Comparison of distortion correction methods for EPI diffusion tensor MRI

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Introduction

Voxel-based and tract-based group comparison of diffusion tensor (DT) MRI indices is potentially useful for a number of applications. However, as DT MRI is typically acquired using echo-planar imaging (EPI), it is prone to geometric distortions caused by magnetic field inhomogeneity. As the amount of susceptibility-induced distortion depends on the shape and the position of the head in the magnet, it is hard to achieve a good spatial match between DT MRI maps from different subjects, thus making the voxel-based approach particularly challenging for DT MRI. In order to address the problem of geometric distortions, it has been suggested to directly measure the field inhomogeneity by acquiring a B_0 field-map and to use it to correct EPI retrospectively [1]. Although the use of field-maps allows the geometric properties of the imaged sample to be restored, it cannot reverse the signal intensity modulation, which is also caused by rapid susceptibility variation across the object. An alternative solution consists of the acquisition of two data sets with opposite k-space traversal direction (reversed gradient method), and therefore opposite distortion, which can later be combined to form a distortion-corrected image [2] without loss of information. Here we compare qualitatively 3 correction methods (gradient-echo B_0 field-mapping, EPI B_0 field-mapping, and the reversed gradient method) by means of their ability to preserve the directional information in a single subject dataset, and after averaging across subjects.

Methods

Seven subjects (F/M=3/4, median age = 33yrs, range 26-42yrs) were scanned on 1.5T scanner (General Electrics, Milwaukee, USA). The protocol included A) a cardiac-gated pulsed-gradient spin-echo EPI (TE=96ms, echo spacing=596μs, slices=60, matrix=96x96, slice thickness=2.3mm, FoV=22mm^2) with diffusion gradients applied along 61 directions [3] (b_{max}=1200smm^{-2}) and 7 b=0 images; B) a field-mapping gradient-echo EPI (TE1/TE2/TR=34.2/38.7/4000ms, same FoV and resolution as the DT scan); and C) a field-mapping spoiled gradient-echo (SPGR) sequence (TE1/TE2/TR=3/7.5/18ms, slices=30, matrix=256x128, slice thickness=4.6mm, FoV=24x18mm^2). Sequence A was repeated 3 times, once reversing the direction of k-space traversal. The scan pair obtained with different k-space directions was combined according to [4]. In order to obtain data sets with comparable SNR, the two scans obtained with the same gradient direction underwent identical processing and then averaging. They were first corrected for eddy current distortion using a 2D affine registration [5] and then corrected for susceptibility using either field-map. Field-maps were computed using a modified version of *fieldmap_undistort* [6], while EPI field-map inversion was obtained according to the algorithm in the SPM2 *Fieldmap tool box* [7]. The following procedures were performed using *Camino* [8] and they were repeated once for each dataset (1-corrected for eddy currents only, 2-corrected for distortions using EPI field-maps, 3-corrected for distortions using SPGR field-maps, and 4-corrected using the reversed gradient method). First, the diffusion tensor was computed for all subjects. Then the transformation matching every subject's volume to that chosen as reference was obtained by coregistering their fractional anisotropy (FA) images using *Flirt* [9]. Tensors were realigned using the preservation of principal direction algorithm [10] and averaged across subjects; FA and colour-coded direction maps (modulated by FA) were computed from the mean tensors.

Results

Fig 1 shows the colour-coded direction maps from a single subject in a section through the pons, the cerebellum and the temporal lobes. Eddy current effects are still partially visible in images a-c (yellow arrows), while not in d (the reversed gradient correction method). While the gross geometric properties of the sample were clearly improved by the SPGR field-map correction, the directional information is lost (red arrows). Such information is better preserved when using the reversed gradient method. Very little change is provided by the EPI field-map correction with respect to the uncorrected image (white arrow). Fig 2 shows the colour-coded direction maps obtained from the average tensors at a more superior location. White matter structures appear sharper and better defined on the reversed gradient corrected image (d), particularly in thin structures, such as the external capsule, in frontal regions, and within regions of lower anisotropy, such as the thalamus. Brain edges and grey matter are also less visible, indicating a better alignment between subjects and reduced eddy current-related errors.

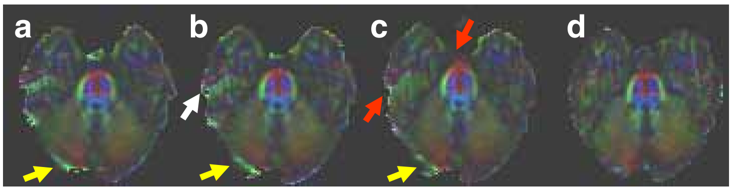

Fig 1. *Colour-coded direction maps from a single subject. a) uncorrected, b) corrected with EPI field-maps; c) corrected with SPGR field maps; d) corrected with the reversed gradient method*

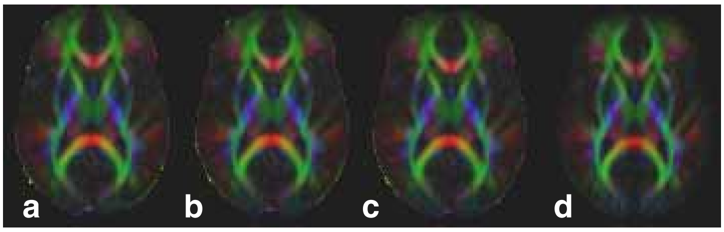

Fig 2. *Colour-coded direction maps from mean tensors. a) uncorrected, b) corrected with EPI field-maps; c) corrected with SPGR field maps; d) corrected with the reversed gradient method*

Discussion

We have shown that the reversed gradient method improves the spatial match of DT MRI between subjects and is able to preserve signal intensity as well as geometric properties of the sample in the presence of magnetic susceptibility. SPGR field-maps allow the shape of the sample to be restored, but not the correct intensity profile. EPI field-maps provide little advantage compared to not performing any correction, most likely because being distorted themselves, information of field variation is lacking where is most needed, i.e. where field inhomogeneity shows the steepest variation.

References

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