Dynamic correction of geometric distortions in EPI: "CURED"

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Purpose: Implementation of a robust method for dynamically correcting head-pose dependent EPI-distortions.

Introduction: Echo Planar Imaging (EPI), used in fMRI, suffers from geometric distortions caused by local magnetic field inhomogeneities. This unwanted effect increases with the field strength. One can estimate and correct voxel shifts by measuring the distribution of the field inhomogeneities, the field map (FM). Usually a single static FM is calculated from a reference Multi-echo Gradient Echo (MGE) data acquired additionally to the fMRI series[1]. Head motion, often unavoidable during long fMRI experiments or certain tasks (e.g. those involving speech or chin motion), however, introduce nonlinear changes in local field inhomogeneities, which are not detectable by a static approach and may cause significant errors in the unwarping procedure. Moreover, head motion enhances Nyquist ghosting. We propose here a new dynamic distortion correction (DC) method to obtain nearly ghost-free and distortion-free functional MRI results. In our DC approach field maps are calculated from phase difference between the adjacent volumes in the EPI time series. We call this method Cursive Unwarping via Repeated Estimation of Distortion (CURED).

Materials and Methods: In order to reduce Nyquist ghosting, the interleaved dual echo with acceleration (IDEA) EPI was used[2]. This EPI sequence was modified so that every even volume in the time series had a slightly longer echo time (by 2 ms) than every odd volume, which introduced a phase difference between adjacent time points. From this, a field map was derived for each pair of volumes. CURED acquisitions were performed on 3 healthy subjects with a 7T Siemens scanner using 32 channel head coil. Additionally, MGE data were acquired for a comparison with a conventional static DC. For all measurements separate channel phase images were recorded for the FM calculation. Both EPI and MGE were acquired with a matrix size of 128 x 128 x 40 and voxel size of 1.7 x 1.7 x 3 mm. The EPI had TE = 21 ms for odd and TE = 23 ms for even volumes. The MGE sequence with two echoes, TE = [5, 12] ms, was used. In first evaluation experiment volunteers were asked to perform a small rotation of the head (approx. 5°) about the left-right axis between the acquisition of MGE and EPI, then remain still during the EPI run. In the second experiment, they performed a chin motion task and separately hand task (opening and closing a fist) in block-design (4 passive and 3 active blocks). Three runs were acquired for each task.

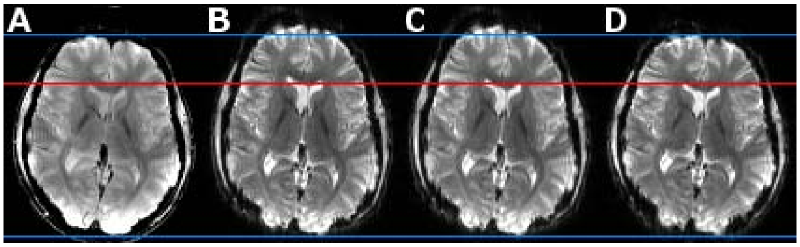

Fig.1 Images acquired for single subject after head rotation of about 5°. A) Nearly distortion-free GE reference. B) Original EPI image. C) Image corrected using static DC. D) Image corrected using dynamic DC here proposed.

Analysis: Both static (GE-based) and dynamic (EPI-based) FMs were calculated using the sum over channels of the Hermitian inner product [3], as described in Ref [4]. For all EPI runs, static as well as dynamic DC was performed. In the static approach, FSL's FUGUE was used for unwarping. For dynamic DC an unwarping method suitable for EPI-based FMs was used[5], which corrects not only voxel positions but also their intensities. In case of hand and chin tasks, both distortion corrected and original data were subjected to slice time correction, motion correction, coregistration between runs and GLM analysis in SPM8. Activation was overlaid on a nearly distortion-free GE reference.

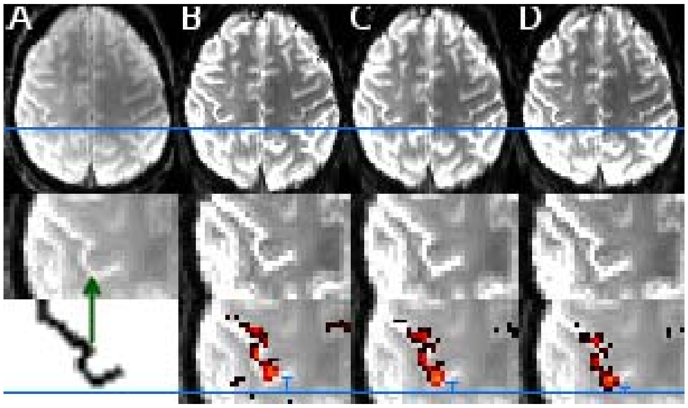

Fig. 2 Single subject results from the fMRI measurement with a hand task. Top row: Images of a transverse slice. Middle row: magnification showing the central sulcus around which hand activation is detected. Bottom row: A sketch of a central sulcus (bottom left) and hand activation overlaid on GE distortion-free reference. Columns represent: A) distortion-free GE reference. B) original (distorted) EPI. C) DC EPI with static approach. D) DC EPI with dynamic approach here proposed.

Results: Distortions up to about 7 mm were observed in the original EPI images after head rotation (Fig. 1B) when compared with nearly distortion-free GE reference (Fig. 1A). These distortions were reduced, but not totally removed, by static DC (Fig. 1C). EPIs corrected with CURED corresponded to the GE reference very well. In the fMRI task experiments, distortions of 2-4 mm were observed in the hand region (Fig.2 top and middle row) and 0-2mm in the chin region (both in primary motor cortex). The difference in the localization of the activation between the data with and without DC was correspondingly 2-4 mm in case of hand task (Fig.2 bottom) and 0-2mm in chin task.

Discussion and Conclusion: Head motion within and between fMRI runs create nonlinear changes in the distortion which cannot be corrected using static DC. The dynamic approach proposed here, based on calculation of the FM between adjacent EPI volumes, is able to track those nonlinear changes and accurately compensate them, which leads to a better precision in activation localization.

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