High-resolution functional imaging in the human brain using passband bSSFP at 9.4T

Klaus Scheffler[1,2] and Philipp Ehses[1,2]

[1]*Dept. of Biomedical Magnetic Resonance, University of Tübingen, Tübingen, Germany,* [2]*High-Field MR Center, Max Planck Institute for Biological Cybernetics, Tübingen, Germany*

Introduction: The use of balanced SSFP (bSSFP) for the detection of neuronal activation-related signal changes has been proposed in 2001 [1] and since then, different bSSFP variants have been investigated for this purpose in detail [2]. At 9.4T, the original stopband method is too instable, as breathing already produces frequency shifts of 20-50 Hz. Passband bSSFP was introduced by Bowen et. al. [3] and, depending on sequence parameters, the contrast is a combination of diffusion-, T_2-, and T_2^*-contributions [4]. At 9.4T, a short TR is mandatory to minimize banding artifacts and to speed up the acquisition. Therefore, with an echo time of about 2 ms, contributions from T_2^* are probably negligible. The goal of this study was to demonstrate the feasibility of bSSFP for functional brain imaging at 9.4T. Furthermore, the resulting signal changes and patterns as well as temporal SNR were compared to GE- and SE-EPI.

Methods: All experiments were performed at 9.4T on healthy volunteers with informed consent and approval by the local ethics committee. A custom-built head coil [5] was used for signal transmission/reception (16 transmit / 31 receive channels). Two 3D bSSFP fMRI experiments (each on 5 volunteers) were performed at an isotropic resolution of 0.8 mm and 1 mm, respectively (TR=4.2 ms, TE=2.1 ms, FA=13°, GRAPPA R=3; 16 partitions, volume acq. time=4.6/3.7 [s]). For comparison, single-shot GE- and SE-EPI data were obtained at an isotropic resolution of 1 mm (GE-EPI: TR=1.85 s, TE=20 ms, FA=53°, GRAPPA R=3; SE-EPI: TR=3.7 s, TE=40 ms, FA=90°, GRAPPA R=3). EPI data were corrected for distortions using point spread function (PSF) mapping based techniques (GE-EPI: [6]; SE-EPI: [7]). In all experiments, the fMRI stimulus consisted of a flickering radial checker-board (7 Hz), which was presented ten times in alternating 18.5 s off- and on-periods (acq. time=6:10 min). For analysis, the data were processed with FSL FEAT [8] using a standard hemodynamic response function and temporal filtering. No spatial smoothing was applied during the analysis.

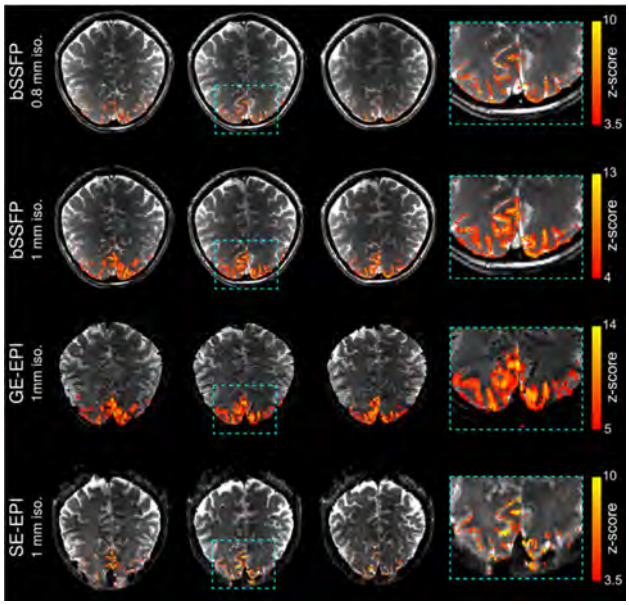

Fig 1: Comparison of activation maps from all four fMRI experiments of one volunteer. From top to bottom: 0.8 mm bSSFP, 1 mm bSSFP, GE-EPI, SE-EPI. Three representative slices are shown.

Results: Figure 1 shows a comparison of bSSFP, GE-EPI and SE-EPI at an isotropic resolution of 1 mm (and one bSSFP at 0.8 mm, top row). Due to the sufficient quality of the local shim around the visual cortex, no banding patterns are visible in the bSSFP acquisitions. In all volunteers bSSFP activation patterns were similar in terms of measured signal change and activation pattern. As visible in the zoomed bSSFP images, the activation patterns closely follow the grey matter structure, with some reduced statistical power at 0.8 mm. The pattern is similar (but more significant) to SE-EPI, indicating a strong T_2 and minor T_2^* signal contribution. Figure 2 shows corresponding signal changes and tSNR maps demonstrating the excellent signal stability of bSSFP at 9.4T.

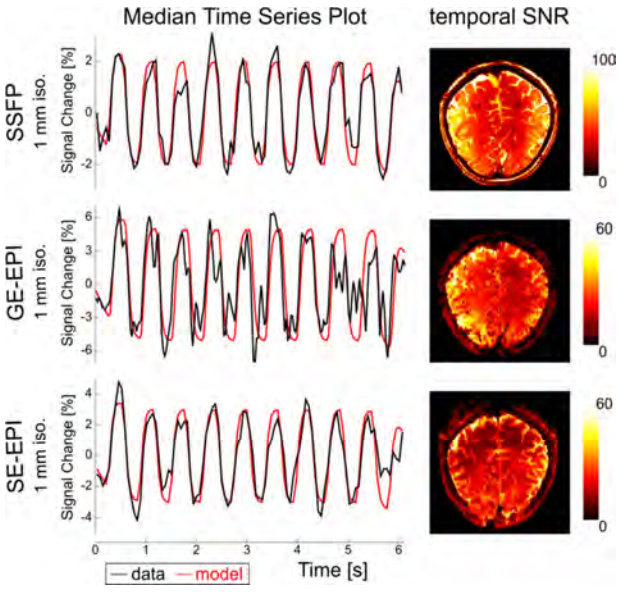

Fig 2: Left: Median time series for bSSFP, GE-EPI and SE-EPI. The median was calculated from brain voxels with z-scores over a certain threshold (bSSFP: z-scores>4; GE-EPI: >5; SE-EPI: >3.5). Right: temporal SNR for all three sequence types.

Conclusion: A common problem of EPI at very high fields is the loss of grey-white matter contrast, which makes segmentation and/or overlay to anatomical images difficult and prone to misalignment. bSSFP has no distortion artifacts (but also a weak grey-white matter contrast) and can be directly overlaid to anatomical images which potentially allows for a very detailed analysis of intra cortical structures. In addition, as T_2^* effects are negligible, the contribution of CSF signal changes via partial volume effects and T_2^* is strongly reduced compared to GE-EPI. This also indicates a reduced sensitivity to larger draining veins and thus higher spatial specificity. Furthermore, the PSF of bSSFP does not suffer from T_2^*-related blurring in PE-direction as in EPI. The current implementation of bSSFP is about 3 times slower than EPI. However, with more advanced k-space trajectories we aim to approach the speed of EPI.

References: [1] Scheffler K., et. al. NMR Biomed (2001); 14:490-496. [2] Miller K.L. Neuroimage (2012); 62:713-719. [3] Bowen C.V. Proc 13th ISMRM (2005); p. 119. [4] Miller K.L. MRM (2008); 60:661-673. [5] G. Shajan, et al. MRM (2014); 71:870-79. [6] In M.-H, et al. MAGMA (2012); 25:183-92. [7] Zaitsev M., et al. MRM (2004); 52:1156-66. [8] Smith S.M., et al. NeuroImage (2004); 23:208-19.