Reduced image distortions in fMRI using accelerated EPIK sequence at 3T

Seong Dae Yun[1], Martina Reske[1], Kaveh Vahedipour[1], Tracy Warbrick[1], and N. Jon Shah[1,2]

[1]*Institute of Neuroscience and Medicine - 4, Forschungszentrum Jülich, Jülich, Germany,* [2]*JARA - Faculty of Medicine, RWTH Aachen University, Aachen, Germany*

Introduction

EPI is in widespread use in MR studies acquiring time series data due to its capability of achieving a relatively high temporal resolution. However, the fact that EPI acquires echoes with evolving time delays makes it prone to inhomogeneities of the main magnetic field resulting in potentially severe image distortions. An approach to overcome this problem, EPIK (EPI with Keyhole), was proposed by Shah et al. [1,2] and validated by Zaitsev et al. at 1.5T [3,4]. Essentially, a keyhole is updated faster than the periphery of k-space in an approach merged with multi-shot EPI; importantly, use of a sliding window ensures that only the last few shots contribute to any given image. A higher temporal resolution and robustness against field inhomogeneities is thus achieved when compared to interleaved EPI and single-shot EPI, respectively. The present work demonstrates i) that the performance of EPIK can be further improved by combining it with the parallel MRI method GRAPPA [5] and ii) verifies its use in human functional MRI (fMRI) studies. For this work, EPIK accelerated with GRAPPA (EPIK-G) was tested at 3T and validated with visual fMRI measurements as well as MRI simulation results using JEMRIS [6].

Methods

Figure 1a shows the schematic representation of the k-space trajectory for a three-shot EPIK sequence. Each measurement scans the central k-space region (keyhole region: R_k) completely with Δk_y = 1/FOV, whilst the peripheral k-space regions (sparse region: R_s) are sparsely sampled with $\Delta k_y' = 3/FOV$ (SPARSE factor of 3) resembling a multi-shot EPI scheme. By sharing the sparse region data from three consecutive scans with the keyhole region updated for every measurement, one obtains an image per TR excluding 2 initial dummy runs. Furthermore, this example features one-fourth of k-space as the keyhole region. The k-space trajectory of EPIK-G is shown in Fig. 1b, where the sampling distance of the phase encoding lines is increased twofold according to a parallel MRI acceleration factor of 2. Thus, the total number of phase encoding lines to be sampled reduces to 1/4 of that for a comparable EPI sequence. The EPIK-G reconstructed images can be obtained by subsequently applying the GRAPPA reconstruction to the EPIK reconstructed k-spaces. To ensure that the phase error increases smoothly when sharing the sparse region data, correct echo time shifting (ETS) [7] was integrated in the sequence. The configuration of the SPARSE factor or the size of keyhole region may be changed depending on the purpose of the particular study. For this work, the above configuration was used in a Magnetom Tim Trio 3T MRI scanner (Siemens Medical Solutions, Erlangen, Germany) with the manufacturer's 12 channel-phased array coil.

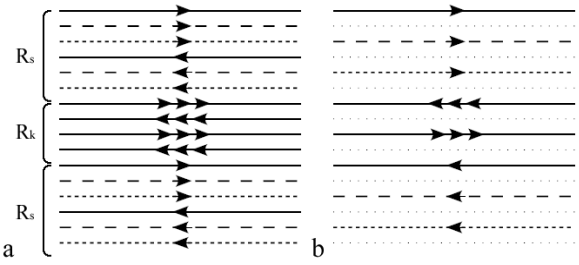

Figure 1 Schematic representation of the k-space trajectory for (a) EPIK (b) EPIK-G acquisitions. The solid, dashed and fine-dashed lines in R_S regions indicate the sampling positions performed during three consecutive measurements, respectively. The dotted lines in (b) indicate the encoding lines skipped by the parallel MRI technique.

Results

To investigate the feasibility of using the EPIK-G method for fMRI, a visual checkerboard paradigm was employed for in vivo fMRI experiments to elicit circumscribed activation in the visual cortex. Sixteen healthy volunteers (8 males) participated in the study and written, informed consent was obtained. For each subject, 78 volumes (6 dummy and 6 cycles of baseline-activation states, each lasting 6 TR) of 25 slices of fMRI data were acquired with the following imaging parameters: FOV = 240 × 240 mm, matrix size = 96 × 96, flip angle/TR/TE = 90°/3000/35 ms, slice thickness = 3mm. To evaluate the performance of EPIK-G, the same measurements were repeated with single-shot EPI and EPIK sequences. Figures 2a-c show the reconstructed images from the fMRI data of one representative subject; to aid comparison, a GRE image is displayed alongside as a reference (Fig. 2g). Visual inspection of the reconstructed images suggests that both the EPIK and EPIK-G images were well reconstructed and are comparable to the EPI image in terms of the spatial resolution. When compared to the EPI image, both EPIK and EPIK-G images display less image distortions, caused by susceptibility variations around the frontal and temporal poles, as well as the fourth ventricle (marked by white arrows); the EPIK-G image has the least distortion and the highest similarity with the GRE image. For all subjects, each fMRI run was analysed with SPM8 (Wellcome Department of Imaging Neuroscience, UCL, UK). The first level activation-baseline contrasts for each subject were taken to the group level to evaluate the activation pattern elicited by each imaging sequence. Figures 2d-f show the activation regions obtained with an uncorrected p-value of < 0.001; the slice which had the maximum t-value was chosen. For all imaging sequences, visually induced brain activations were consistently detected around the visual area. To check the effect of the EPIK-G method on the behaviour of the blood oxygenated level dependent (BOLD) response, another fMRI data set was obtained by means of an MRI simulator, JEMRIS. For this simulation, the same EPIK-G sequences and only 2 cycles of baseline-activation blocks employed in the above fMRI experiments were used. The artificial BOLD signal was designed so that the peak signal change was 5% of the baseline. Activation regions were defined inside the simulation object with a small circle whose diameter was equal to 4 voxels. In the reconstructed time-series images, the behaviour of the BOLD signals was obtained from the pre-defined activation region. As shown in Fig. 3, the BOLD responses obtained from the EPIK-G fMRI data were similar to that of the originally designed one, which verifies the use of the EPIK-G method for fMRI.

Conclusion

EPIK-G was implemented and validated at 3T with human fMRI and simulation results. It was shown that the EPIK-G outperforms EPIK and single-shot EPI in terms of the robustness against the geometric distortions and its use in human fMRI studies was also verified.

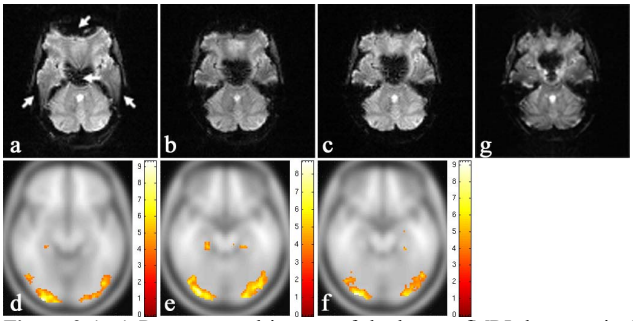

Figure 2 (a-c) Reconstructed images of the human fMRI data acquired with single-shot EPI, EPIK, EPIK-G and (d-f) their corresponding activation results; (g) GRE image for reference.

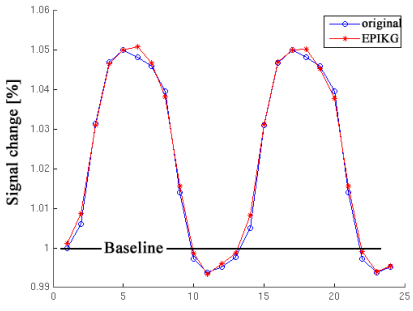

Figure 3 BOLD responses obtained from originally designed one (blue line with circle) and EPIK-G (red line with star)

References

[1] Shah NJ et al., German Patent: DE 199 62 845. [2] Shah NJ et al., US Patent: 6,781,372 B2. [3] Zaitsev M et al., Magn Reson in Med 2001;45:109-117. [4] Zaitsev M et al., Phys Med Biol 2005;50:4491-4505. [5] Griswold MA et al., Magn Reson Med 2002;47(6):1202-1210. [6] Stöcker et al., Magn Reson Med 2010;64:186–193. [7] Feinberg DA et al., Magn Reson in Med 1994;32:535-539.