Shifting echoes without tremendous signal loss: T2*-weighted, double echo-shifted gradient echo imaging

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Introduction: Recently it was shown that a combination of PRESTO, parallel imaging and partial-Fourier acquisition leads to susceptibility-weighted sequence that offers whole brain coverage with a volume repetition time of 0.5 seconds [1]. In the partial-Fourier PRESTO-SENSE sequence, additional gradients shift the echo signal over one TR period resulting in an effective echo time of 44ms. However, at 1.5 T longer echo times are desirable in fMRI applications to optimize BOLD contrast. The purpose of this work was to evaluate the signal behavior of a two-fold echo-shifted gradient echo sequence. The steady state magnetization with and without the application of rf-spoiling was simulated using the phase-graph formalism [2,3] and compared with phantom experiments. An initial functional motor experiment demonstrated obtained susceptibility weighting.

Methods: Resulting magnitude transverse magnetization of different dephasing states was simulated for optimal flip angle with and without rf-spoiling. For this, TR=15ms, T1=220ms and T2=150ms was assumed and the magnetization was calculated in the steady-state after 200 rf excitations. For rf-spoiling a quadratic phase increment of 50° was used. The flip-angle dependency of the transverse magnetization was verified in MR phantom experiments for a 3D one- (TE=22ms) and a two-fold (TE=37ms) echo shifted gradient echo sequence. Experiments were performed on a Siemens Sonata 1.5 Tesla system using a standard headcoil. The functional experiment consisted of a bilateral finger tapping block paradigm with 4 rest and 3 stimulation periods, each of 75 seconds duration and covered by 3 volume acquisitions of the two-fold echo shifted sequence. During the volume repetition time of 25s, 32 3D partitions were acquired of which 6 were discarded to avoid aliasing due to non-rectangular excitation profiles. Activation maps were obtained by correlation analysis, voxels exhibiting a correlation coefficient cc > 0.5 ($p < 0.01$) were classified as activated.

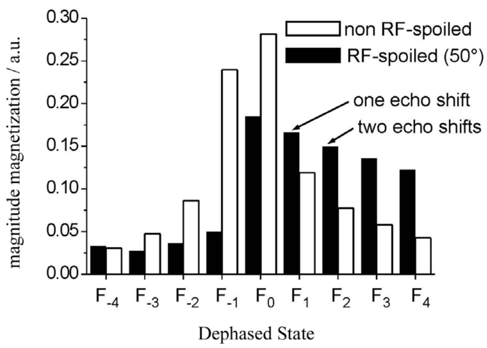

Fig. 1: Population of different dephased states for non rf-spoiled and rf-spoiled steady states.

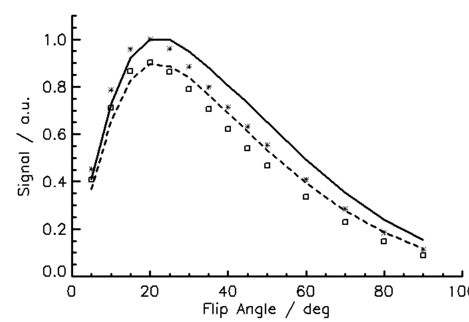

Fig. 2: Signal dependency of one-fold (experimental: solid line, calculated: asterisks) and two-fold (experimental: dashed line, calculated: squares) echo-shifted sequences on the excitation angle.

Results: Simulations using TR/T1/T2=15ms/220ms/150ms showed that for F1 (F2) state acquired in one-fold (two-fold) echo-shifted sequence, the resulting transverse magnetization in the steady-state is 29% (94%) higher for the rf-spoiled case than without rf-spoiling (Fig. 1). The theoretical and experimental signal dependency on the flip angle for rf-spoiled one-fold and two-fold echo-shifted sequences is shown in Fig. 2. Transverse magnetization is only about 10% lower for the two-fold shifted echo than for the single-shifted echo. Using relaxation parameters of gray matter and a TR of 15ms, maximum signal will be obtained for α=10°. In this case, the rf-spoiled signal of both F+1 and F+2 states is 50% higher than without the use of rf-spoiling. The optimal flip angle of 10° was used in the fMRI experiment that resulted in consistent activation in the left and right primary motor cortex as well as in supplementary motor areas. Average signal change for the 3 partitions shown in Fig. 3 was 3.1%. Fig. 4 shows the signal time-course averaged over the voxels marked as activated in Fig.3.

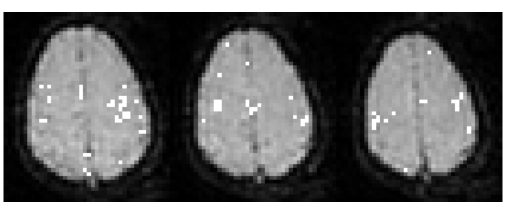

Fig. 3: Activated voxels in 3 partitions of the two-fold echo-shifted 3D gradient echo sequence.

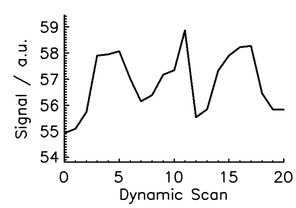

Fig. 4: Signal time-course averaged over the activated voxels shown in Fig. 3

Discussion: The presented simulations and measurements demonstrate that F1 and F2 (and F3) states used for 1-3-fold echo-shifted sequences have nearly same populations or signal amplitudes. As a result, going from single to double-shifted sequences increases T2* sensitivity without the penalty of a significantly decreased signal amplitude. Despite the mixture of different pathways that form the echo-shifted signal in the steady-state, T2*-weighting was sufficient to produce a robust BOLD signal. A two-fold echo-shifted PRESTO sequence with increased BOLD sensitivity and preserved volume repetition time is envisaged.

References:

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