Comparison of EPI distortion correction methods at 3T and 7T

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Introduction

Functional and diffusion-weighted MRI are usually performed using echo-planar imaging (EPI). A major problem with EPI are geometric distortions caused by magnetic field inhomogeneities, especially at high field strength. To determine the best way to deal with these, we compared three methods for EPI distortion correction.

Methods

To evaluate the different methods, we applied the pipeline outlined in Figure 1 to four datasets, each containing pairs of EPI images acquired with phase encoding direction anterior-posterior and posterior-anterior (A»P and P»A) and a T1-weighted (T1w) scan.

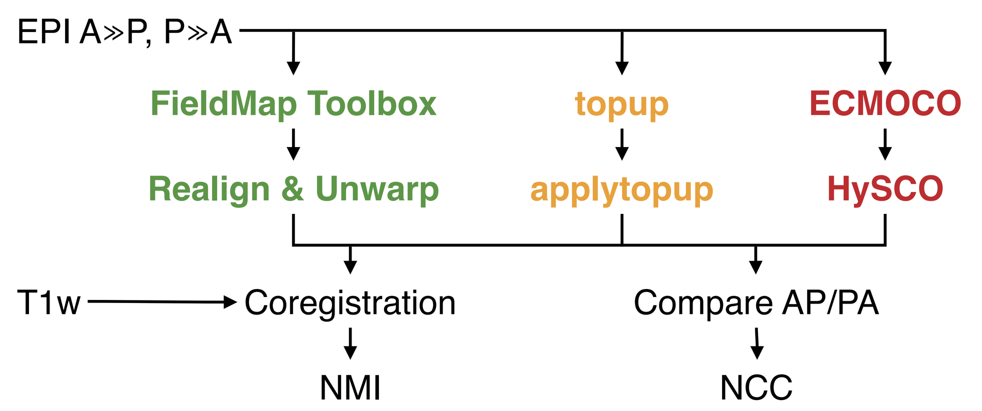

Figure 1. Evaluation pipeline.

Distortion correction methods

We used three different implementations of distortion correction for EPI images:

- The FieldMap toolbox and Realign & Unwarp procedure (Hutton 2004) of SPM8 implement the method described in Jezzard 1995. A B0 fieldmap is used to determine the parameters for unwarping, then motion correction and distortion correction are performed in one step.
- FSL's Topup implements the method of Andersson et al 2003. It takes pairs of EPI images acquired with opposite phase encoding direction as input, determines the necessary corrections using image alignment and then performs motion and distortion correction in one step.
- HySCO (Hyperelastic Susceptibility Artifact Correction, Ruthotto 2013) is also based on aligning images acquired with opposite phase encoding direction. It is implemented as part of the ACID toolbox for SPM, which also includes a component called ECMOCO (Mohammadi 2010) for eddy-current and motion correction. We used ECMOCO for motion correction (disabling eddy-current correction), then applied HySCO to the resulting images.

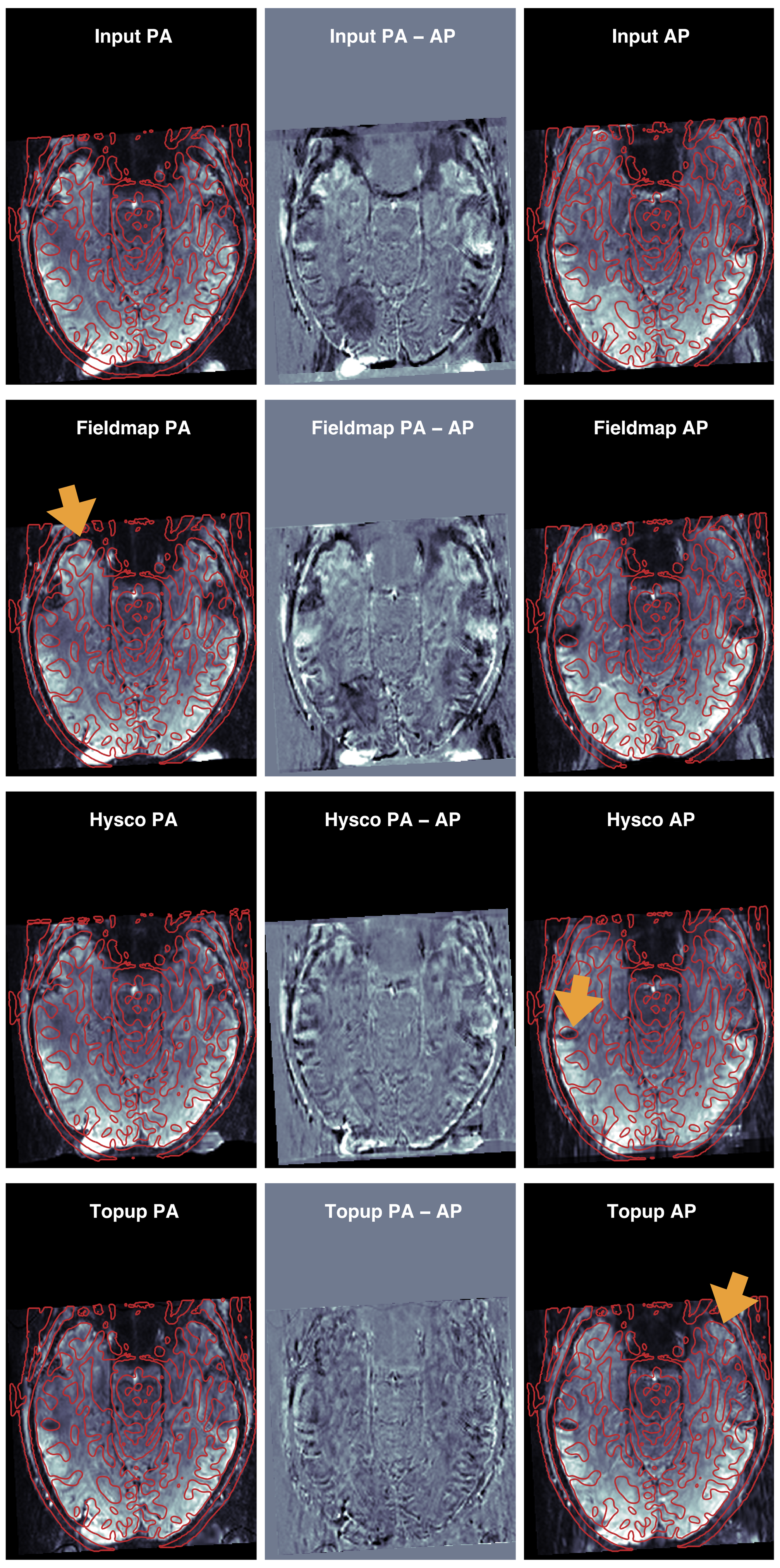

Figure 4. One slice of 3D GE-EPI data before and after correction with the different methods. The left and right columns show results for data acquired with phase encoding direction P»A and A»P, overlaid with an outline of a T1w image to which they were coregistered. The middle column shows the difference image of the slices on each row. The arrows indicate areas where a much better fit can be observed in the corrected images.

Evaluation

We used two measures of the quality of distortion correction:

NCC: Ideally, after correction, the pairs of A»P and P»A images would be identical. To see how close the different methods got to this ideal, we compared the image pairs voxel-by-voxel by computing the normalized cross-correlation (NCC).

NMI: We aligned each EPI image to an anatomical scan acquired in the same session using SPM's function for between-modality coregistration with rigid transformation, which uses normalized mutual information (NMI) as a cost function. Since distortion correction should improve alignment with the T1 image, we use the final value of NMI as the second measure of correction quality.

We calculated these separately for each volume, then used the average to get one value for each combination of dataset and correction method.

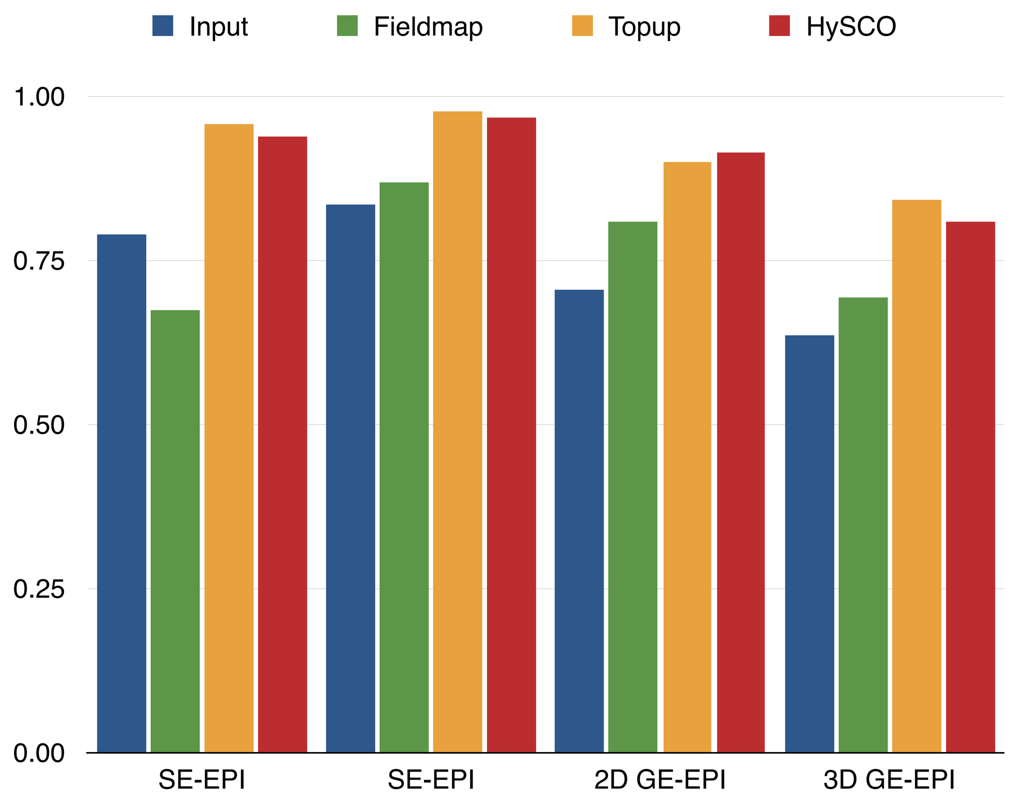

Figure 2. Normalized cross-correlation (NCC) between P»A and A»P images.

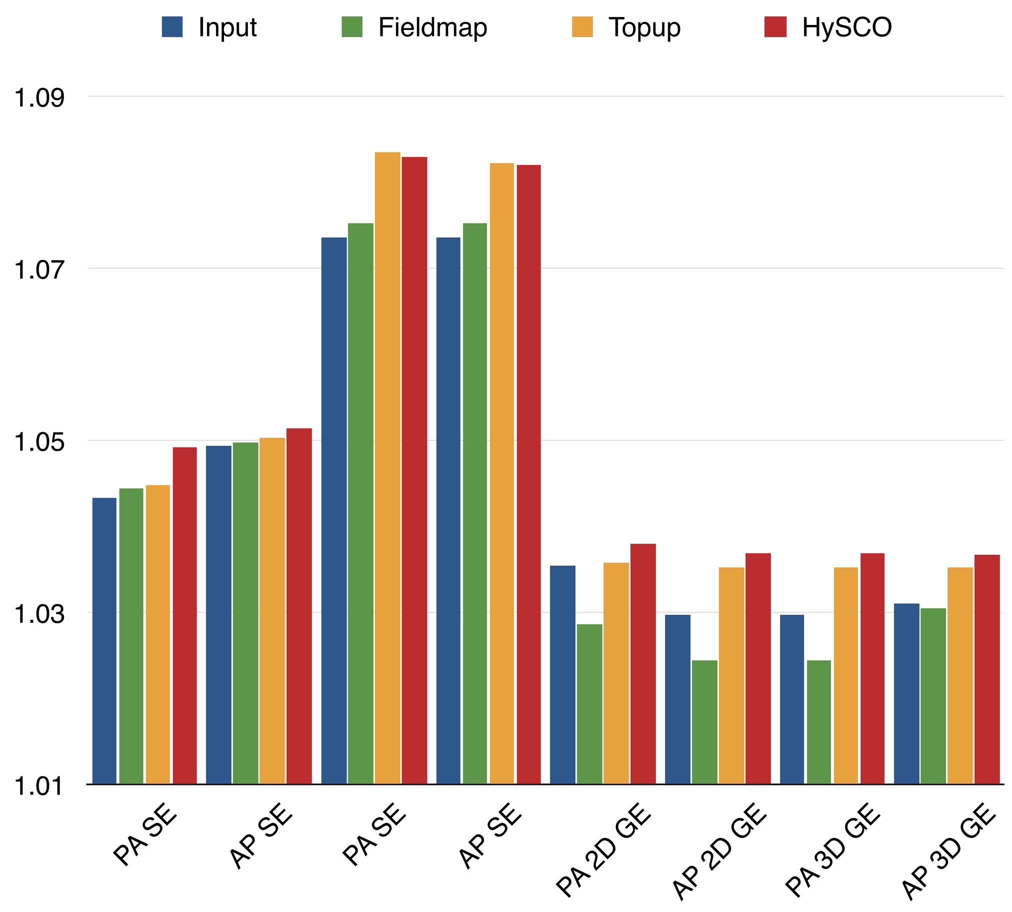

Figure 3. Normalized mutual information (NMI) with anatomy.

Datasets

We applied the pipeline to four datasets: two 3T spin-echo EPI (SE-EPI), a 7T 2D gradient-echo EPI (GE-EPI) and a 7T 3D GE-EPI dataset.

Results

Results are shown in Figure 2 and 3. Figure 4 uses one slice of EPI data to illustrate the effect of distortion correction.

Overall, the methods based on opposite phase encoding directions consistently outperform the fieldmap-based method. These first results also indicate that Topup performs best in most cases, although HySCO was significantly faster.

Literature cited

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