Passband bSSFP: Functional contrast compared to GRE-EPI and SE-EPI at 3T.

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Introduction

Passband balanced steady-state free precession (pbSSFP) with 3D segmented EPI readout has been proposed as an alternative to GRE-EPI for functional MRI [1-2], the advantage being less geometric distortions and signal drop-out, the disadvantage being banding artefacts. Previous studies have successfully demonstrated functional contrast in pbSSFP and explored different mechanisms for the contrast [3-6]. In this study we wanted to assess the functional contrast of pbSSFP compared to GRE-EPI and SE-EPI at 3T, in a setting with identical functional paradigm and overall geometry, and with each scan protocol optimized for minimum volume TR. In addition we wanted to find the best TR-choice for pbSSFP.

Methods

All experiments were performed on a Siemens 3T TIM TRIO equipped with an 8 channel head matrix. For each subject (n=6), six different scan protocols were used with the following identical parameters: FOV = 240x240x64 mm, matrix size 120x120, 32 slices/partitions, bandwidth per pixel 1776 Hz. In addition, the following parameters were used for the different protocols: GRE-EPI: TE = 35 ms, Grappa 2, volTR = 2.27 s. SE-EPI: TE =80 ms, Grappa 2, volTR = 3.77 s. pbSSFP: FA 30 deg, phase increment 180 deg, time-bandwidth product 16, rf pulse duration 0.5 ms. In total, five different versions of pbSSFP were tested with the following sets of TR/TE/EPI-factor/volTR: 6.5ms/3.6ms/6/4.2s, 11ms/5.5ms/12/3.5s, 19ms/9.6ms/24/3.0s, 33ms/18ms/40/3.2s, 45ms/22ms/60/2.9s. The two longest TR-protocols were run on three subjects each. EPI-factor is the number of echoes after each excitation. The shim was held constant throughout the scan-session. A standard flickering checkerboard paradigm was used: 8 Hz, 30/30 sec off/on, total duration 4min 30 sec. After three of the functional scans, a 5 min anatomical scan was acquired before the three final functional scans. The order of the different scan protocols were randomized for each subject.

FSL-FEAT was used for motion correction, spatial smoothing (2mm FWHM) and GLM analysis, while the SPM5 mutual information algorithm was used for between-scan coregistration. The z-statistics maps were further analyzed in the following way: For each subject a mask was defined from a fixed effects analysis across the different methods, calculated as the mean z-stat across N methods divided by sqrt(N). To avoid biasing the map to favour pbSSFP data (with five protocols), we first calculated the fixed effects across pbSSFP runs, and then calculated the fixed effects statistic map across GRE, SE and pbSSFP. This fixed effects statistic map was then thresholded (z>2.3) to define the final mask, and the number of voxels with z>2.3 inside the mask was calculated for each scan protocol and subject. Also the total number of voxels with z>2.3 was calculated for each protocol and subject. Standard error of the mean (SEM) across subjects were calculated.
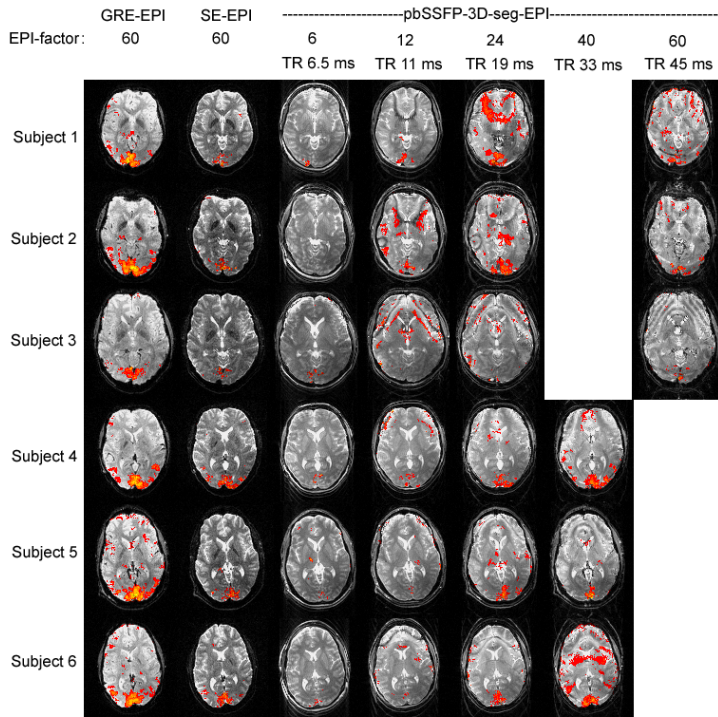

Figure 1. Example slice from each subject and scan protocol. Activated voxels (z>2.3) as color overlay. Reduced geometric distortions in short-TR pbSSFP is observed at the expence of banding artefacts and lower functional contrast.

Figure 2. Total number of activated voxels (z>2.3) and number of activated voxels inside mask based on thresholded average z-statistics map across all scan protocols (z>2.3). Mean value across the six subjects +/- SEM.

Results and Discussion

Reduced distortions can be observed in the short-TR pbSSFP images as compared to GRE-EPI and SE-EPI, see figure 1. For the long-TR pbSSFP protocols the distortions approach that of GRE/SE-EPI. Banding artefacts are visible in the pbSSFP protocol except in some of the TR6.5 ms images, the number of bands increasing with TR as expected due to the 1/TR dependence of the band distance in Hertz. Also some fat-shift artefact is observed in the pbSSFP images, varying with the EPI-factor. Significant activation in the region of the visual cortex is observed in all subjects. GRE-EPI has stronger activation in the visual cortex than the other scan protocols, and the pbSSFP protocols suffer from false activations along the bands. SE-EPI has weak activation, but located to the visual cortex. For pbSSFP the number of activated voxels peaks at the TR=33 ms protocol, the total number matching that of GRE-EPI, see figure 2. However, a majority of these voxels are located outside the defined mask, and are therefore most probably false detections. Inside the mask, pbSSFP TR 33ms has about half the number of activated voxels compared to GRE-EPI and about twice the number of activated voxels compared to SE-EPI. Different contributions from physiological noise in the different scan protocols might influence the z-statistics, both since we are comparing 2D and 3D scans and since there are indications that the physiological noise sensitivity in pbSSFP varies with TR [5].

In conclusion, for pbSSFP with 3D segmented EPI readout the functional contrast is best at intermediate TR of around 30 ms, with sensitivity in between SE-EPI and GRE-EPI. When optimizing the protocol for minimum volume repetition time, TR=33ms corresponds to an EPI-factor of 40 at the chosen bandwidth, for which the geometric distortions are no longer negligible and approach that of GRE/SE-EPI.

References

[1] Bowen, Menon and Gati Proc ISMRM 2005 p 119, [2] Lee et.al. MRM 59:1099-1110 (2008), [3] Scheffler and Hennig MRM 49:395-397 (2003), [4] Miller and Jezzard, MRM 60:661 (2008), [5] Miller et.al. NeuroImage 37:1227-1236 (2007), [6]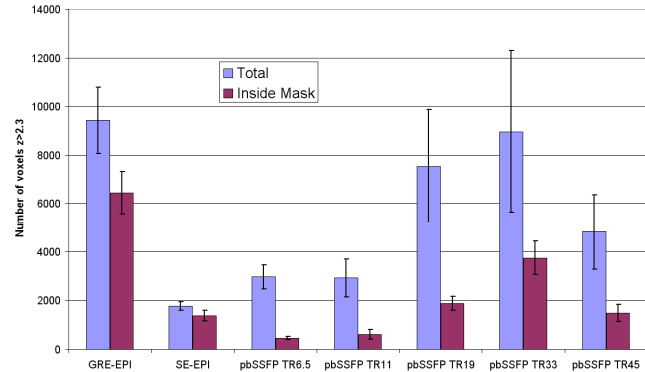 Zhong et.al. MRM 57:67-73 (2007).