Estimation of the eddy-current induced magnetic field from affine-transformation parameters and its relevance for the comparability of DTI data

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Introduction: Diffusion tensor imaging (DTI) offers the possibility of estimating quantities, e.g. the fractional anisotropy (FA) [1], that are related to white matter (WM) microstructure and could be used for group comparisons [2]. Imaging artifacts like eddy-current (EC) induced image distortions and subject motion during prolonged acquisitions cause misalignments of the DW images, which bias the estimation of the diffusion tensor and FA. Although EC distortions can be significantly reduced by using a twice-refocused spin echo sequence [3], this technique is not uniformly available on all commercial MR scanners. EC distortions could also be minimized by *slice-wise* or *whole*-brain registration. The advantage of the whole-brain approach is that EC distortions and movements are corrected simultaneously. However, for both approaches residual imaging artifacts persist; meaning that solely DTI data suffering from a similar *kind* of EC-induced magnetic field ($\mathbf{B}_{EC}$) should be used for group comparison. *Non-linear* registration has been shown to permit correction of EC distortions and estimation of $\mathbf{B}_{EC}$ from the transformation parameters [4]. However, a 12-parameter affine transformation is often used for EC correction. It remains to be shown whether it is possible to estimate $\mathbf{B}_{EC}$ from the affine transformation parameters. Objectives of the current study were thus to investigate *(i)* the possibility to estimate $\mathbf{B}_{EC}$ form the 12 parameters of an affine transformation for correcting EC distortions and motion artifacts, *(ii)* the reliability of this estimation of $\mathbf{B}_{EC}$ in terms of inter-individual variation.

Methods: Data were acquired from 9 volunteers using a Gyronscan Intera 3T system (Philips, Best, The Netherlands) with a birdcage head coil and 33mT/m gradients. DTI data were recorded with EPI with 20 DW and 3 b0 images (NEX 2, matrix 128×128, 36 axial slices, thickness 3.6mm). EC distortions were derived for the whole volume in static first-order approximation leading to 3 well known EC distortions (z_{xy}: shearing in the *xy*-plane, s_y and t_y: scaling and translation along the phase-encoding direction (*y*-axis) [5,6,7]) plus one previously unconsidered EC distortion (z_{yz}: shearing in the *yz*-plane, Fig. 1a). Each distortion parameter corresponds to one $\mathbf{B}_{EC}$ component in z-direction in the first-order approximation $B_{EC,z} \approx B^0_{EC,z} + \vec{r} \cdot \vec{G}_{EC}$, i.e. $t_y \propto B^0_{EC,z}$ (homogeneous component), $z_{xy} \propto G_{EC,x}$, $s_y \propto G_{EC,y}$, and $z_{yz} \propto G_{EC,z}$ (*x*-, *y*-, and *z*-components of the EC gradient). For correction of EC distortions and motion artifacts each DW image was registered to the b0 image via an affine transformation. For each subject, the estimated EC-related transformation parameters were plotted as a function of the diffusion gradient number (Fig. 1b showing z_{yz} parameters). The contribution from each EC parameter to the improvement of diffusion tensor estimation was quantified by the relative residual error (Fig. 1c).

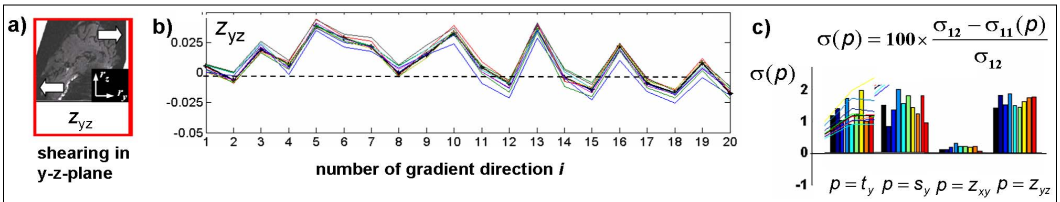

Fig. 1. (a) Previously unconsidered (new) EC distortion, i.e., shearing in the *yz*-plane (z_{yz}) ∝ z component of the EC gradient. **(b)** For each subject (color coded), the z_{yz} parameter is plotted as a function of the diffusion-gradient direction number *i*. **(c)** Relative residual error, σ(*p*), for each EC parameter (color coding as in **(b)**); σ_{12} and $\sigma_{11}(p)$ are residual tensor errors [7] after EC correction by employing a 12- and a 11-parameter affine transformation, respectively, *p* denotes missing affine parameter for 11 parameter transformation.

Results and Discussion: (*i*) Four linear components of $\mathbf{B}_{EC}$ could be estimated by one *affine* image transformation. In most previous studies, the EC distortions were derived slice-wise. In the slice-wise representation, two of the linear $\mathbf{B}_{EC}$-components ($B^0_{EC,z}$ and $G_{EC,x}$) lead to the same affine distortion (t_y, translation in *y*-direction [5]). By deriving the EC distortions for the *whole* volume, we found that $B^0_{EC,z}$ and $G_{EC,x}$ cause different affine distortions: translation along the *y*-axis and shearing in the *yz*-plane. (*ii*) Among the four affine EC distortions, the translation parameter t_y showed the largest inter-individual variation because individual patient movements also lead to translations besides EC effects. The new EC distortion parameter z_{yz} permitted reliable estimation of the *z*-component of the EC gradient field ($G_{EC,z}$) with minimal inter-individual variation (Fig 1b) and large improvement of the residual tensor error (Fig. 1c). Moreover, the z_{yz} parameter varied strongly as a function of the diffusion gradient direction reflecting the long-term time course of $G_{EC,z}$. Hence, a part of the EC field could retrospectively be reconstructed from the EC distortions.

Conclusion: It is possible to estimate four linear components of $\mathbf{B}_{EC}$ from the EC parameters of the affine transformation that has been employed for EC and movement corrections. Further, the long-term time course of parts of $\mathbf{B}_{EC}$ can be reliably reconstructed from the EC parameters. By comparing this time course of $\mathbf{B}_{EC}$ for different DTI data, the presented method provides a possibility to assess the comparability of ambiguous DTI data in a retrospective manner.

References: [1] Basser et al., JMR B **111**, 209-19, 1996; [2] Deppe et al., Neurology, in press; [3] Reese et al., MRM **49**, 177-82, 2003; [4] Rohde *et al.*, MRM **51**, 1103-11, 2004; [5] Haselgrove et al., MRM **36**, 960-64, 1996; [6] Jezzard et al., MRM **39**, 801-12, 1998 ; [7] Andersson et al., NeuroImage **16**, 177-99, 2002.