Shim Requirements for High-Order Localised Shimming of the Human Brain

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Introduction

When a subject is placed in a uniform magnetic field (B0), differences in magnetic susceptibility between air, bone and tissue introduce large, local variations in the B0 field. This problem is particularly acute in the frontal lobes. Spherical harmonic basis functions are typically used to describe the field for shimming [1], and local B0 variations contain significant amounts of the high-order spherical harmonic terms. Local B0 inhomogeneities are beyond the capability of conventional room-temperature (RT) shims when shimming over the whole brain, which has lead to the development of local active [2] and passive [3] shim methods. MR spectroscopy requires good field homogeneity only within the MRS voxel, thus MRS can utilise localised shimming (correcting the field only in the MRS voxel, at the expense of the global field homogeneity). For MRS studies in Psychiatry, the measurement of neurotransmitter content in the frontal lobes is particularly relevant. However, due to the poor homogeneity in this region, many studies have been confined to the occipital lobe [4]. One aim of this work was to quantify the improvement in performance of a “high-order” (Up to 3rd order, plus Z4) localised shim over a second-order shim for Psychiatric studies by comparing the shimmed magnetic field in a voxel placed in the occipital lobe (a region of good homogeneity) with a voxel in the frontal lobe (covering a part of the pre-fontal cortex and anterior cingulate). Previous work compared the effectiveness of a second-order shim to that of a high-order shim at improving the global (whole brain) homogeneity based on a large sample of *in vivo* fieldmaps [5]. *Clare et. al.* derived an RT shim specification for whole brain shimming, but acknowledged the fact that application-specific shimming techniques, such as dynamic shimming or *in vivo* spectroscopy may have different shim requirements. This abstract reports the strength requirements for localised shimming, and compares them with the requirements for global shimming.

Methods

Using a 3T Varian INOVA system, 449 whole-brain fieldmaps were acquired over a 6 month period using a symmetric-asymmetric multislice spin-echo sequence with the following parameters; data matrix = 32x32, 16 slices, FOV 256x256x160mm, TR/TE=800/20ms, t_{asym}=2.5ms. Using an unconstrained least squares approach, spherical harmonic basis functions were fitted over the following regions (Fig 1); (a) 40x40x40mm^3 frontal lobe voxel, (b) 40x40x40mm^3 voxel positioned in the occipital/parietal region, and (c) whole brain. The voxel volume was chosen to provide a sufficiently large number of measurement points; the 40x40x40mm^3 voxel contained 100 field measurements. Assuming complete correction of the fitted basis functions by the appropriate shim coil, the RMS magnetic field variation (B_{rms}) was calculated following a (i) simulated second order and (ii) simulated high-order shim. For comparison, B_{rms} was also calculated for the MRS voxels after performing a simulated global shim (i.e. mask consisting of all brain voxels), as well as by a localised shim using only the first order shims (linear gradients).

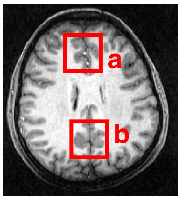

Fig 1: Voxel positions

Results

From the 449 fieldmaps, the mean±SEM whole brain B_{rms} after second order and high-order shimming were 24.7±0.3Hz and 22.5±0.3Hz respectively, when calculated across the entire brain (consistent with those previously reported [5]). The mean predicted B_{rms} values within the two MRS voxels under various shimming strategies are shown in Figs 2 and 3 (error bars represent SEM). The RT shim strengths ($\mu T/m^n$) required to shim 95% of the population (mean+2SD) are shown in Fig 4.

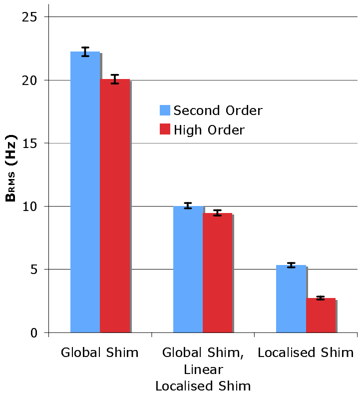

Fig. 2: Brms, Frontal Lobe.

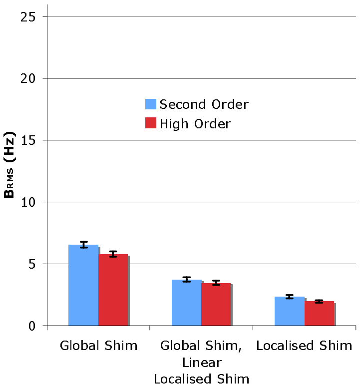

Fig. 3: Brms, Occipital Lobe.

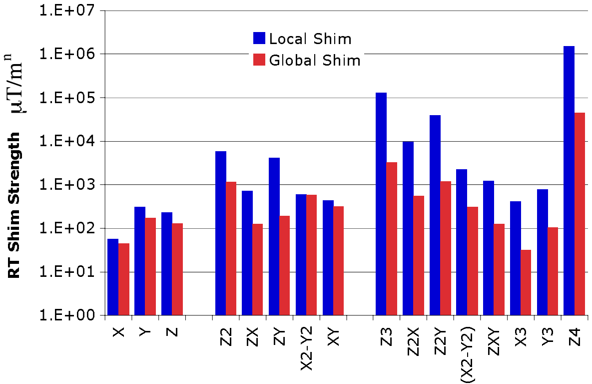

Fig. 4: RT shim requirements

Discussion

As expected, the resulting B_{rms} for a voxel placed in the occipital lobe was significantly lower than that of a frontal lobe voxel, irrespective of the shim method used. Although performing a high-order shim resulted in a statistically significant improvement in B_{rms} in the occipital lobe, the improvement was modest; e.g. 2.3±0.1Hz to 2.0±0.1Hz for a localised shim. This would not yield a substantial benefit in the quality of MR spectra. However, a high-order shim in the frontal lobe voxel reduced B_{rms} from 5.3±0.2Hz to 2.7±0.1Hz; a factor of two improvement in the linewidth. The shim strengths required to achieve this reduction in linewidth were significantly higher than those required for a global shim; typically a factor of 10 higher for the third order terms (Fig 4). The actual requirements may depend on the size and position of the voxel, but the results should indicate the limits of performance for a voxel of comparable size, having investigated the homogeneity in both ‘good’ (occipital) and ‘poor’ (frontal) homogeneity regions. These results were obtained at 3T and are applicable at other field strengths, with the appropriate scaling. Further work is needed to evaluate the effect on B_{rms} of constraining the available shim strength to an actual RT shim design.

References

[1] Romeo F, Hoult DI. Magn Reson Med 1984;1:44. [2] Hsu JJ, Glover GH, Magn Reson Med 2005; 53:243 [3] Wilson JL, Jezzard P, Magn Reson Med 2003; 50:1089 [4] Sanacora et al, Arch. Gen. Psychiatry 1999; 56:1043 [5] Clare S et al, Magn Reson Med 2006; 55:210