Correction of vibration artefacts in DTI using phase-encoding reversal (COVIPER)

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Introduction: Diffusion tensor imaging (DTI) is widely used in research and clinical applications, but still suffers from substantial artefacts. Patient table vibrations induced by strong diffusion gradients in DTI [1] can lead to an echo shift in k-space and consequential signal-loss [2]. The goal of this study was to retrospectively correct vibration-induced signal loss using the concept of acquiring two data sets with opposite phase encoding direction (PE) [3,4,7]; a well established approach for reducing susceptibility-induced signal loss due to echo shifts in gradient echo echo-planar imaging (EPI) [3,5]. Using this concept, we have developed a simple method for correction of vibration artefacts in DTI using phase-encoding reversal (COVIPER).

Background: Rotational motion during the diffusion-weighting period may shift the echo centre over the edge of k-space in PE direction (Fig. 1a) and lead to signal loss [6]. To capture the shifted main echo the acquisition window can be shifted by reversing the PE direction (Fig. 1). If two images with reversed PE direction (subsequently denoted as blip-up and blip-down data set) are acquired, the signal lost in one of these images may be recovered in the other.

Methods: Three healthy volunteers (2 female, 1 male) were scanned on a TIM Trio 3T scanner (Siemens Healthcare, Erlangen, Germany). DTI data were acquired using the following parameters: 60 DW images with spherically distributed diffusion-gradient directions, 6 non-DW images, matrix 96x96, 60 slices, 2.3mm isotropic resolution, 5/8 Partial Fourier in PE direction using zero filling reconstruction, TE=86ms. For each subject four DTI datasets were acquired: (a-b) two short repetition-time (TR) images using blip-up and blip-down PE directions (TR=8.2 s, $DTI^{\pm}_1$), (c-d) the same measurement as in (a) and (b) but using a longer TR=10.4s. Increasing the TR in (c) and (d) made the data less affected by vibration artefacts (see [2]), and appropriate as the reference dataset. In the first step of the COVIPER method, the diffusion tensor and the residual error of the tensor fit were calculated for all four DTI datasets. In the second step, the apparent diffusion coefficients of the blip-up and blip-down DTI data were combined using a local weighting function of their tensor-fit error. To assess the method, the bias in FA was calculated using the root-mean-square (RMS) FA-difference between affected and reference data (details see Fig.3).

Results: Fig. 2 shows the RMS of the error of the tensor fit, and Fig. 3 shows the quantified bias in FA. For dataset $DTI^{\pm}_1$ the vibration-induced bias in FA was visible in at least one dataset and in different spatial locations for the blip-up and blip-down dataset of each subject (Fig. 2, arrows). Moreover, the extent of the bias varied between individuals ($\Delta FA^{bias} \in [0.29, 0.39]$, Fig. 3). Averaged over subjects the standard arithmetic mean combination of blip-up and blip-down data reduced the vibration-induced bias in FA by 49% (from $\Delta FA^{bias} = 0.35$ to $\Delta FA^{mean} = 0.18$, Fig. 3). In contrast, the proposed COVIPER correction based on weighted-sum combination of blip-up and blip-down data reduced the error in FA by 72% ($\Delta FA^{COVIPER} = 0.1$, Fig. 3). The contribution of miscellaneous effects that could not be attributed to vibration effects in the COVIPER method was about 6% (Fig. 3). Note that the arithmetic-mean combination affects the tensor estimate for all regions showing vibration artefacts in the original data, i.e. the union of affected regions in the blip-up and blip-down data. As a result the arithmetic-mean combination may show more widely spread artefacts (data not shown), than any of the two original datasets (though usually at a lower artefact level).

Discussion and Conclusion: Previous models of movement-induced echo shifts showed that table vibrations can induce rotational movement of the brain tissue [8], which in turn can lead to signal-loss in DTI [6]. By refining these models, we showed that asymmetric k-space coverage in widely used Partial Fourier acquisitions results in locally differing signal loss in images acquired with reversed phase encoding direction, and developed the COVIPER method. Using low-vibration reference data the COVIPER method was validated, resulting in an error reduction of about 72% in FA maps. COVIPER can be combined with other corrections based on phase encoding reversal, providing a comprehensive correction for eddy currents [9], susceptibility-related distortions [10] and vibration artefact reduction.

Acknowledgement: This study was supported by the Wellcome Trust. **References:** [1] Hiltunen, NI, **32**, 93 ('06), [2] Gallichan, HBM, **31**, 193 ('10), [3] Deichmann, NI, **15**, 120 ('02), [4] Weiskopf, NI, **24**, 1068 ('05), [5] Posse, MRM, **25**, 12 ('92), [6] Storey, MRM, **57**, 614 ('07), [7] De Panfilis, NI, **25**, 112 ('05), [8] Gallichan, MRM, **62,** 815 ('09), [9] Gallichan, MRM, **64**, 382 ('10), [10] Andersson, NI, **20**, 870 ('03).

Fig. 1:

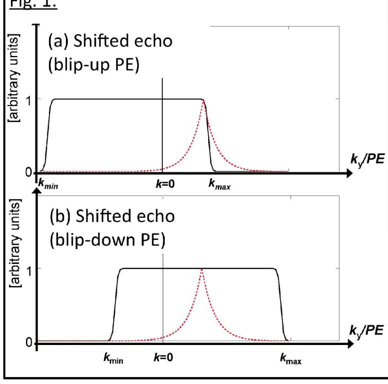

Fig. 2:

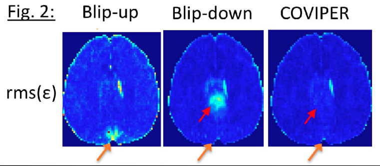

Fig. 3:

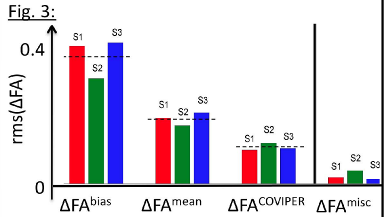

Fig. 1: Schematic diagrams showing the k-space coverage (black) and the echo (red) for both blip-up (a) and blip-down (b) acquisition. **Fig. 2:** The root-mean-square (RMS) of the error of the tensor fit rms(ε) using the $DTI^{\pm}_1$ data sets of subject S1, blip-up (left), blip-down (middle), and the weighted sum of blip-up and blip-down data (COVIPER, right). Note that the location of the artefact is disjoint for the blip-up (orange arrows) and blip-down (red arrows) data. **Fig. 3:** Quantification of the bias in FA for subjects S1 to S3 using the RMS FA-difference between affected and reference data within: the measured data (ΔFA^{bias}), (b) their arithmetic-mean (ΔFA^{mean}), (c) and their weighted-sum combination ($\Delta FA^{COVIPER}$). Furthermore, miscellaneous effects of the proposed correction method (ΔFA^{misc}) were assessed using the RMS FA-difference between the arithmetic-mean and weighted-sum combination of the reference data containing negligible vibration artefacts.