

# Comparison between Synb0-DisCo and Fieldmap-based methods to correct for distortion artifacts in diffusion MRI

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**Introduction:** Diffusion-weighted images acquired with echo planar imaging (EPI) are sensitive to static magnetic field inhomogeneities that can cause distortion artifacts in the phase encoding direction. These artifacts are detrimental for the analyses and several methods have been developed to correct them. Some methods require the acquisition of a dedicated B<sub>0</sub> map like the

fieldmap-based method and the state-of-the-art "blip-up/blip-down" method (for example, as implemented in the TOPUP algorithm [5]). Others do not, like methods using non-rigid registration to a structural image, but they show weaker results [1]. Recently, a method called Synthesized b<sub>0</sub> Distortion Correction (Synb0-DisCo) that uses deep learning to perform corrections

without additional data (Schilling et al. 2020 [2]) has been developed. This study evaluates the Synb0-DisCo algorithm against the other mentioned methods. We performed comparisons on the displacement fields, the b = 0 (diffusion-unweighted) images, and between the b = 0 images and the T1-weighted images ; using monocentric data from 50 healthy subjects.

## Methods

### Participants:

- 50 healthy subjects from the SENIOR cohort [3] (acquired at NeuroSpin, CEA Paris-Saclay, France)
- Mean age: 65,5 years (min : 55 years, max : 78 years)
- 26 males and 24 females

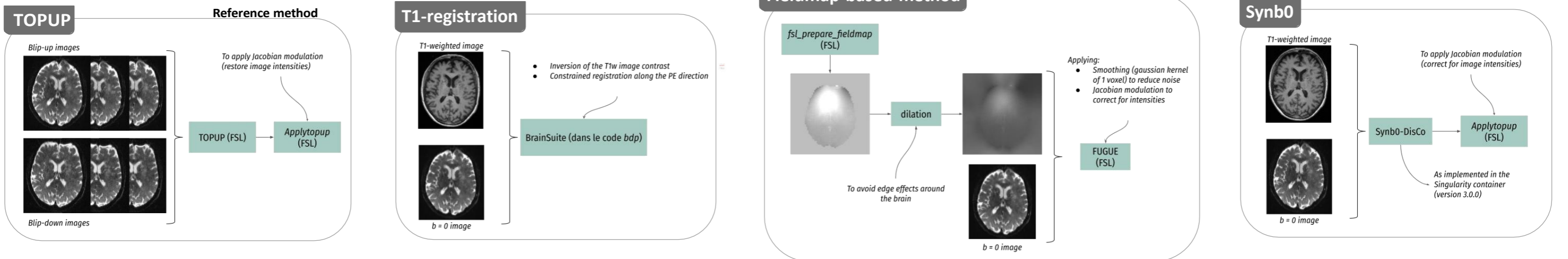
### Acquisition:

- Scanner: 3 T Siemens Magnetom Prisma

Modality	Sequence	TE (ms)	TR (ms)	Voxel size (mm iso)
3D T <sub>1</sub>	MPRAGE	2,98	2300	1
Diffusion	Spin-echo EPI (multi-band = 2 / phase encoding direction : postero-anterior) 3 shells with one b = 0 each time 3 b = 0 in the reverse phase encoding direction	77	7000	1,3
Double gradient echo fieldmap	3D GRE	ΔTE = 2,46	800	3

### Image Processing:

- denoising (*dwdenoise*, MRtrix3 [4])
- Implementation of the 4 following methods, each with default parameters, for each subject



### Comparison methods :

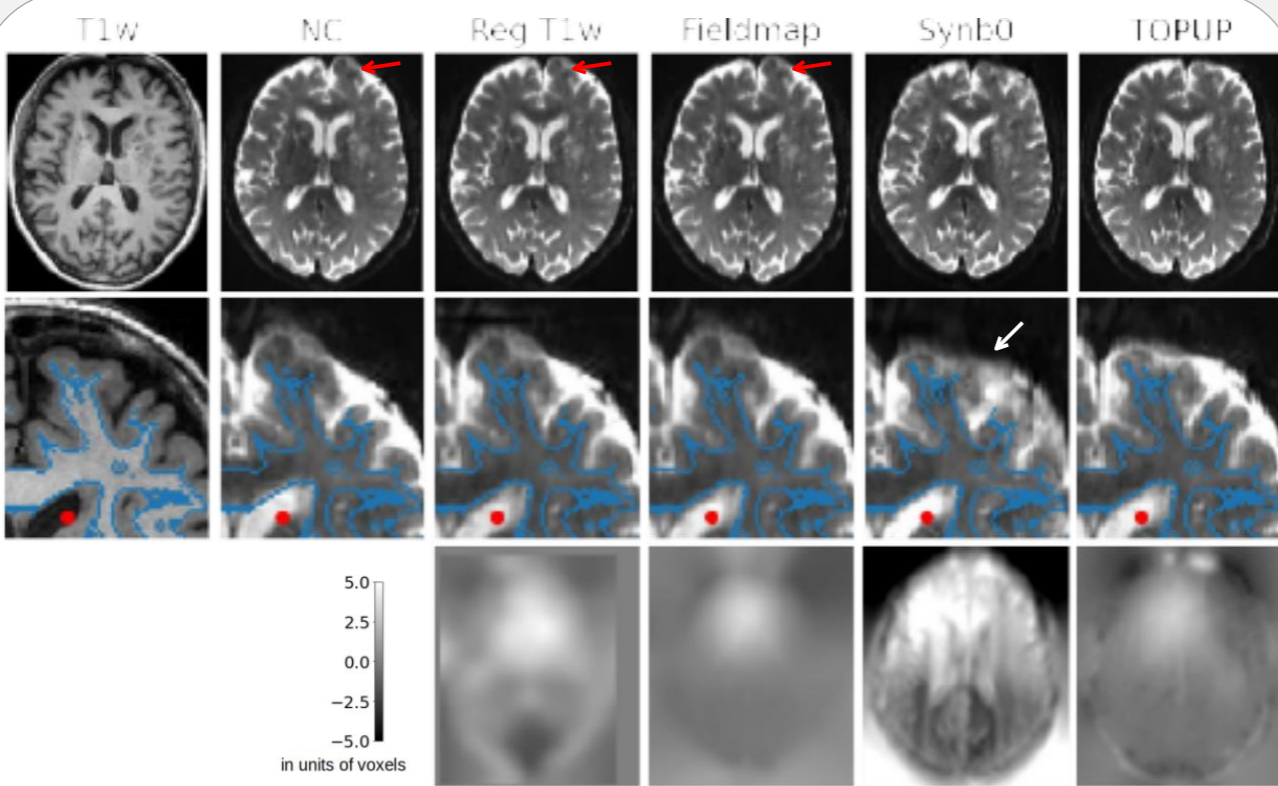
We performed comparisons in order to evaluate the ability of each method to 1) correct brain structures' positions with comparisons of the displacement fields, and comparisons of the undistorted images with the T1-weighted image; and 2) recover signal values, with comparisons between the b = 0 images.

We first calculated masks on the T1-weighted images with the HD-BET algorithm [8]. To include edge effects, we dilated those masks by 7 mm. We then registered each b = 0 volume to the T1-weighted image with the FSL *epi\_reg* function [9]. The inverse transformations were used to obtain the dilated brain masks in each b = 0 space.

$$\begin{aligned}
 \text{Eq (1): } \mathbb{I}(Y) &= \sqrt{\sum_{\mathbb{I}} \mathbb{I}_i^2 / \mathbb{I}} \quad \rightarrow \quad \mathbb{I}(Y) = \mathbb{I}(Y - \hat{\mathbb{I}}) \quad (2) \\
 &\text{with } Y, \text{ an image} \quad \text{with } F, \text{ a centered disp field and } \hat{\mathbb{I}} \text{ the reference centered disp field (TOPUP)} \\
 \text{Eq (2): } \mathbb{I}(Y) &= \mathbb{I}(Y - \hat{\mathbb{I}}) \quad (3) \\
 &\text{with } \mathbb{I}, \text{ an image and } \hat{\mathbb{I}} \text{ the reference image (TOPUP)} \\
 \text{Eq (4): } \mathbb{I}(Y, \mathbb{I}) &= \frac{\mathbb{I}(Y, \mathbb{I}) + \mathbb{I}(Y, \mathbb{I})}{\mathbb{I}(Y, \mathbb{I})} \quad (4) \\
 &\text{with } \mathbb{I}(Y) \text{ the marginal entropy of } \mathbb{I} \text{ and } \mathbb{I}(Y, \mathbb{I}) \text{ the joint entropy} \quad [10]
 \end{aligned}$$

## Results

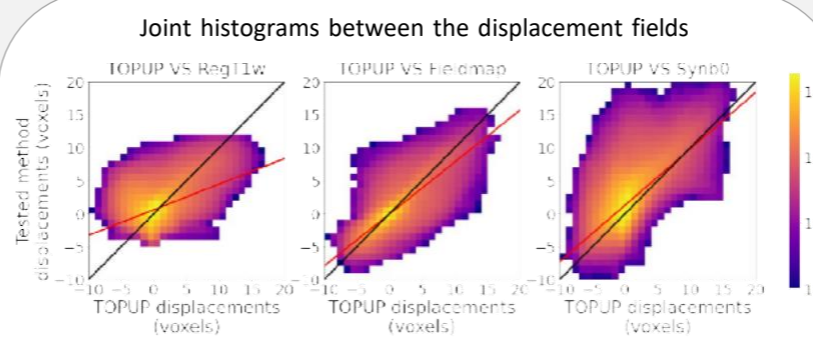
### Comparison of results on a representative slice



**Figure 1:** Results obtained for a representative slice with each distortion correction method. Top row: b = 0 volume corrected by each method; middle row: zoom of the first row images registered to the T1-weighted image; bottom row: displacement fields obtained with each method. The red dot is placed at the same coordinates on each image. Blue lines: segmentation of the gray-white interface performed on the T1-weighted image

- Both TOPUP and Synb0 correct strong local distortions at the edge of the brain
- Blue line : The ventricles are not well registered in the non corrected image (NC) but this is corrected with every method
- Synb0 : The red dot is not inside the ventricle as it is for the other methods
- Synb0 : The white arrow highlights reconstruction artifacts

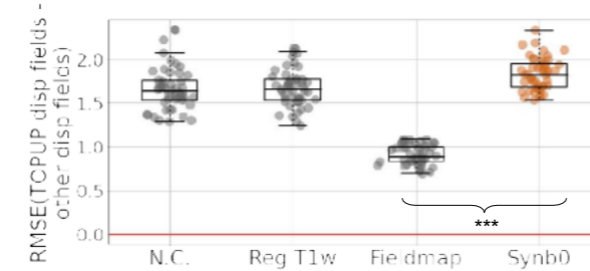
### Comparison of displacement fields



**Figure 2:** Joint histograms between the displacement fields for the Reg T1w method (left), the FM method (middle) and the Synb0 method (right), and the TOPUP displacement field, computed using all 50 subjects. Black line: y = x line, red line: linear regression.

- In general, the Reg T1w method underestimates displacements
- On average, the fieldmap method and Synb0 performs similar estimation (red lines)
- Synb0 performs a noisier estimation

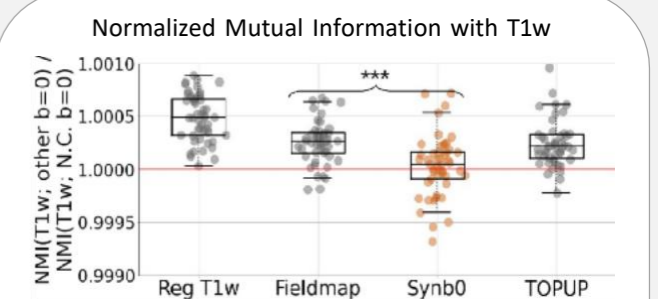
### Root Mean Square Error on centered displacement fields



**Figure 3:** Distribution of RMSEar (Equation 1) across the 50 subjects.

**The fieldmap method performs significantly better than the Synb0 method**

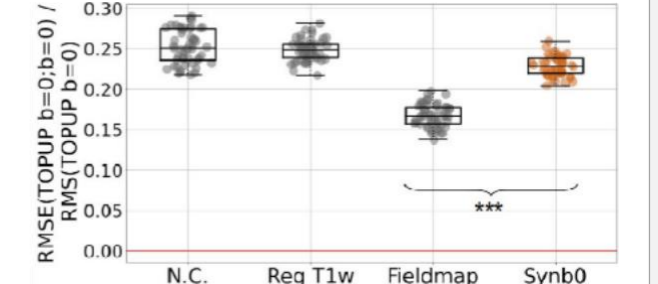
### Comparison of images



**Figure 4:** Ratio between the NMI (Equation 2) calculated between T1-weighted image and b = 0 volumes obtained with each correction method and the NMI calculated between T1-weighted image and the NC b = 0 volume across the 50 subjects.

On average, all methods perform better than no correction

### Normalized Root Mean Square Error (RMSE) between b = 0 images



**Figure 5:** Distribution of RMSEar (Equation 3) across the 50 subjects.

**On both metric, the fieldmap method performs significantly better than the Synb0 method**

The significance for the tests of the difference between the fieldmap method and the Synb0 method is tested at p < 0.001 (\*\*\*) with a one-sided Wilcoxon signed-rank test

## Discussion

### Comparison between the fieldmap method and Synb0

Synb0 can correct strong local distortions like the ones appearing at the edge of the brain

Synb0 performs a noisy estimation of the displacements  
-> It adds some displacements where it should not

### Comparison between other methods

Consistently with the literature, the fieldmap method performs better than the T1-registration method

Synb0 performs a good estimation on average but introduces noise, whereas T1-registration tends to underestimate the displacements

## Limitations

- It should be noted that results may vary according to the quality and resolution of the data. In the original Synb0 paper [2], tests performed on the database that is most similar to ours (HCP) showed the least improvement with Synb0. Therefore, our results may not generalize to databases with very different acquisition parameters.
- In a further study, it could be interesting to perform the analysis on simulated data with various acquisition parameters to test this hypothesis. This type of analysis could also enable to compare the results with a ground truth instead of using the TOPUP method as reference.
- Finally, it would also be interesting to evaluate the influence of each method on diffusion metrics such as Fractional Anisotropy.

**Conclusion** Although the Synb0 method presents better visual results for the correction of strong local distortions, it is more advantageous to use the fieldmap method to perform the correction if the double-echo GRE images are available, even when this fieldmap is acquired with limited spatial resolution.

[1] Graham MS et al, "Quantitative assessment of the susceptibility artefact and its interaction with motion in diffusion MRI," *PLOS ONE*, 2017. [2] SchillingKG et al, "Distortion correction of diffusion weighted MRI without reverse phase-encoding scans or field- maps," *PLOS ONE*, 2020. [3] Haeger A et al, "Imaging the aging brain: study design and baseline findings of the senior cohort," *Alz Res Therapy*, 2020. [4] Tournier JD et al, "Mrtrix3: A fast, flexible and open soft- ware framework for medical image processing and vi- sualisation," *NeuroImage*, 2019. [5] Andersson JL et al, "How to correct susceptibility distortions in spin-echo echo-planar images: application to diffusion tensor imaging," *NeuroImage*, 2003. [6] Bhushan C et al, "Co-registration and distortion correction of diffusion and anatomical images based on inverse contrast normalization," *NeuroImage*, 2015. [7] Smith SM et al, "Advances in functional and structural MR image analysis and implementation as FSL," *NeuroImage*, 2004. [8] Isensee F et al, "Automated brain extraction of multisequence MRI using artificial neural networks," *Hum. Brain Map.*, 2019. [9] Greve DN et al, "Accurate and robust brain image alignment using boundary-based registration," *NeuroImage*, 2009. [10] Studholme C et al, "An overlap invariant entropy measure of 3d medical image alignment," *Pattern Recognition*, 1999.