Phase encode directional optimization in EPI acquisition

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Introduction

Echo planar imaging (EPI) is highly sensitive to static magnetic field inhomogeneities, which lead to image distortions in the phase-encoding direction. The degree of local image compression or stretching is a function of the static field gradient (SFG) in the phase-encoding direction. Although any static field shift will lead to a position shift in the reconstructed EPI data, it is the regions with large SFGs that are the most difficult to correct. In some fMRI studies, it may be desirable to focus on one or more specific brain regions. However, within those regions, high SFGs will lead to undesirable local warping in those ROIs. Approaches to this problem include field shimming, post-processing algorithms (e.g. corrections using field-maps, point spread functions, or non-linear registration transforms) for un-warping the EPI data. The degree of distortion can also be minimized by setting the phase encoding direction of the scan plane in the direction of the smallest SFG. In this study, we introduce a method for optimizing the EPI phase encoding direction within subjects using 3D fieldmap data.

Method

i) Fieldmap data acquisition & 3D fieldmap reconstruction: Two sets of whole-brain gradient-echo phase maps (TE1 = 8ms, TE2 = 11ms) were collected on a 3T MRI scanner. 3D phase unwrapping was performed and the field map was calculated using the expression: $\Delta Bo = \Delta\Phi/(\gamma \cdot \Delta TE)$.
ii) ROI Selection & SFG Calculation: One or more voxels may be selected to form an ROI. At each location, the local static field gradient (SFG) in 3D is computed from the field map. In this study, only the amplitude and not the polarity of the field gradient was measured. The data was displayed in polar coordinates so that $SFG(\alpha,\beta) = \partial\Delta Bo/\partial D$, [$Dx = R\cdot\cos(\alpha)\cdot\cos(\beta)$, $Dy = R\cdot\cos(\alpha)\cdot\sin(\beta)$, $Dz = R\cdot\sin(\alpha)$, α = -89° to 90°, β = -89° to 90°], where R = Radius of hemisphere, α,β = vertival/horizontal angular displacements. For the ROI analysis, the SFG values from all the voxels in the ROI are averaged.
iii) Selection of Optimum Phase Encoding Direction for Minimum Local SFG: The directional SFG was mapped on a sphere for efficient visualization using Matlab(The MathWorks, Inc.). By interpreting the color distribution we were able to determine a range of optimum phase encoding directions. In this step we selected a direction, which is closest to conventional phase encoding directions (i.e. α,β = [-180°, -90°, 0°, 90°, 180°])

Experiment and Results

In one study, we selected two highly separated voxels (in right insular cortex and the left amygdala) for a fMRI study as shown in Figures 1 and 2. The SFG was calculated for both voxels. In Figure 3, the sphere shows the directions of minimum SFG for the insular cortex (green) and amygdale (blue). Also mapped are the directions where the SFG is relatively large, which are red for the amygdale and pink for the insular cortex. Note that the amygdala has a larger angular area of undesirable directions because it is closer to the sphenoid sinus, which has large field gradients, whereas the field homogeneity is much better in the insular cortex region. Finally, in this insular cortex/amygdala example, the most desirable phase encoding direction is anterior/posterior tilted down to inferior by 40°~50° or rotated to right by 30°~40° and the most undesirable directions are the S/I and R/L directions, which means that a coronal acquisition would be suboptimal.

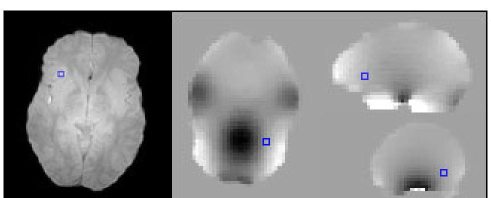

Figure1.-Insular Cortex
Left: ROI on anatomical image
Right: ROI on fieldmap

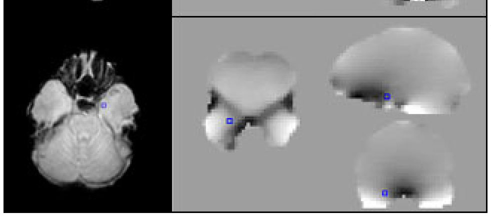

Figure2. -Amygdala
Left: ROI on anatomical image
Right: ROI on fieldmap

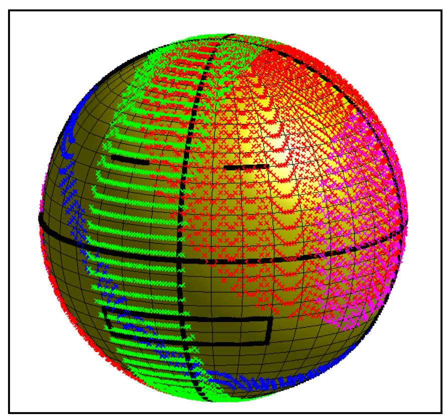

Figure 3.
SFG in 3D model from 2 ROIs

Discussion

We have introduced a method to estimate the optimum direction of phase encoding for specific ROIs in an EPI study. By using the optimum phase-encoding, the images in those regions will show the least deformation of our ROI. This approach can be used either with or without prior shimming. Since the SFG polarity was not considered, there was no preference of the selection toward either image compression or stretching. In general, stretching is more easy to compensate, so future version of this approach will take the SFG polarity into account. The results may also be used to optimize the sequence for minimizing the effects of susceptibility gradients for gradient echo EPI. In this case, it is desirable to set the minimum voxel dimension in the direction of the steepest SFG. Future studies will attempt to simultaneously optimize the phase-encoding distortions and susceptibility artifacts.

References

[1] J. Wilson et. al., MRM, 48:906-914,2002