Multiple gradient- and spin-echo EPI acquisition technique with z-shimming to compensate for susceptibility-induced off-resonance effects

H. Schmiedeskamp[1], M. Straka[1], R. D. Newbould[2], S. Skare[1], K. P. Pruessmann[3], and R. Bammer[1]

[1]Lucas Center, Department of Radiology, Stanford University, Stanford, CA, United States, [2]GlaxoSmithKline, London, United Kingdom, [3]Institute for Biomedical Engineering, University and ETH Zurich, Zurich, Switzerland

INTRODUCTION – Images obtained with gradient-echo echo planar imaging (GRE-EPI) suffer from magnetic field variations within the brain, such as in regions adjacent to air-tissue interfaces. In these regions, magnetic field inhomogeneities cause spins to dephase more rapidly, resulting in signal dropouts. Thus, conventional GRE-EPI pulse sequences used for dynamic susceptibility-contrast perfusion-weighted imaging (DSC-PWI) or blood oxygenation-dependent functional MRI (BOLD-fMRI) usually confine image analysis to homogeneous brain regions. Compensation mechanisms based on z-shimming (originally proposed in [1]) apply additional field gradients prior to repeated signal readouts of the same imaging plane, with the drawbacks of prolonging scan time ([2],[3]) or increasing image distortions ([4],[5]). Extending PERMEATE [6], a multi-echo EPI pulse sequence developed for DSC-perfusion quantification, z-shimming gradients were added prior to the first and second echo train, to restore T_2*-related signal dropouts in the first echo train, while maintaining regular contrast for the following echo trains. Using this technique, functional brain activity could be successfully detected in typical dropout regions close to the auditory canals in a breath-holding fMRI experiment [7], therefore facilitating whole-brain EPI-based BOLD-fMRI with unchanged acquisition time and low spatial image distortions due to parallel imaging accelerated acquisition. In this study, we propose adding a similar z-shimming approach to a combined gradient-echo/spin-echo (GRE-/SE-) EPI sequence [8], in which each EPI train is preceded by different z-shim gradients (see Fig. 1) in order to restore susceptibility-induced signal-dropouts and facilitate full-brain coverage in combined gradient- and spin-echo measurements, for application in DSC-PWI and fMRI.

METHODS – Fig. 1 shows the pulse sequence design used for the present study. Following an α-β pulse combination to form a Hahn spin echo (α = 90°, β = 180°), a spin-echo signal is sampled by an EPI readout train at TE_{SE}. Additional gradient-echo readouts acquired at $TE_{1,GRE}$ and $TE_{2,GRE}$ fit into the time between the 90° and 180° pulse, combined gradient-echo/spin-echo readouts measured at $TE_{3,GRE}$ and $TE_{4,GRE}$ were placed between the 180° pulse and the spin-echo readout at TE_{SE}. Individual z-shim gradients G_{zshim1} to G_{zshim4} were added prior to each gradient-echo EPI readout train. In order to acquire four gradient-echo EPI trains followed by a spin-echo signal at TE_{SE} = 100 ms (≈ T_2 of gray matter), a parallel imaging reduction factor of R = 3 and an in-plane resolution of 84x84 voxels were used on our 3T system with gradient strength = 50 mT/m and gradient slew rate = 200 T/m/s. The experiments were carried out using the following acquisition parameters: TR = 2000 ms, $TE_{1-4,GRE}$ = 14.6, 37.0, 65.6, 84.1 ms, FOV = 24 cm, slice thickness = 3 mm, number of slices = 16. Z-shimming gradients $G_{zshim,1-4}$ in the present version of the pulse sequence can be adjusted so that G_{zshim2} compensates for G_{zshim1}, and G_{zshim4} compensates for G_{zshim3}. Thus, EPI trains 2 and 4 were acquired on-resonance, while EPI trains 1 and 3 were acquired at different off-resonance settings in order to correct for susceptibility-induced off-resonance effects.

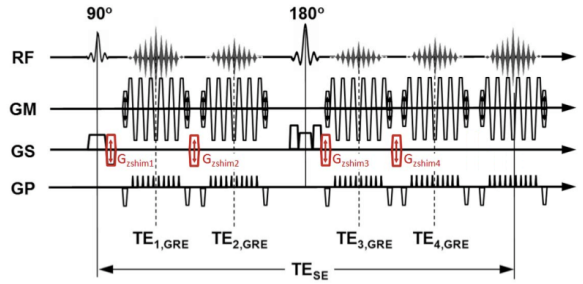

Fig. 1: Simultaneous spin- and gradient-echo EPI acquisition technique with z-shimming. Z-shimming gradients $G_{zshim,i}$ (i=1-4) added between EPI-readout trains to counteract susceptibility-induced off-resonance effects.

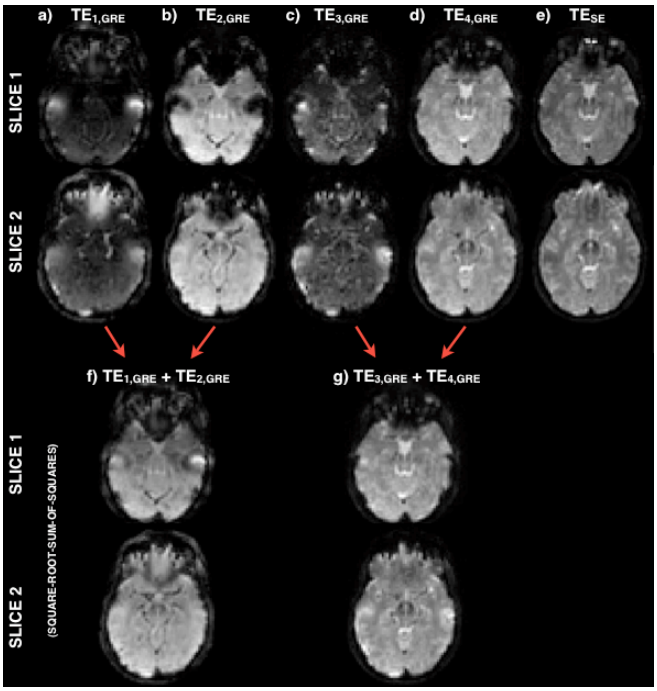

Fig. 2: Multi-echo combined GRE-/SE-acquisition with signal dropout compensation through z-shimming gradients. GRE-EPI images (Fig. 2a-b) and combined gradient-echo/spin-echo EPI images (Fig. 2c-d) are summed up using a square-root-sum-of-squares operation, successfully reducing signal-dropout in inhomogeneous brain regions near auditory canals and nasal cavities (Fig. 2f-g). Square-root-sum-of-squares images (Fig. 2f-g) are similar to SE-EPI images (Fig. 2e) in terms of signal dropouts.

RESULTS – Fig. 2 shows the results achieved in a female volunteer using the abovementioned acquisition parameters and z-shimming values of G_{zshim1} = – G_{zshim2} = – 0.75·G_{zrep} and G_{zshim3} = – G_{zshim4} = 0.75·G_{zrep}, with G_{zrep} the slice-selective refocusing gradient. Square-root-sum-of-squares images were produced from the gradient-echo EPI trains (Fig. 2a-b) as well as from combined gradient-echo/spin-echo EPI trains (Fig. 2c-d). Fig. 2e shows the spin-echo image acquired at TE_{SE}.

DISCUSSION – Signal dropouts caused by susceptibility effects could be compensated for in the square-root-sum-of-squares images (Fig. 2f-g) in areas close to the ear canals as well as above the nasal cavities, therefore approaching the spin-echo image in terms of signal dropouts. The presented technique is particularly promising for applications in functional imaging, with the possibility to simultaneously acquire a GRE-signal, a combined GRE-/SE-signal, as well as a SE-signal, all of them with minimal signal dropouts. Multi-echo simultaneous GRE- and SE-EPI acquisitions with z-shimming benefit from reduced signal contributions from large vessels in order to increase signal specificity through SE-EPI readout, while increased sensitivity in typical signal dropout regions can be achieved in the GRE-EPI readouts. Together, a powerful tool for BOLD-fMRI and DSC-PWI is presented with minimal signal dropout artifacts, and fast image acquisition in order to achieve the high temporal resolution necessary for functional imaging.

REFERENCES: [1] Frahm *et al*, MRM 6:474-480, 1988; [2] Song *et al*, MRM 46:407-411, 2001; [3] Gu *et al*, NeuroImage 17:1358-1364, 2002; [4] Posse *et al*, NeuroImage 18:390-400, 2003; [5] Yang *et al*, MRM 52:1418-1423, 2004; [6] Newbould *et al*, MRM 58:70-81, 2007; [7] Schmiedeskamp *et al*, Proc. ISMRM 2008, p3561, [8] Newbould *et al*, Proc. ISMRM 2007, p1451 – **ACKNOWLEDGEMENTS**: NIH (2R01EB002711, 1R21EB006860, 1R01EB008706, P41RR09784), Lucas Foundation, Oak Foundation.