Strategies for improved correction of EPI distortions in diffusion MRI with blip-up blip-down acquisitions

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Target Audience: The strategies proposed in this study are relevant to those seeking improved corrections for echo-planar imaging (EPI) distortions for diffusion MRI data sets with large distortions.

Purpose: EPI suffers from geometrical distortions along the phase-encode (PE) direction due to susceptibility gradients, accompanied by signal pile-up or dilution. Recently implemented effective correction methods [1,2] involve the acquisition of a pair of datasets with reversed phase encoding or "blip-up blip-down" [3]. In this work, we propose a novel robust blip-up blip-down method specialized for diffusion MRI data. In our experience, data with large distortions such as the "connectome" data (*www.humanconnectomeproject.org*) are not fully corrected with existing approaches. Moreover we found that structures with homogeneous signal on the b=0s/mm^2 images often present internally distorted anatomy in the diffusion metrics even if the gross morphology appears properly corrected. Our goal is to overcome these issues. Our correction method takes advantage of a structural image (T_2W) to cope with large distortions and of diffusion-weighted images (DWIs) to improve the correction in white matter (WM).

Materials: Datasets with large distortions were collected with no parallel imaging on 3T scanners from the three main manufacturers, 32-channel RF coils and 2mm isotropic resolution. 30 DWIs (b=1100s/mm^2) were acquired along with 5 b=0 images and this protocol was repeated for right-left and anterior-posterior PE and up and down blips. A fat suppressed T_2W FSE image was also acquired with 0.93x0.93x1.7mm resolution.

Methods: *Registration method:* The up and down EPI images were used as the start and end points of a "large deformation", time-dependent velocity based, diffeomorphic registration passing through a middle image at t=0.5 which represent the best estimate of the resulting distortion free EPI image. We used the T_2W image as a constraint for the middle image in a symmetric registration framework [4]. This facilitates registration's convergence in presence of very large distortions. Our algorithm also addresses lack of perfect collinearity between the PE direction of the up and down images caused by motion and considers proper signal redistribution to account for local contractions and expansions during the correction. A quadratic registration [5] of the b=0 to the structural image was also performed to account for the effects of concomitant fields.

To improve the correction in WM regions the blip-up blip-down DWIs were used along with b=0s/mm^2 images in a multi-channel registration framework. Given that registering each DWI pair is computationally expensive if a large number of directions is used, we also implemented a dimensionality reduction method which uses "synthetic" DWIs generated from the diffusion tensor model for this task.

Registration Validation: We compared our proposed method to both "FSL Topup" [2] and the method proposed by Holland [3]. For each method, the corrected data's b=0 images and DEC color maps were visually inspected. Additionally, the agreement of RL and AP data after correction was quantified by computing the average of their variances over a population of five subjects as previously described for a different project [6].

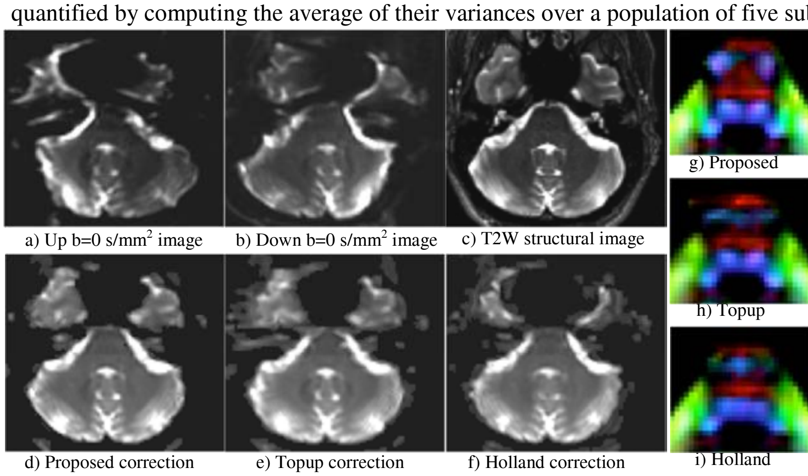

Figure 1. The proposed and two reference methods used to correct largely distorted data with RL PE.

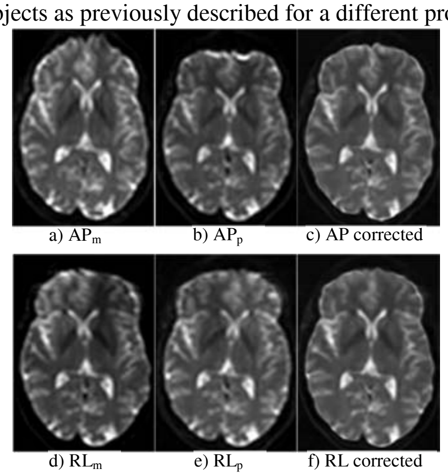

Figure 2. Correction of AP and RL data

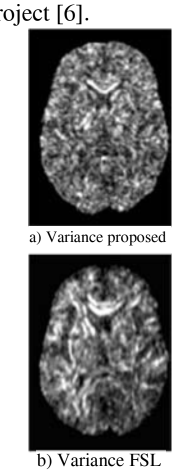

Figure 3. Variance maps

Results: Figure 1 shows representative results from the correction methods we tested. For all methods, the corrected b=0 images show significant improvement of the gross anatomy, with our proposed method showing better correction in severely distorted areas of the temporal lobes. However, color maps at the level of the Pons reveal improper correction for both Topup and Holland's algorithms with clearly abnormal anatomy of the cortical spinal tracts. Figure 2 shows the good correction achieved by the proposed method at a different level of the brain. The images corrected by the proposed method usually have sharp tissue interfaces. Fig 3 shows the population-averaged fractional anisotropy variance maps for Topup and for our method. The variance map of the proposed method shows very good correction except for a small portion of the genu of corpus callosum whereas Topup method shows several structures that are not well aligned between AP and RL data.

Conclusions: The proposed method produces better correction of EPI distortions than existing algorithms. In analyzing the performance of EPI distortion correction methods applied to diffusion MRI data, it is very important to evaluate the anatomical accuracy of the derived diffusion metrics, not only of the b=0 image.

References: 1. Holland D., Neuroimage, 2010; **2.**Andersson J., Neuroimage, 2003; **3.** Bowtell R., ISMRM, 1994; **4.**Avants B., Med. , 2008; **5.** Rohde G., MRM, 2004; **6**. Wu M., MICCAI 2008