A Modified EPI Sequence for High-Resolution Imaging at Ultra-Short Echo Times

S. Hetzer[1], T. Mildner[1], and H. E. Möller[1]
[1]Max Planck Institute for Human Cognitive and Brain Sciences, Leipzig, Germany

Introduction

Single-shot EPI provides excellent temporal resolution but often produces images with low spatial resolution and pronounced artifacts. Such issues can be addressed by multishot EPI, however, at the expense of increased scan time. Mosaic (1) and partial-Fourier (2) EPI techniques may further suffer from echo-shifting induced by susceptibility gradients in the phase-encoding direction which leads to a loss of significant signal contributions in the *k*-space window (3). This can be avoided by reversing the sign of the phase-encoding gradient to obtain center-out sampling trajectories, which also achieves a very short echo time (*TE*) (4). The current work proposes a further improvement of this strategy by omitting navigator lines. In particular, the central *k*-space line is sampled twice in two tiles along the phase-encoding direction. This data is exploited for inter-segment correction of phase and intensity, averaged, and used for image reconstruction. The minimum *TE* is thus drastically reduced with a concomitant gain in SNR.

Methods

Figure 1 shows the basic sequence scheme and the corresponding *k*-space trajectories. The first tile of *k*-space is sampled with positive phase blips following a 45° excitation pulse. After appropriate spoiling gradients and a 90° slice excitation, negative phase blips are employed to sample the second tile (5). Reduction of Nyquist ghosting artifacts was based on a separate reference scan without phase blips and correction of the phase differences between odd and even echoes in each tile pair-by-pair. The central lines of both tiles were used for inter-segment phase- and intensity correction, and the average of the two corrected lines was used as the central line of the final full *k*-space data. Because both tiles were acquired with opposite signs of the phase blips, field inhomogeneities produce simultaneous shifts in two opposite directions along the phase-encoding axis. Correction of this artifact was performed in the Fourier domain (6) using a separately measured multi-echo field map which was acquired with the same gradient strengths and bandwidths as employed for the EPI scan.

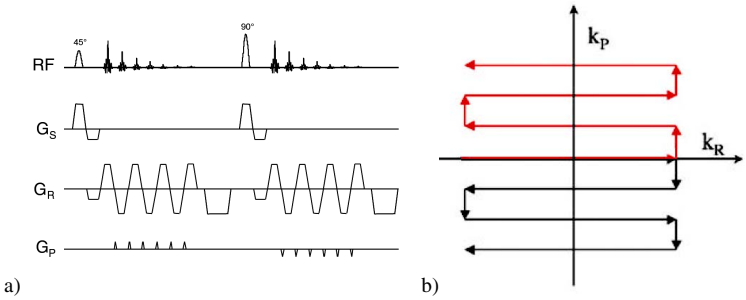

Fig. 1. *Modified EPI sequence* ***(a)*** *and corresponding k-space trajectory* ***(b)****.*

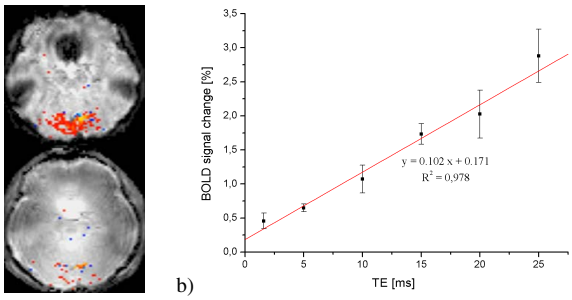

Fig. 2. *Echo-time dependence of the BOLD signal change.*

All experiments were performed on a 3-T whole-body scanner (Bruker Medical, Ettlingen, Germany) with a maximal gradient amplitude of 45mT/m and a maximal slew rate of 150T/m/s. Four healthy volunteers were examined. Patterns of randomly rotating L-shaped objects were presented as visual stimulus for a period of 10s followed by a resting period of the same duration. In each session, 6 functional scans of 100 repetitions (*TR*=2s, acquisition bandwidth 100 kHz) and *TE* = 25, 20, 15, 10, 5, and 1.5 ms were recorded using the modified EPI sequence shown in Fig. 1a. An additional standard single-shot EPI scan (*TE*=25ms) was recorded for comparison. 18 slices (thickness 5mm, inter-slice distance 5.5mm) were acquired with an image matrix of 66×76 and a FOV of 16.5×19.2cm^2 corresponding to an in-plane resolution of 2.5×2.5mm². Signal changes were computed for each *TE* by averaging voxels that reached statistical significance ($P < 0.001$) in the experiment with the longest *TE*. In a second set of experiments, high-resolution images (1×1mm² resolution) were recorded using a FOV of 19.2×19.2cm^2, an image matrix of 192×192, and a bandwidth of 200kHz. Results were compared to standard FLASH images.

Results & Discussion

The modified EPI sequence permitted center-out acquisition of both tiles with a minimum delay (≈3 ms), thus allowing fMRI with the same temporal efficiency and sensitivity as conventional single-shot techniques. At *TE*=25 ms, the modified EPI sequence yielded similar sensitivity, stability, and localization of activation as the conventional single-shot EPI sequence. Fig. 2 shows (a) activation maps at *TE*=25ms (top) and 1.5ms (bottom) overlaid onto the corresponding center-out EPI images and (b) the *TE* dependence of the BOLD signal change averaged over 4 subjects. The BOLD signal dropped from about 3% at *TE*=25 ms to <0.5% at *TE*=1.5 ms. The remaining BOLD signal is probably caused by intravascular contributions observable due to the very low flow-weighting of the sequence. Decreasing TE from 25 to 1.5 ms resulted in a 40% improvement of temporal signal stability (measured in a white-matter ROI) due to the suppression of physiological noise.

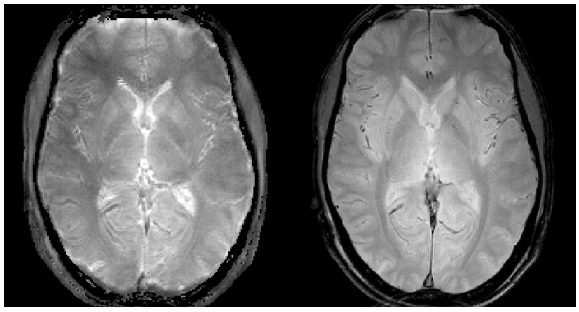

Fig. 3.
left: high-resolution EPI image (TE=1.6ms, resol. 1×1mm²)
right: FLASH image (TE=6ms, resol. 0.75×0.75mm²)

Figure 3 shows a high-resolution image acquired with the modified EPI sequence in comparison to a standard gradient-echo (FLASH) image. An excellent correspondence between both images is obtained even for small anatomical structures, which reflects a point-spread function in phase-encoding direction well-suited for high-resolution imaging experiments (2). The ultra-short *TE* markedly reduces signal dropouts (Fig. 2a) in regions that are prone to artifacts due to susceptibility gradients. A broad range of contrasts is easily obtainable by combining a suitable preparation scheme with the modified EPI readout. Non-BOLD imaging applications such as perfusion or diffusion MRI would benefit by the associated superior signal stability and BOLD suppression capability.

References

1. Rzedzian, *U.S. patent* no. 4,767,991 (1988)
2. Hyde et al., *MRM* 46:114-125 (2001)
3. Chen et al., *MRM* 59:916-924 (2008)
4. Kim et al., *MRM* 35:895-902 (1996)
5. Mansfield, *MRM* 1:370-386 (1984)
6. Noll et al., *IEEE TMI* 10:629-637 (1991)