The Benefits of Higher Order B0 Shimming of the Human Brain at 7T

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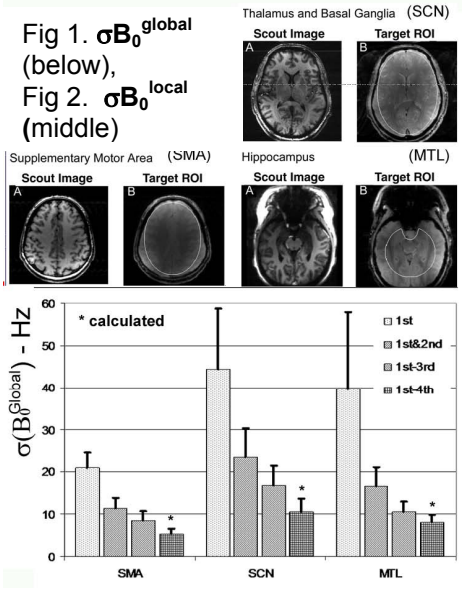
Introduction: With the advent of ultrahigh field systems (7T), significant improvements in spectroscopic imaging (SI) studies of the human brain have been anticipated. However, these gains are dependent upon the achievable B_0 homogeneity, both globally (over the entire ROI or slice) and locally (the linewidths of individual SI voxels within the ROI). The goals of this work were to: 1) determine the improvements with higher order shimming (1^{st}-4^{th} order) and 2) determine and demonstrate the feasibility and benefits of 4^{th} order shimming in the human brain at 7T.

Methods: Data were acquired with a Varian Direct Drive system and a head only (68cm ID) actively shielded 7T magnet. The gradient system (Varian) included all 2^{nd} and 3^{rd} order shims, with each shim driven by two 10A shim power supplies (Resonance Research Inc.). Whole slice data from 60 subjects (20 subjects per region) from three brain regions (supplementary motor (SMA), thalamus and basal ganglia (SCN), and hippocampus/medial temporal lobe (MTL)) were acquired. A non-iterative multi-slice B_0 mapping method was used to set all shim terms. The predicted and measured (after shimming) B_0 field over the target ROIs varied by less than 1Hz for a single pass. Global homogeneity, (σB_0^{global}), was determined by calculating the standard deviation of the B_0 field over the selected ROI, (Fig. 1) for each subject and averaging across subjects. Local homogeneity was evaluated by subdividing the ROI into ~1cc "SI voxels" consisting of an array of 3x3x3 B_0 imaging pixels, and calculating the standard deviation (σB_0^{local}) across each "SI voxel". The data across the ROIs of subjects was pooled and plotted as a function of the fraction of pixels achieving a given (σB_0^{local}). To demonstrate the feasibility and potential benefits of even higher order shimming in the human brain at 7T a 36/42cm id/od shim insert was constructed (Resonance Research Inc.) containing C4, S4, ZC4, ZS4 shims. The choice of shims was based on the symmetry of the B_0 inhomogeneity remaining after 3^{rd} order shimming. The insert was driven with a 5A power supply. Whole plane spectroscopic imaging data was acquired using an 8 element transceiver array.

Results: Displayed in Fig. 1 are representative ROIs for the three regions along with σB_0^{global} achieved (1^{st}-3^{rd} order shimming) and calculated (all 1^{st}-4^{th} orders) for the 60 subjects. Significant reductions of 38%, 37% and 24% in σB_0^{global} are obtained when 4^{th} order shims are added to 3^{rd}s in the SMA, SCN and MTL respectively. Similarly, plots of σB_0^{local}, Fig. 2, shows substantial improvements in σB_0^{local} for all three regions with higher order shimming (red 1^{st} only, blue 1^{st}&2^{nd}, green 1^{st}-3^{rd}, black 1^{st}-4^{th}). Thus, despite the small size of the voxel ~1cc, significant residual B_0 inhomogeneity remains after 2^{nd} and even 3^{rd} order shimming. Fig. 3 shows a photograph of the shim insert along with B_0 maps acquired with 2^{nd}, 3^{rd} and with 3^{rds} and the shim insert from the SMA and SCN of a volunteer at 7T. Inclusion of only four 4^{th} and 5^{th} order terms was sufficient to reduce the σB_0^{global} by 48% (10.85 → 5.59Hz) and 20% (17.49 → 14.06Hz) in the SMA and SCN respectively. Fig. 4 shows a short TE spectra acquired from the thalamus with the insert.

Fig 1. σB_0^{global} (below),
Fig 2. σB_0^{local} (middle)



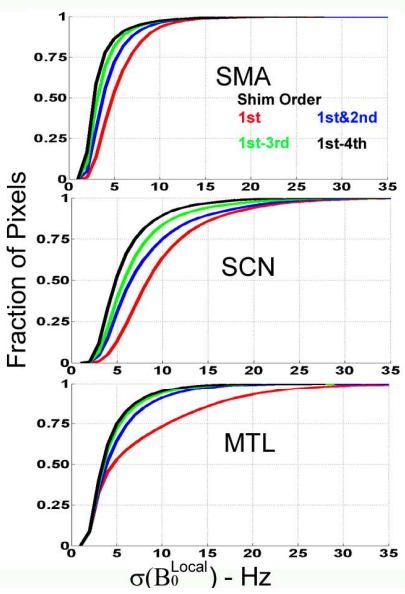
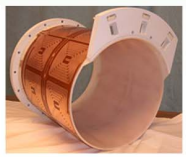
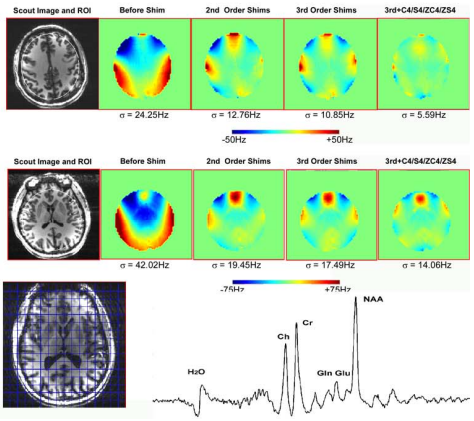


Fig. 3 Shim Insert and field maps.
Fig. 4 Thalamus spectrum.





Conclusions: Our data demonstrates that substantial improvements in both global and local homogeneity can be achieved using 1^{st}-3^{rd} and higher order shims. The required strengths to achieve higher order terms (4^{th} and 5^{th} orders) can be achieved using a shim insert and modest strength power supplies.