarine fissure. For fMRI, a SE- ($[\alpha - T_E/2 - 2\alpha - T_E/2 - \mathrm{SE}]_{slices}$) and a STE ($\alpha - T_E/2 - \alpha - T_{M0} - [\alpha - T_E/2 - \mathrm{STE}]_{slices}$) (Figure 1) sequence, where $\alpha = 45°$ in the center of the brain and $[\ldots]_{slices}$ indicates the slice loop, were employed. All radio frequency (RF)-pulses excite 3 mm slices except for the first and second RF-pulse which select a slab of 1.9 cm in the STE sequence. The echoes were acquired using an EPI-readout (FOV: 19.6 cm, acquisition matrix: 64 x 64, six slices, interslice distance: 3 mm, T_E = 60 ms, for STE: T_{M0} = 20 ms, ΔT_M = 65 ms). The repetition time for SE, T_R^{SE}, was 6s. To achieve the same power deposition in the SE and STE study ($P_{SE} = P_{STE}$), a repetition time of T_R^{STE} = 6 s for the STE experiment was employed according to $6(\alpha^2+(2\alpha)^2)/T_R^{SE} = (\alpha^2+\alpha^2+6\alpha^2)/T_R^{STE}$ for 6 slices. 16 repetitions of the functional experiments were performed alternating between the two sequence types. In order to avoid Nyquist ghosts, even and odd echoes of the EPI echo train were reconstructed separately using SENSE with a reduction factor of two utilizing the anatomical image for sensitivity calibration [3]. After unaliasing, the data sets of each sequence type were combined for even and odd echoes separately. Maps of signal changes which significantly correlate with the stimulus were calculated. Regions-of-interest (ROIs) in primary visual cortex were defined in each subject. The trial averages of signal changes in the ROIs were computed.

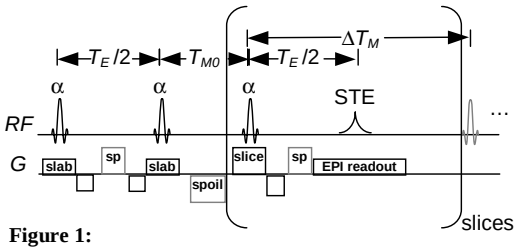

Figure 1:
Multi-slice stimulated echo sequence. In the preparation period magnetization within the slab, which covers the volume-of-interest, is rotated in the –z direction. The slices are then read out by a series of 'third' RF pulses as indicated by $(\ldots)_{slices}$. The gray boxes mark gradient pulses to spoil gradient echoes and transverse magnetization created in the mixing period.

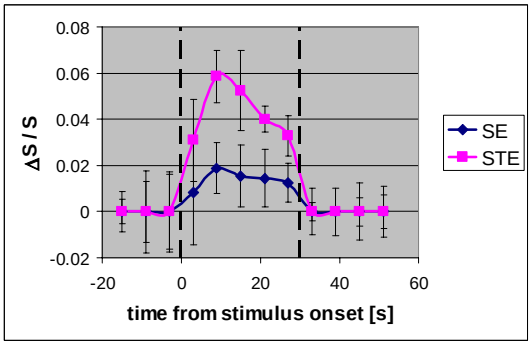

Figure 2:
Trial averages of a ROI in the primary visual cortex. Data points are binned with a resolution of 6s. The error bars represent the standard deviation of the group average of three subjects. The dashed lines mark beginning and end of the stimulation period.

Results:

For the same power deposition almost four times more time steps than the SE sequence can be acquired using STE. Percent signal changes were ~three fold higher in the STE sequence due to the additional sensitivity introduced by diffusion in the presence of gradients near microvasculature. Despite lower signal-to-noise in STE images, the contrast-to-noise was comparable or better than in SE images.

Discussion:

The main advantages of the suggested STE sequences are low power deposition and relative functional signal changes which are larger than in SE fMRI experiments. The SAR limit severely constrains the number of slices and the repetition time in SE EPI experiments at high magnetic fields. SE-EPI has therefore mainly been used to investigate various contributions to functional signal changes. Using the suggested STE sequence, rapid sampling in combination with whole brain coverage is a feasible experiment at high fields. A much broader range of applications can take advantage of the specificity of T_2-sensitized fMRI and the high sensitivity at high magnetic fields.

References:

[1] Duong TQ, Yacoub E, Adriany G, Hu XP, Ugurbil K, Kim SG, MRM 49 (6): 1019 (2003); Harel N, Lin J, Zhang L, Ugurbil K, Yacoub E, ISMRM Kyoto (Japan) 2004
[2] Adriany G, van de Moortele PF, Andersen PM, Strupp JP, Ritter JB, Snyder JP, Moeller S, Vaughan JT, Ugurbil K, ISMRM Kyoto (Japan) 2004
[3] Pruessmann KP, Weiger M, Scheidegger MB, Boesiger P, MRM 42 (5): 952 (1999)

Acknowledgments:

Financial support by the MIND Institute, the KECK Foundation, and the grants NIH RR008079 and NIH ROI-EB000985 is acknowledged.