Functional imaging at 14.1T using high-resolution pass band bSSFP

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Introduction

The value of EPI for functional imaging at very high resolution and field strength is limited due to potential distortions and loss of signal during the echo train. As a possible alternative, balanced SSFP was introduced in 2001 as a novel and complementary method to detect neuronal activation [1]. Depending on sequence parameters, the measured signal depends on T2, diffusion, and T2*, and probably blood volume changes [2]. In this study we investigate the possibility of very high-resolution bSSFP for fMRI at 14.1T, a regime that is hardly accessible with conventional EPI sequences. Using a very short echo time of 3 ms the expected T2* contribution to the signal changes is expected to be low, and thus dominated by T2 and volume changes. The goal of this study was to evaluate the feasibility of high resolution bSSFP for functional imaging as a replacement for conventional T2* FLASH imaging.

Methods

All animal studies were approved by the local authority, Regierungspräsidium Tübingen, Germany. To evaluate the signal properties of bSSFP in total five rats were used for BOLD-fMRI mapping. The detailed fMRI procedure is described in the previous study [3]. The 2D bSSFP slice was aligned perpendicular to the venules penetrating the forepaw somatosensory cortices (FP-S1). The individual penetrating venules in the deep layer FP-S1 will be highlighted as the dark dots as previously observed by EPI images [4]. Images have been acquired on a 14.1T system with Bruker console. BSSFP was implemented with the following parameters: TE, 3.3 ms, TR 6.6 ms, FA, 10°, matrix is 128x128, resulting in a slice repetition time of 850 ms. In-plane resolution was 100 μm x100 μm and slice thickness=0.4mm. The block design (forepaw stimulation) was 20s rest and 5s stimulation, repeated for 5 times. Electrodes were placed on the forepaw to deliver a 2.5mA pulse sequence (300μs duration repeated at 3Hz). For analysis, the bSSFP images were processed by AFNI software without spatial smoothing process. The most active BOLD voxels were selected by choosing the statistical threshold of p=0.001. Total 8 voxel clusters were highlighted in the FP-S1 area and the time course of each clusters were measured and represented as mean±sem.

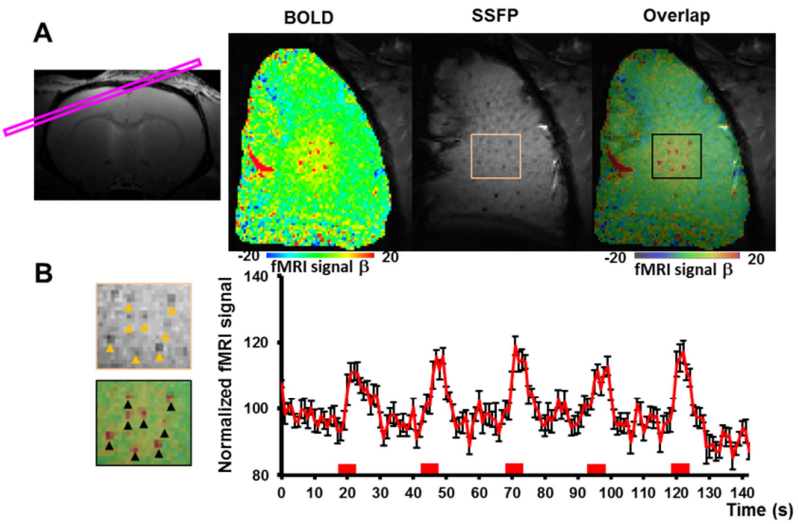

Fig 1. A. BOLD-fMRI map based on bSSFP. Individual penetrating venules were directly detected as the dark dots in the bSSFP raw images. The most active BOLD voxel clusters (red color) were overlapped with the penetrating venules. B. BOLD-fMRI time course of most active voxel clusters (n=8, p<0.001, black arrowheads), which were overlapped with the penetrating venules (orange arrowheads).

Results

Task-related pass band bSSFP signal changes have been detected in all experiments with changes ranging from 5% to 20%, which is about two times smaller than with FLASH, but similar to spin echo acquisitions. Within the selected FOV only minor banding artifacts are visible at a TR of 6.6 ms. Significant signal changes are located within and partially very close to small (100 μm) draining venules. This indicates that the measured signal largely depends on T2, and probably also some inflow effects as a single slice perpendicular to the penetrating vessels has been used. The temporal signal stability (tSNR) of bSSFP was in the range of 10-15 corresponding to a very high scanner stability for the used resolution.

Conclusion

The use of bSSFP for functional imaging benefits from faster acquisition times and increased spatial specificity as compared to FLASH. The currents studies indicate a strong T2 dependence of the bSSFP signal similar to spin echo acquisitions. A detailed analysis of the contrast sources, however, can only be achieved with appropriate Monte Carlo simulations and measurements with different parameter sets of TE and flip angle. The promising potentials of BOLD bSSFP imaging are completely distortion free images allowing overlay to anatomical scans in the sub-millimeter range as well as a blurring-free pixel point spread function.

References [1] Scheffler K. et. al. NMR Biomed (2001); 14, 490–496. [2] Miller K.L. MRM (2008); 60:661-673. [3] Yu, X. et al. *Nature methods* (2014) **11**, 55-8 (2014) [4] Yu, X. et al. *NeuroImage* (2012) **59**, 1451-60.