Quantitative analysis of directional bias imposed on primary eigenvector estimations in DTI when gradient table correction is neglected

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Target Audience: Researchers and clinicians who are interested in DTI and Tractography techniques.

Introduction: In Diffusion Tensor Imaging (DTI) image misalignments caused by head motion and geometric deformations caused by eddy currents are corrected by applying spatial transformations to the images. It has been suggested that the gradient table should be reoriented using the same motion corrections to ensure that the gradient directions used in DTI estimation are accurate. The effects of gradient table correction on estimates of Fractional Anisotropy (FA) and primary eigenvalue were demonstrated before. However, its effects on fiber tracking were studied qualitatively and a quantitative analysis of adjustments to primary eigenvector (PE) has not been presented. In the study presented here, we conducted a quantitative analysis of directional bias imposed on PE when gradient table correction is neglected. We compared this bias with the inherent uncertainty in the estimation of orientation distribution functions (ODF). Although the directional bias in voxels were very small, our results also showed that the effects might accumulate along the fiber tract and lead to inaccurate fiber tracking. The findings were validated using simulations.

Methods: DTI data used for this analysis was selected from a set acquired from 126 children (age: 6-10yrs) for an ongoing study of cognitive development. The study was approved by the Institutional Review Board and written consents were obtained from the parents. A SE-EPI pulse sequence was run on a 3T Philips Achieva system (Best, Netherlands) with 32 gradient directions with b=800 and a single acquisition with b=0 (60 axial slices, 1.75x1.75x2mm3 voxel size, NEX=1, TR/TE=9290ms/55ms and SENSE=2.4). Total data acquisition time was 6 minutes.

DTI data were processed by FSL 4.1 software package (http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/FDT). Head motion and geometric deformations were corrected using 12 parameter affine transformations. The variances of rotation angles used in motion correction were calculated to quantify the amount of motion for each subject. The subject with the maximum amount of motion was selected to analyze the worst-case scenario. Calculations were performed for all voxels in the cingulum (in the cingulate gyrus area) and Corticospinal Tracts (CST) for this subject as well as 4 more subjects.

This showed us how motion biased the diffusion estimates in two major tracts in two orthogonal directions. In the voxels of these fiber tracts, we calculated gradient table correction angle (GTCA, Eq.1), which is defined as the angle between corrected ($e_i$) and uncorrected ($e'_i$) vectors of the primary diffusion direction. In the first step, we investigated if the angular corrections were larger than the inherent uncertainty in the estimation of fiber orientation inside a voxel (random noise). The FSL program provides estimates of diffusion vector dispersion, which is a measure of this uncertainty. It characterizes how broad the ODF is around the main diffusion vector. It can be transformed into degrees as given in Eq. (2). We compared the dispersion angle and GTCA in each voxel and calculated the percentage of voxels that have larger dispersion angles than GTCA. This comparison only shows if the directional corrections were below or above the noise level in general. However, it should be noted that even though GTCAs might be smaller than dispersion, if they are biased in a particular direction, the effects might accumulate coherently in subsequent voxels.

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\begin{align*}
GTCA &= \min \left[ \arccos \left( e'_i \cdot e_i \right) \right] \\
\text{Dispersion angle} &= \arccos(1 - \text{Dispersion})
\end{align*}
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Figure 1. (a) Histograms of GTCA and dispersion angle in cingulum (background) and CST (foreground). (b) The distribution of difference vectors calculated by subtracting the uncorrected vectors of the primary diffusion direction from the corrected ones.

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