Pass-band balanced SSFP fMRI at 7 Tesla

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INTRODUCTION

In fMRI, gradient-echo (GRE) single shot EPI allows a reasonable spatiotemporal resolution with robust functional activation. However, the combination of the long readout duration and echo time makes the method susceptible to image distortion, image blurring and signal dropout. Recently, balanced SSFP (bSSFP) fMRI has been proposed as an alternative method to compensate for these shortcomings [1-4]. In a previous study, feasibility of bSSFP fMRI was demonstrated at 7 T using small-flip-angle (4º and 7º transition-band SSFP fMRI [4]). A limitation of this study was the limited spatial coverage (approximately 4 Hz off-resonance frequency coverage) because of signal drop-outs related to the SSFP banding artifact. Here we demonstrate that pass-band SSFP fMRI at 7 Tesla using a larger flip angle (20º) with π RF phase cycling can provide high quality images and large spatial coverage with limited signal null (bSSFP banding artifact) areas. The characteristics of the bSSFP functional contrast were also investigated using multi-echo and multi-TR experiments. The results were compared to GRE with matching parameters.

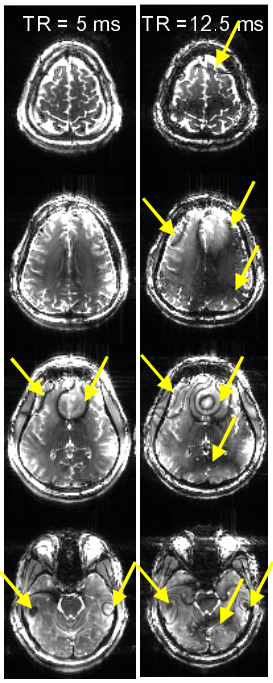

Figure 1. Banding artifacts

METHODS

(1) *Image quality and spatial coverage:* All experiments were performed using a GE 7 T scanner and a NOVA 32 channel head coil. A 3D balanced SSFP sequence with different TRs (5, 7.5, 10 and 12.5 msec) was used to scan entire brain to identify the location of the signal null areas (banding artifacts). To compare image quality bSSFP, GRE EPI and an anatomical reference were acquired. (2) *Contrast characteristics:* A 3D multi-echo SSFP sequence was scanned at four different TRs (5, 7.5, 10 and 12.5 ms) with 1 to 7 echoes (FOV = 24 x 15.8 cm^2, resolution = 2 x 2 x 4 mm^3, α = 20º, number of slices = 6, BW = ±50 kHz). The same parameters were used for a RF spoiled GRE sequence for contrast comparison (n = 4). One each subject, functional data were aligned to the GRE data of TR =12.5 ms. The ROI for the analysis was defined as the commonly activated voxels of the last echo of the TR = 12.5 ms SSFP and GRE data at low threshold (z > 1.57) while excluding the high threshold (z > 3.11) activated voxels of the first echo GRE TR = 12.5ms data to avoid large veins. The ROI was further restricted to visual cortex.

RESULTS

The signal nulls were observed primarily in limited brain areas including frontal (above the sinus) and temporal (above the ear canal) lobes for the 5 ms TR whole brain scan. The areas spread out to large portions of brain including the occipital lobe for TR=12.5 ms (Fig 1). Compared to the EPI GRE result, SSFP image quality was superior (Fig. 2a and 2b, the red contours were drawn from the anatomical reference). In the fMRI experiment using the bSSFP (TR = 5 and 7.5 ms), the entire visual cortex area was banding free. The activation map shows significant activation in visual cortex area (Fig 3). When the relative signal changes of the multi-echo and multi-TR bSSFP were compared with those of the GRE with the matching parameters, larger percent changes were observed in bSSFP results (Figure 4, TR =5, 7.5, 12.5 ms showed statistically significant results for TE ≈ TR/2 datasets). This result was particularly prominent at the earlier echoes where the GRE results showed close to zero intercepts when extrapolated to TE = 0 whereas bSSFP results suggested significantly large intercept values. This is attributed to the substantial contribution of stimulated echoes (that increase T2 weighting) to the SSFP signal.

CONCLUSION AND DISCUSSION

Pass-band bSSFP fMRI at 7 Tesla can provide large spatial coverage and high image quality. The results of the multi-echo multi-TR experiments reveal substantial contrast at the early echoes suggesting that the contrast from multiple echo pathways contributes significantly at 7 Tesla for the given parameters.

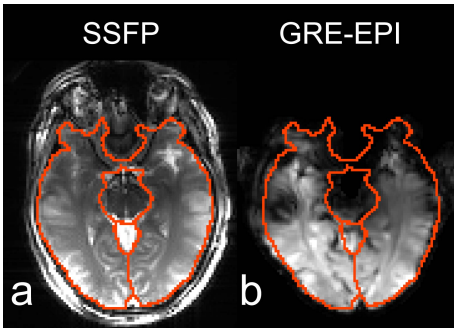

Figure 2. bSSFP vs GRE

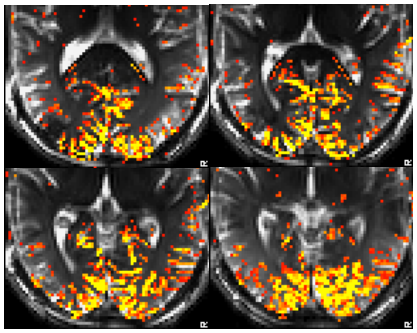
Figure 3. bSSFP activation map TR = 5 ms

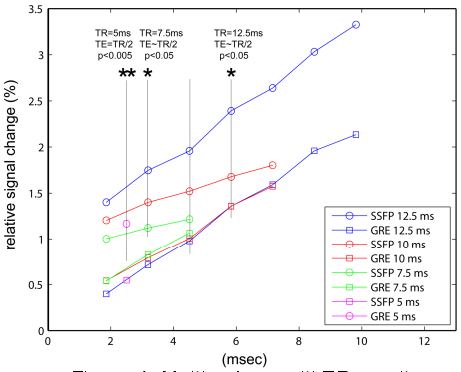

Figure 4. Multi-echo, multi-TR results

[1] Bowen et al., ISMRM, p.119, 2005
[2] Miller et al., MRM, p.675, 2003
[3] Lee et al., Research topics on brain mapping, chapter 3, Nova publisher, 2008
[4] Miller et al., NI, p.1127, 2007