Twofold Improvement in Single-Shot EPI Efficiency using Echo Shifting and Parallel Imaging

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INTRODUCTION

Echo planar imaging (EPI) is the workhorse of many advanced neuro-imaging applications such as fMRI and pMRI. Parallel imaging techniques are frequently applied to EPI in order to reduce the geometric image distortions. However, the efficiency of EPI is not dramatically improved by parallel imaging since the echo time has to be kept for the desired contrast (BOLD or contrast agent). Echo shifting can be used to shift the acquisition after the excitation of the next slice and thus increase the scan efficiency significantly [1].
The purpose of this study was to combine echo shifting along the slice dimension with parallel imaging for efficiency improvement. The possibilities of this speed advantage are used to increase temporal resolution, to reduce susceptibility related signal voids, or to increase volume coverage. The method has also been compared to EPI with and without acceleration using parallel imaging.

MATERIALS AND METHODS

All experiments were performed on a 3T system (Siemens Magnetom TIM Trio) using a 12 channel head array. The method was evaluated in three healthy subjects. The product EPI sequence was modified to include shift gradients (Fig. 1). These additional gradients shift the signal to after the excitation of the next slice, thereby allowing to realize a inter-slice TR shorter than TE. Water-only excitation was realized by a binomial 1-2-1 pulse allowing balanced gradient conditions. Reference data for parallel imaging reconstruction are acquired in the last dummy repetition. The base parameters were identical in all experiments (TE 38ms, FOV 192 mm, matrix 64*64, 2694 Hz/px). fMRI was performed during bilateral complex finger tapping (30s off, 30s on) for 3 minutes. The speed-up was either used for shorter TR or to acquire more and thinner slices. For reference, standard EPI was performed with and without acceleration (factor 2). The TR was chosen to be minimal for all variants and the flip angle was adjusted to the Ernst angle for gray matter (see Table).
All data sets were processed with SPM5 using a box-car GLM. The effect to (temporal) noise (CNR) of the different variants was assessed as the effect strength beta divided by the residual error epsilon.

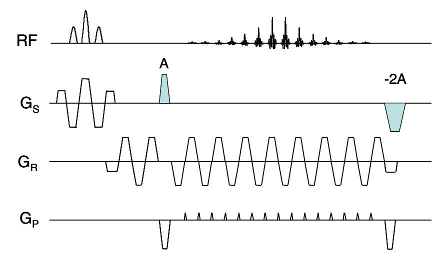

Fig. 1: Echo-shifted EPI sequence. The colored gradients shift the signal to after the next slice excitation resulting in TE longer than TR.

RESULTS

The echo shifted sequence allowed to acquire 40 slices per second without loss in image quality. All variants of the echo-shifted as well as the standard sequence showed strong bilateral activation of the motor cortex and midline activation of the SMA in all subjects. The quantitative analysis reveals that the CNR is only mildly reduced despite the speed increase of a factor of two. Signal voids can be reduced by the use of thin slices (Fig.3).

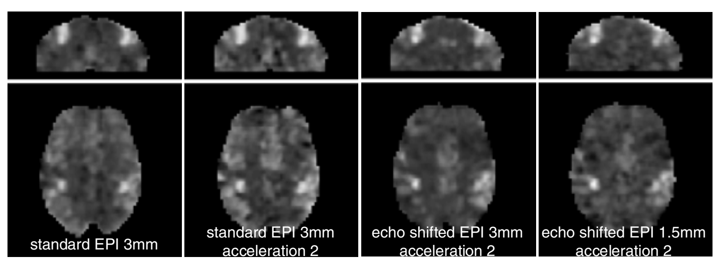

Fig. 2: CNR maps (effect beta divided by residual noise epsilon) of the activation effect during finger tapping for the different versions of standard and echo-shifted EPI.

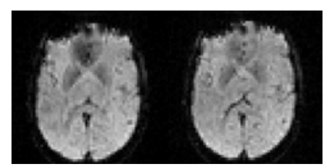

Fig. 3: Standard EPI (left) and echo-shifted EPI (right) with half the slice thickness but identical coverage and TR. The signal loss is significantly reduced.

	EPI	EPI p=2	ES-EPI p=2	ES-EPI p=2
thickness	3mm	3mm	3mm	1.5mm
slices	25	25	25	49
TR/ms	1400	1200	629	1240
flip	83°	80°	66°	80°
CNR	28.7	15.1	23.3	12.4

DISCUSSION

In contrast to PRESTO [2] shifting echoes into the next slice does not compromise signal intensity since the RF pulse does not act on the same magnetization but a different slice. Thus no additional coherences are generated and the efficiency of EPI can be increased dramatically up to 40 slices per second for the hardware used and the moderate acceleration factor of 2. The sensitivity for detection of activation is only mildly reduced for the high temporal resolution scan. If the increased efficiency is used to reduce the slice thickness, increased signal is observed in the inferior frontal brain improving the sensitivity in inhomogeneous regions (Fig. 2). In this case the CNR relative to the echo-shifted version is reduced due to the reduced voxel size. However, it is still similar to the standard EPI method with equal acceleration.
In conclusion, the combination of echo-shifted single-shot EPI with parallel imaging increases the efficiency by a factor of two compared to standard EPI. This can be exploited to increase the temporal resolution without loss of sensitivity or to reduce the signal void without loss of speed.

REFERENCES

[1] Gibson A, et al. MRI 24: 433 (2006)
[2] Liu G, et al. MRM 30: 764 (1993)