Slice-by-Slice Grey Matter Optimised Z-shimming for fMRI Applications

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Introduction Both task-modulated and resting-state functional MRI (R-fMRI) acquired using gradient-echo echo-planar imaging (GE-EPI) [1] suffer from a range of artefacts that can seriously degrade image quality. Of particular concern to the whole brain multivariate data analyses typically used in R-fMRI, such as independent component analysis (ICA), are the susceptibility induced signal dropouts in the orbitofrontal and inferior temporal lobes which may potentially hinder the detection of resting-state networks in these regions. Previous workers [2] have shown that it is possible to recover signal in regions with susceptibility gradients whilst maintaining signal in unaffected regions by combining two images acquired using different z-shim gradients, Fig. 1. As an extension to this work we seek to recover the BOLD signal in the affected regions using a z-shimming sequence optimised on a slice-by-slice basis to recover the maximum signal in all voxels containing grey matter.

Methods

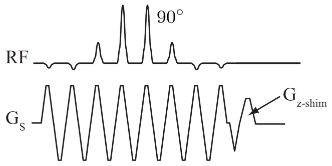

Fig. 1: SPSP-RF pulse with an additional z-shim gradient $G_{z\text{-shim}}$

As a proof of concept a single healthy subject was studied. A z-shim calibration image was acquired using a GE-EPI sequence modified to enable z-shimming (TE/TR 25.5ms/2s, flip angle 90° using a spectral-spatial RF-pulse, 64×64matrix, 24cm FOV, 4mm slice thickness, 24 slices, 41 z-shim steps in the range ±2.3 $G.cm^{-1}$, acquisition time 1min32s). This was masked with a grey matter map collected using a Dual Inversion Recovery EPI (DIR-EPI) sequence [3] tailored to null signal from both white matter and cerebrospinal fluid (3T GE Signa HDx system (General Electric, Waukshua, WI, USA) TE/TR 45ms/4s, flip angle 90°, 64×64matrix, 24cm FOV, 4mm slice thickness, 26 slices, TI_1 1760ms, TI_2 440 ms, acquisition time 1min36s, NEX=8). The DIR-EPI sequence was chosen to for grey matter masking as the images are implicitly registered to the z-shim calibration scan with identical spatial distortions. A MATLAB (The Mathworks Inc.) program was written to calculate the two z-shim gradients that would give the maximum signal across all voxels containing grey matter in each single slice when the two images were combined by sum of squares (SSQ)[4]. Following simulation work [2,5] the spacing of the two z-shim gradients ΔG_{shim} was fixed at 0.9 (in units of $2\pi/\gamma$.TE.slice thickness).

Results The signal dropout in the orbito-frontal and inferior temporal lobes seen in the conventional GE-EPI images is partially recovered when two images acquired with different $G_{z\text{-shim}}$ for each slice are combined by SSQ. Comparing the images acquired using z-shims optimised slice-by-slice Fig.2(c) and those optimised for the whole brain Fig.2(f), following the technique of Marshall et al. [2], we find that 57% of grey matter voxels showed increased signal, as Fig.2(e).

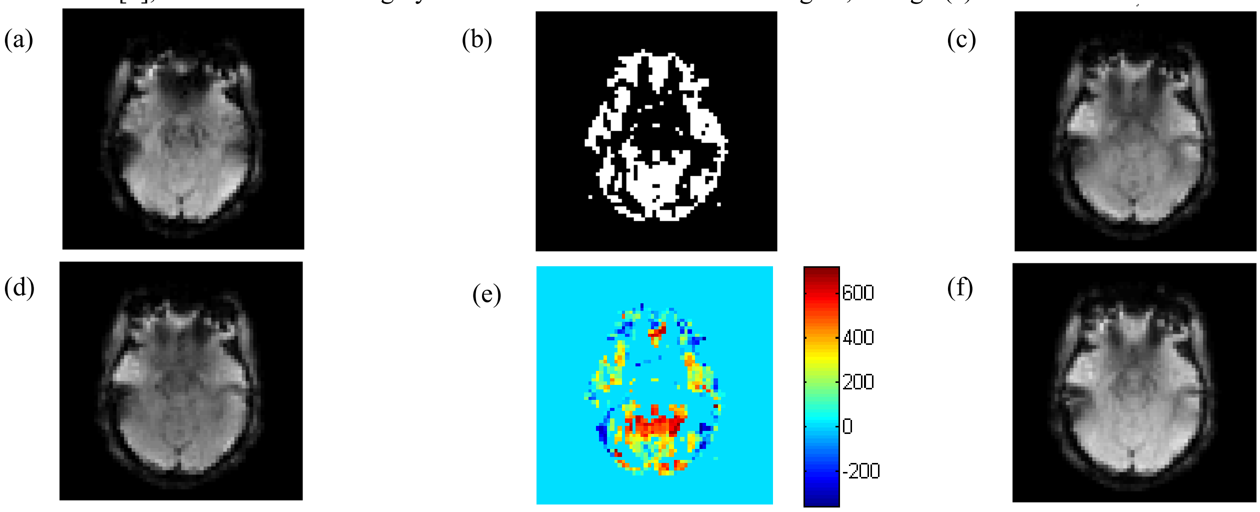

Fig. 2: (a) Conventional GE-EPI image showing signal dropout in the frontal lobe (b) DIR-EPI grey matter mask used in slice-by-slice optimisation (c) Sum of squares combination of 2 images acquired with ΔG_{shim}=0.9 optimised for each slice (d) Sum of squares combination of 2 volumes acquired with ΔG_{shim}=0.9 optimised across the whole brain (e)Difference between (c)&(d) (f) maximum recoverable signal using z-shimming shown by MIP of 41 z-shim volumes

Conclusions We have demonstrated that by constraining the algorithm used to select z-shims to grey matter voxels improves signal recovery over a whole-brain optimisation. Given that the acquisition of a grey matter mask requires only 1min36s we believe that this methodology will prove useful in any fMRI studies using z-shimming. In addition the grey matter mask may be used to constrain fMRI processing to grey matter where appropriate.

References [1] P. Mansfield, Journal of Physics C - Solid State Physics 10 (1977) [2] Marshall, H. et al., Magnetic Resonance Materials in Physics Biology and Medicine 22 (2009) [3] S. Meara et al. (2005) Proc. ISMRM p.494 [4]Ordidge et al., MRM 32 (1994) [5] S.J.Wastling et al. submitted to ISMRM 2011