Optimizing correction of geometric distortion in MR images

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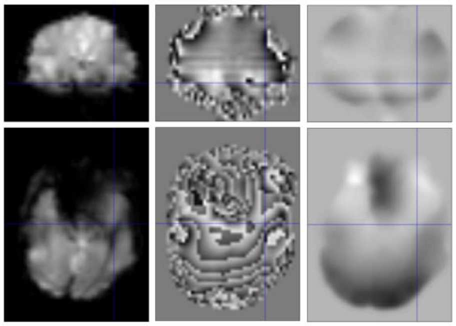

Fig.1. Magnitude (left) and phase (mid) images and the resulting field map (right) at ΔTE = 4 ms.

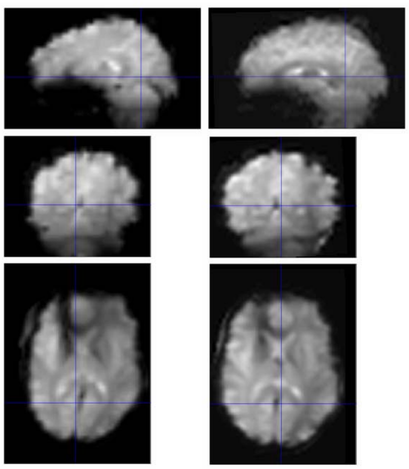

Fig.2. Warped (left) and unwarped (right) images corrected at echo time shift ΔTE = 4 ms.

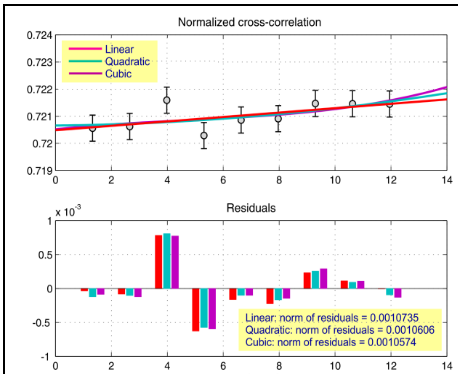

Fig.3. Normalized cross-correlation coefficients overall increase with spin-echo time shift ΔTE.

Purpose.

Sleep data acquisition was carried out using uncommon low bandwidth in the phase encoding direction and low gradient amplitude for functional EPI readout resulting in low scanner noise, but substantially increasing the static magnetic field inhomogeneity. EPI images are prone to substantial signal dropout and spatial distortion in regions where the field is inhomogeneous. Two major sources of artifacts affect EPI reconstructions: Nyquist ghosts and geometric distortion [1]. Post-processing optimization of geometric distortion correction in EPI FSE images based on paired field maps acquired at 3T in terms of spin-echo time difference is presented hereafter.

Methods

Methods to correct for geometric distortion address gradient echo, offset spin-echo, or EPI images acquired at different values of TE [2, 3]. The phase and magnitude of MRI images map the magnetic field since the phase difference between two gradient/spin-echo images with different echo times is directly proportional to the field offset at that location [4]. Deformations can be reduced by mapping the spatial distribution of field inhomogeneities [5].

Experiments

Field maps were generated by collecting short spin-echo spaced in time EPI sequences of both magnitude and phase images at increments of 1.328 ms (Fig.1), which allowed to estimate the changes of magnetic field independent of imaging gradients and artifacts generated by the excitation pulse. An optimal echo time difference, ΔTE, was sought on the basis of the registration quality between the corrected functional EPI and the structural images determined for each subject. The rationale was that a linear registration between an undistorted image and the corresponding anatomical one should result in a better match compared to a linear registration between the distorted image (containing nonlinear terms in the direction of distortion - gradient encoding) and the anatomical image (Fig.2). The normalized cross-correlation (NCC) of uncalibrated images (Fig.3) was chosen as a similarity measure of matching tasks due to its invariance to imaging modality, small rotations, and scale changes [6].

Results and Discussion

The signal to noise ratio (SNR) was calculated as the difference in signal intensity between an area of interest (e.g., thalamus) and the background (e.g., off-brain) divided by the standard deviation of the background noise. Contrast to noise ratio (CNR) was computed as signal intensity differences between two regions of interest (e.g., thalamus - medial prefrontal cortex) scaled to image background noise.

ΔTE (ms)	1.328	2.656	3.984	5.312	6.640	7.968	9.296	10.624	11.952
SNR	44.31	44.83	44.72	46.31	45.66	45.16	45.21	45.82	46.06
CNR	13.13	13.55	13.90	12.34	12.98	13.87	13.06	13.05	13.48

The raw warped image had NCC=0.70, which inferred an overall quality improvement in its unwarped counterpart image of about 15%. Changes in SNR and CNR, if discarding the results corresponding to the shortest two spin-echo shifts, are irrelevant in assessing the quality of field correction. Analysis of normalized cross-correlation coefficients fitting shows a slightly better match with the structural (undistorted) image for higher ΔTE values.

Conclusion

Geometric distortion adversely affects registration with structural images, spatial normalization, and investigation of brain regions with severe homogeneity issue, like the inferior frontal lobe, orbito-frontal cortex, or medial temporal lobe. Geometric deformations of the MR images can be partly corrected by collecting field maps, which provide information on the static magnetic field inhomogeneity. We found optimal a spin-echo time shift such as 1.3 ms<ΔTE<4 ms, with larger values favoring a bit higher CNR. Unwarping is even more beneficial at higher fields where susceptibility gradients entail severe local variations in the static magnetic field that enforces large distortions.

References.

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