Fieldmap-Free Retrospective Registration and Distortion Correction for EPI-based Diffusion-Weighted Imaging

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Introduction

Acquisition of a set Diffusion Weighted Images (DWIs) allows Diffusion Tensors and Tensor-derived quantities such as Fractional Anisotropy (FA) and Trace (TR) to be computed and used to infer the underlying white matter structure in the brain. DWIs are usually acquired with an echo-planar imaging (EPI) pulse sequence that produces images degraded by B0 field inhomogeneity, eddy current distortion and head motion. B0 distortion can be corrected using acquired fieldmaps [1], but these are typically unavailable in clinical studies, while eddy currents at acquisition time can be reduced, but not eliminated with gradient correction schemes [3]. In this work we evaluate a retrospective Fieldmap-Free method for B0, eddy current and motion correction in the context of EPI-based DWI and compare it to previous work that uses acquired fieldmaps and registration-based eddy current correction [2,4].

Methods

Performance of the Fieldmap-Free method **(FF)** is evaluated using the experimental framework previously described in [4]. Distortion of EPI data due to B0 and eddy current effects occurs primarily along the phase encode direction, allowing EPI data sets with different distortion conditions (determined by the phase encode direction and polarity) to be acquired for a single subject. Accurate unwarping of the distorted data sets should improve registration and reduce variability in tensors, FA, and TR images computed for each distortion condition.

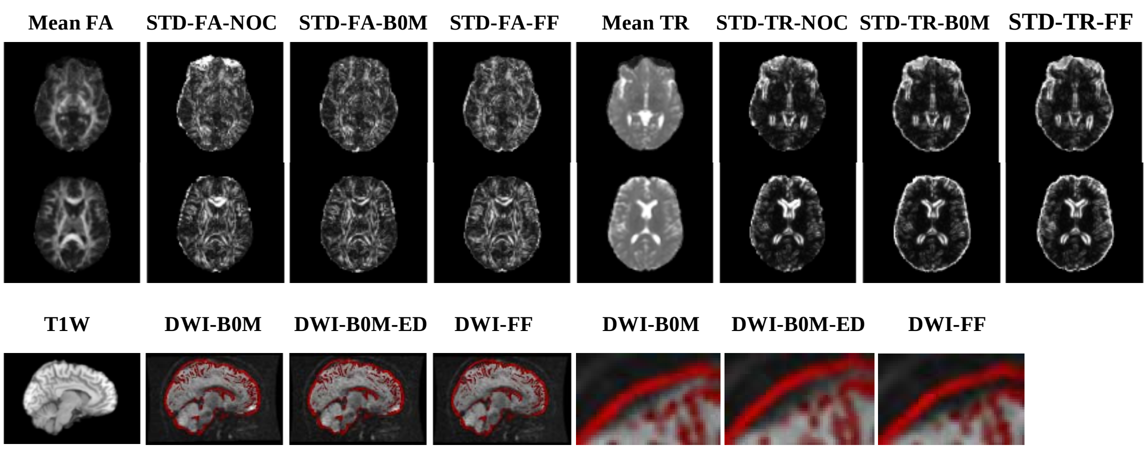
Imaging: Five young subjects (2 male; mean age = 35.95, range 24-48 years old) participated in [4]. Four axial DWI datasets for each subject were acquired: the phase encode direction was either anterior/posterior (A/P), or right/left (R/L), and the phase encode blips had positive or negative sign resulting in compression or expansion distortion along the A/P and R/L axes. Data was acquired on a 1.5 Tesla GE scanner with a single-shot spin-echo EPI sequence: FOV = 24x24cm, slice thickness = 2.5mm, no gap, matrix = 96x96 zero filled to 128x128, 60 axial slices. Each DWI dataset consisted of 2 images with b=0s/mm^2 and 12 images with b=1100s/mm^2 with different orientations of diffusion sensitization. Undistorted T1 weighted (T1W) and T2 weighted fast spin echo (T2WFSE) was acquired and two gradient echo images with different echo times were collected for B0 mapping [4].

B0 EPI distortion correction: All DWI images were co-registered to the T2WFSE to correct for rigid body motion and eddy current distortion [2]. The **FF** method that was previously shown to be effective for correcting B0 distortion in EPI-based functional data [5] was applied to correct the distorted DWIs. A tissue/air segmentation of the T1W data was obtained for fieldmap calculation as described in [5]. Distortion correction from the B0 field data **(B0M)** was also performed using FSL's PRELUDE and FUGUE [6] for comparison with the **FF** results.

Eddy Current distortion correction: The Fieldmap-Free method was used to estimate unknown shim fields, compute a fieldmap, and unwarp the original DWI (b=0 s/mm^2). Unknown eddy current fields present in the DWIs (b=1100 s/mm^2) were modeled using the same spherical harmonic basis used to model the shim fields. The FF method searched over these parameters: the b0 and eddy current displacement field for each volume was obtained by optimizing the agreement between the undistorted T1W and corrected DWI. Following unwarping of each DWI in its native space, rigid body registration to the T2WFSE was carried out to allow comparison with the eddy plus B0M correction method described above **(B0M).**

Results

The figure shows Standard Deviation **(STD)** maps of FA (Display range: black=0, white=0.3) and TR (Display range: black=0 mm^2/s white=2.0 *10-3 mm^2/s) computed across the four distortion conditions for a representative subject in the B0 EPI correction experiment. Correction using the **FF** method agrees well with the **B0M** results, while the results without B0 correction **(NOC)** show greater variability around the ventricles and frontal region. The mean FA (Display range: 0, 0.95), and mean TR (Display range: 0, 5.0 *10^{-3} mm^2/s) from datasets with FF correction are included as anatomical reference. Results of the eddy correction experiment are shown in row three of the figure for a second subject. Results of the FF method for B0 and eddy correction **(DWI- FF)** agree well with those obtained by the eddy plus B0 fieldmap method **(DWI-B0M-ED)** and show improvement over the DWI corrected for B0 but *not* eddy distortion **(DWI-B0M)**. An edge-strength image of the T1W data is shown in red for visualization of the registration results.



Conclusion

EPI B0 distortion correction using the Fieldmap-Free method reduces the variability of FA and TR computed from DWI data with varying distortion, producing results that agree well with standard fieldmap techniques. Preliminary results of eddy current correction using this approach also show agreement with current methods and improvement over results without correction, providing a fully retrospective, Fieldmap-Free method suitable for distortion correction in EPI-based DWI.

References

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