Reducing susceptibility-induced signal loss in echo planar imaging using a shim insert coil at 7T: Implication for BOLD fMRI

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Target audience: Researchers using EPI acquisitions

Purpose: Functional magnetic resonance imaging (fMRI) study is commonly performed by gradient-echo (GE) echo planar imaging (EPI) because of its high sensitivity to blood oxygenation level dependent (BOLD) signal changes. However, GE-EPI acquisitions are also sensitive to the macroscopic field inhomogeneity generated by the difference in magnetic susceptibility between air and tissue. This inhomogeneity results in signal losses and spatial distortions in the vicinity of the medial temporal and frontal lobes and increases with magnetic field strength. Most systems to date are equipped with only 1st and 2nd order shims which are insufficient to correct these susceptibility effects. Alternatively, a Z-shim method[1,2] has been proposed to for correct for some of the field distortion. However, this technique reduces the temporal resolution significantly and cannot correct for higher order/higher degree inhomogeneities. To overcome these limitations, higher order shims (3rd, 4th and above) are required. In this study, we demonstrate the improvements in signal retention and distortion using a very high order shim insert coil (2nd-4th degree shims) at 7T using GE-EPI acquisitions.

Methods: Four healthy volunteers were studied on a 7-T Siemens scanner using an 8 channel inductively decoupled 1H transceiver array. A 28 channel shim insert coil with a 38 cm ID consisting of Z0, all 2nd-4th degree shims and partial 5th and 6th degree shims with 5A shim supplies (Resonance Research Inc.) was used for higher degree/order shimming. B0 mapping was performed using a 6 time point (0.5 to 8ms evolution times) multi-slice measurement. The shim values were calculated using a non-iterative least squares algorithm[3]. A single-shot GE-EPI was acquired with FOV = 25.6 × 25.6 cm^2, matrix size = 96 × 96, slice thickness = 3 mm (voxel size = 2.7 × 2.7 × 3.0 mm^3), TR/TE = 2 s/23 ms, and 10 - 20 measurements. The voxel-wise temporal-signal-to-noise (tSNR) maps were calculated by dividing the mean of the corresponding time series by its standard deviation for GE-EPI. Three dimensional T_1-weighted magnetization-prepared rapid acquisition with gradient echo (MPRAGE) images were acquired for anatomical images with voxel size = = 0.9 × 0.9 × 0.9 mm^3, TR/TE = 3 s/1.8 ms, and TI = 1.2 s with GRAPPA = 2. The brain contour was delineated from the summation of GM, WM and CSF using the anatomical image.

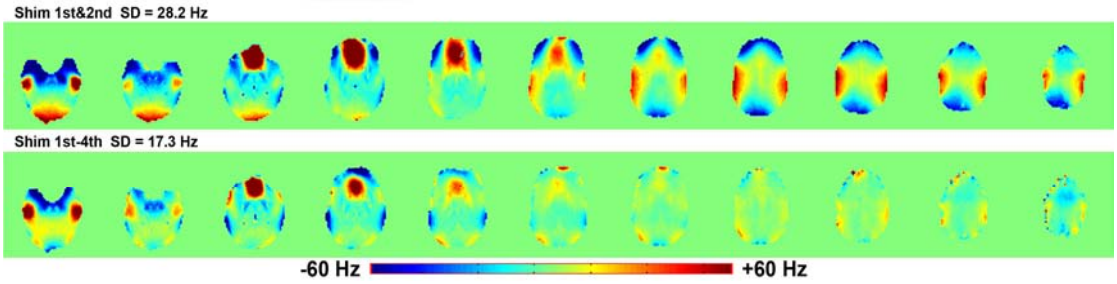

Fig. 1. B0 map.

Results and Conclusion: Fig. 1 displays 11 slices of the B0 map with 1st and 2nd order shims (upper) and 1st – 4th order shims (below), covering the majority of the brain. The standard deviation (SD) of the residual B0 field was reduced by 30% after high order shimming (Table 1). Fig. 2 shows T_1-wieghted images with the brain contour (red outline), GE-EPI and tSNR maps from subject 2. Areas of high signal dropout and distortion in the 1st and 2nd degree shimmed GE-EPI images (white arrows in Fig. 2), were significantly improved after 1st-4th degree shimming. The tSNR of these areas was improved by 31% (Table1). The overall tSNR was also increased with high order shim. Therefore, higher degree/order shimming can enhance the sensitivity of BOLD signal, especially in challenging brain regions such as the inferior temporal and anterior frontal lobes. These brain regions are important loci for memory and emotion.

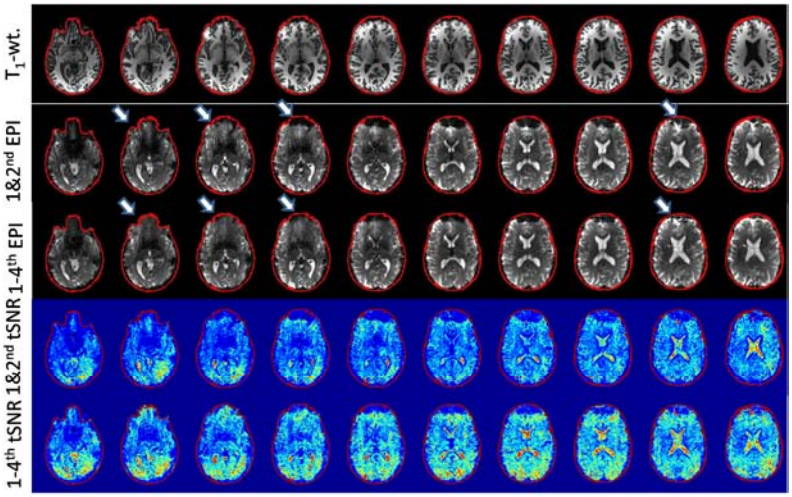

Fig. 2. T_1-wieghted images with brain contour, GE-EPI and tSNR maps. Arrow marks indicate the recovered signal loss area induced by field inhomogeneity.

subject	S.D.		Improvement (%)	tSNR improvement (%)
	1st & 2nd	1st – 4th		
1	36.9	23.43	36.5	77.1
2	28.2	17.3	38.6	153.1
3	37.1	29.2	21.3	51.3
4	30.9	24.1	22.2	163.4
Mean	33.3	23.5	30.0	111.2

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