

Efficient correction of static and dynamic (including eddy current) field inhomogeneity in DTI data

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Introduction:

The majority of diffusion-weighted white matter MR imaging is performed using echo-planar imaging (EPI) with a twice-refocus spin-echo (SE) pulse sequence. Signal to noise is highly dependent on shortening the echo time. An older method of acquiring this data allows a shorter echo time, using a single-refocus spin-echo. This increased SNR comes at the cost of variable eddy current artifact. A recent algorithm by Holland et al [1] produces a displacement map equivalent or superior to that obtained using a field-mapping pulse sequence, requiring a pair of otherwise identical SE EPI images with opposite phase-encoding (PE). We have acquired data with twice-refocus SE (TRSE) DTI and single-refocus SE (SRSE) DTI, both modified to acquire every volume twice, with normal PE direction on all odd scans and opposite PE on all even volumes, acquiring each diffusion direction twice, similar to the method of Gallichan et al [2] but with the same SNR for both PE directions. By obtaining the shiftmap for every acquisition, the data can be 1) unwarped for static field inhomogeneity and 2) corrected for eddy currents arising from diffusion gradients, for every diffusion direction. We compare data with no unwarping correction (NO-UNW), data corrected for static inhomogeneity using the first pair (ONE-UNW), and data corrected for dynamic inhomogeneity using every pair (ALL-UNW). This results in a robust post-processing method to correct for eddy current and dynamic inhomogeneity distortions at the same time as static field inhomogeneity in DTI data. More importantly: dynamic unwarping can correct these static and dynamic inhomogeneities in the presence of motion.

Methods:

A healthy control was scanned with 2 DTI scans in an IRB-approved protocol at 3T in a 12-ch receive head coil. Iso 2mm diffusion tensor imaging (DTI) scans with twice-refocussed spin-echo (TRSE) and with Stejskal-Tanner single refocus echo (SRSE) were acquired with 71 diffusion directions ($b=1000$ sec/mm 2) in two opposite PE directions. The following MR parameters were used: 51 axial slices, seven $b=0$ as reference, BW=1628Hz/pixel. The readout encoding direction was unchanged across scans. Displacement map was calculated [1] for each pair of DTI volumes with the same diffusion gradients. Data was either not unwarped (NO-UNW), unwarped using the first displacement map from the first paired $b=0$ images (ONE-UNW), or unwarped using every displacement map (ALL-UNW). Fractional anisotropy (FA), mean diffusivity (MD) and transverse diffusivity (TD) images are created from the diffusion profiles, to which a fiber orientation distribution is fitted. Probabilistic fiber tracking is performed between pairs of seed ROIs [2,3] and averaged diffusivity values created for each pathway, for each subject as described in [3]. The final FA maps are correlated across pulse sequence and between unwarping methods.

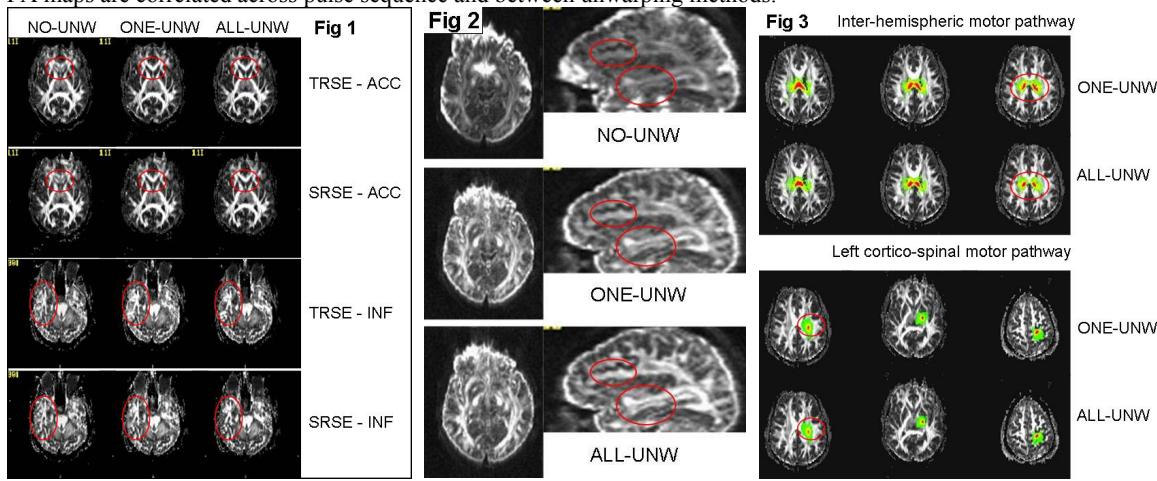


Fig 1: FA from all three unwarps, SRSE and TRSE. Note inferior temporal FA improved with dynamic. Fig 2: stddev across diffusion images in all three unwarps, SRSE only. Note improvement in sagittal images with dynamic. Fig 3: track density maps for motor pathways overlaid on FA for unwarped data. Note tighter tracks, despite similar peak and total track density.

Correlation of FA(DTI_SRSE, DTI_TRSE)				r (NO,ALL)	r (NO,ONE)	r (ONE,ALL)
r NO-UNW	r ONE-UNW	r ALL-UNW	DTI_SRSE	0.9328	0.9506	0.9725
0.9156	0.9171	0.921	DTI_TRSE	0.9449	0.9503	0.9744

Results and Discussion: The averaged FA, MD, TD within both tracks was similar in ONE-UNW and ALL-UNW, but not in NO-UNW suggesting that dynamic artifacts can be ignored for motor pathways. However, in regions we did not track, dynamic unwarping seemed to improve image quality (see the figures sidebar and Fig 2). Furthermore, the correlations across data treatments indicates that dynamic unwarping produces an image more similar across treatments than static unwarping. The tighter track density (with nearly identical peak and total track densities), improved appearance of FA and lack of edge artifacts in the ALL-UNW images suggest that dynamic unwarping with pairs of inverted PE scans produces improved diffusion-weighted images. It is important to note that this does not necessarily incur a penalty in acquisition time, since in common practice multiple averages are required for sufficient SNR, and the unwarped forward and reverse PE images can be averaged together to provide two averages of the same diffusion direction.

References: 1) Holland et al, NI 2010; 50:p175-183, 2) Gallichan et al, MRM 2010;64:p382-390, 3) Sakaie et al, NI 2007; 34:p169-176. 4) Lowe et al, HBM 2008;29:p818-827