Improving the specificity of R_2' to mesoscopic magnetic field inhomogeneity by compensating for through-slice magnetic field gradients during image acquisition.

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Target Audience: Researchers interested in using R_2' measurements for quantification of iron concentration and oxygen metabolism.
Purpose: The reversible transverse relaxation rate, R_2', is sensitive to mesoscopic magnetic field inhomogeneity resulting from subvoxel differences in magnetic susceptibility. This sensitivity has been exploited to measure tissue iron concentration[1], resting oxygen extraction fraction[2] and changes in oxygen metabolism[3]. However, R_2' is also sensitive to macroscopic magnetic field inhomogeneity that left uncorrected will reduce the specificity of these applications. In this work we implemented a method to compensate for the through-slice component of the macroscopic effect during image acquisition.
Background: R_2' is most commonly measured using the GESSE[2], GESFIDE[4] and ASE[1] pulse sequences. The effect of macroscopic magnetic field inhomogeneity is usually corrected via post-processing in combination with a separately acquired magnetic field map[5]. The GESSE/GESFIDE methods produce images with simultaneously varying R_2' and R_2 weighting, whilst the ASE method is able to manipulate R_2' weighting with constant R_2 weighting. This enables R_2' to be fitted directly rather than requiring the removal of the R_2 effect prior to fitting for R_2', as is the case with GESSE/GESFIDE. Compensation for magnetic field gradients in the slice dimension (z-gradients) using the Gradient Echo Slice Excitation Profile Imaging (GESEPI) method has previously been used for R_2^* mapping[6]. Here we utilise this technique for mapping R_2' at 3T.
Methods: An EPI ASE sequence was implemented as a baseline comparison. Imaging parameters were FOV 240mm, 64×64 matrix, twenty 5mm slices, TR 3s, BW 2004Hz/px. Raw data were Hanning filtered prior to reconstruction. Images were acquired with six different levels of R_2' weighting: τ=15, 18, 21, 24, 27, 30ms. A GESEPI ASE acquisition was implemented by phase encoding each 5mm slice in the z dimension. In effect each 5mm slice was split into four 1.25mm subslices and acquired with 100% partition oversampling to reduce aliasing (total 8 k-space partitions). The four reconstructed subslices were then summed to produce a single 5mm slice. Images were acquired in 3 subjects with each sequence matched for scan duration (2min 24s): 8 averages for EPI ASE, 1 average for GESEPI ASE. Images were smoothed[7] with a 2mm kernel and R_2' was mapped using a 2 parameter fit to the following model: $S=S_0\, e^{-\tau R_2'}$.
Results: Fig. 1 presents a subset of 4 slices from R_2' maps generated by EPI ASE and GESEPI ASE. The effect of the z-gradient is visibly reduced in GESEPI ASE. Notably the R_2' of slice 12, which is superior to the nasal sinus, is reduced to be in line with neighbouring voxels. The effect of the z-gradient persists in slice 16 of the EPI ASE images, but is corrected in GESEPI ASE. Finally signal is recovered in slice 10 where the z-gradient is largest, but residual R_2' elevation remains. This pattern is consistent with measured in-plane magnetic field gradients (not shown). Fig. 2ab display histograms of cortical grey matter R_2'. Whilst the mode value of R_2' in both methods ($3.0s^{-1}$) was identical, the spread of values is reduced in GESEPI ASE. Fig. 2c suggests that this is due to effective correction of large EPI ASE R_2' values without overcorrecting voxels unaffected by z-gradients.
Discussion: The GESEPI ASE method enables direct measurement of R_2' with compensation for z-gradients, caused by macroscopic magnetic field inhomogeneity, which is effective in most of the brain. This is achieved in a short scan duration and does not require R_2 to be fitted, removing potential sensitivity to multicomponent R_2 decay. Larger z-gradients can be compensated by increasing the number of subslices acquired, but will result in longer scan times. Further work is required to compensate for in-plane gradients, potentially using postprocessing techniques[7].

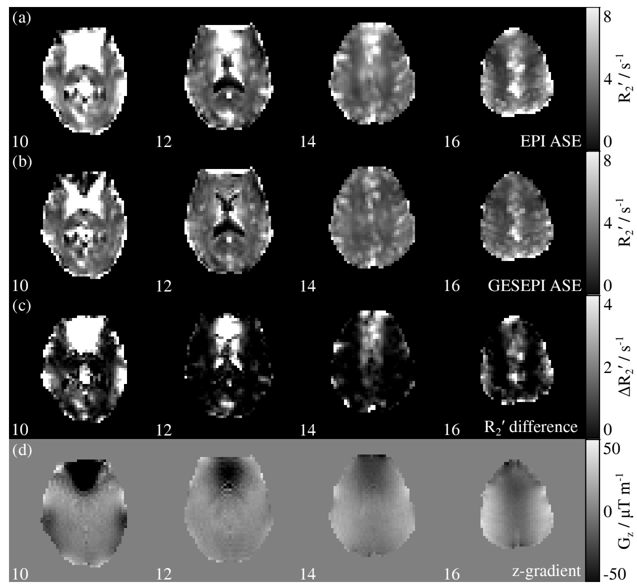

Fig. 1 – Maps of R_2' acquired from a single subject using (a) EPI ASE and (b) GESEPI ASE. The difference between these maps (c) reveals regions in which z-gradients have been corrected resulting in a reduction in R_2'. These regions are consistent with the areas of higher z-gradient as measured from a separately acquired magnetic field map (d).

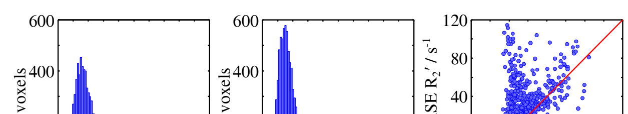

Fig. 2 – Histogram of R_2' extracted from a cortical grey matter ROI for (a) EPI ASE (mode $3.0s^{-1}$) and (b) GESEPI ASE (mode $3.0s^{-1}$). Plot of R_2' measured by each method on a voxel-by-voxel basis (c) displays the effective reduction of large EPI ASE R_2' values by GESEPI ASE.

References: 1. Ordidge *et al.*, Magn Reson Med, 32:335-341 (1994), 2. He & Yablonskiy, Magn Reson Med, 57:115-126 (2007), 3. Blockley *et al.*, Neuroimage, 60:279-289 (2012), 4. Ma & Wehrli, J Magn Reson B, 111:61-69 (1996), 5. Yablonskiy, Magn Reson Med, 39:417-428 (1998), 6. Yang *et al.*, Magn Reson Med, 39:402-409 (1998), 7. Smith & Brady, Int J Comput Vis, 23:45-78 (1997), 8. Yablonskiy *et al.*, Magn Reson Med, 70:1283-1292 (2013). **Acknowledgement:** Funded by the EPSRC.