Evaluating nonlinear coregistration of BOLD EPI and T1 images

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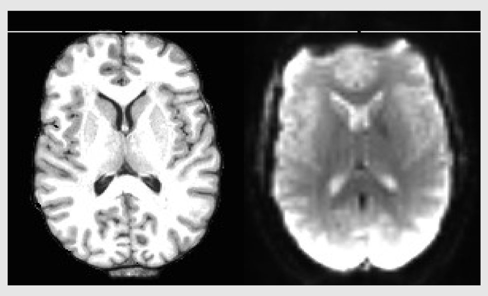
Introduction



Distortions in EPI images. T1 and mean EPI image of one subject after linear registration. Crosshair indicates the same position.

Coregistration of functional and structural images is critical for functional localisation.

Geometric distortions are common in EPI images (see Figure), rendering assumptions of linear coregistration obsolete and analysis in affected areas difficult [1].

Fieldmaps [2] and reversed phase approaches [3] achieve good results in distortion correction but are not always available.

Nonlinear coregistration has been suggested as an alternative method [4-6]. However, **application friendly implementation** and **large-scale evaluation** are outstanding issues and the aim of this project.

Data

For 66 healthy participants from Leipzig, Germany the following scans were acquired on a 3T Siemens Verio Scanner, 32 channel headcoil: MP2RAGE (TR=5 s, 1mm^3, 176 slices), resting state BOLD GRE EPI (TR=1.4s, TE=30ms, 2.3 mm^3, 64 slices, 657 volumes, multiband factor 4), fieldmap GRE EPI (TR=0.68, 2.3 mm^3, 64 slices. TE1=5.19ms, TE2=7.65ms), AP and PA SE EPI (TR=2.2 s, TE=50ms, 2.3 mm^3, multiband factor 4, 64 slices)

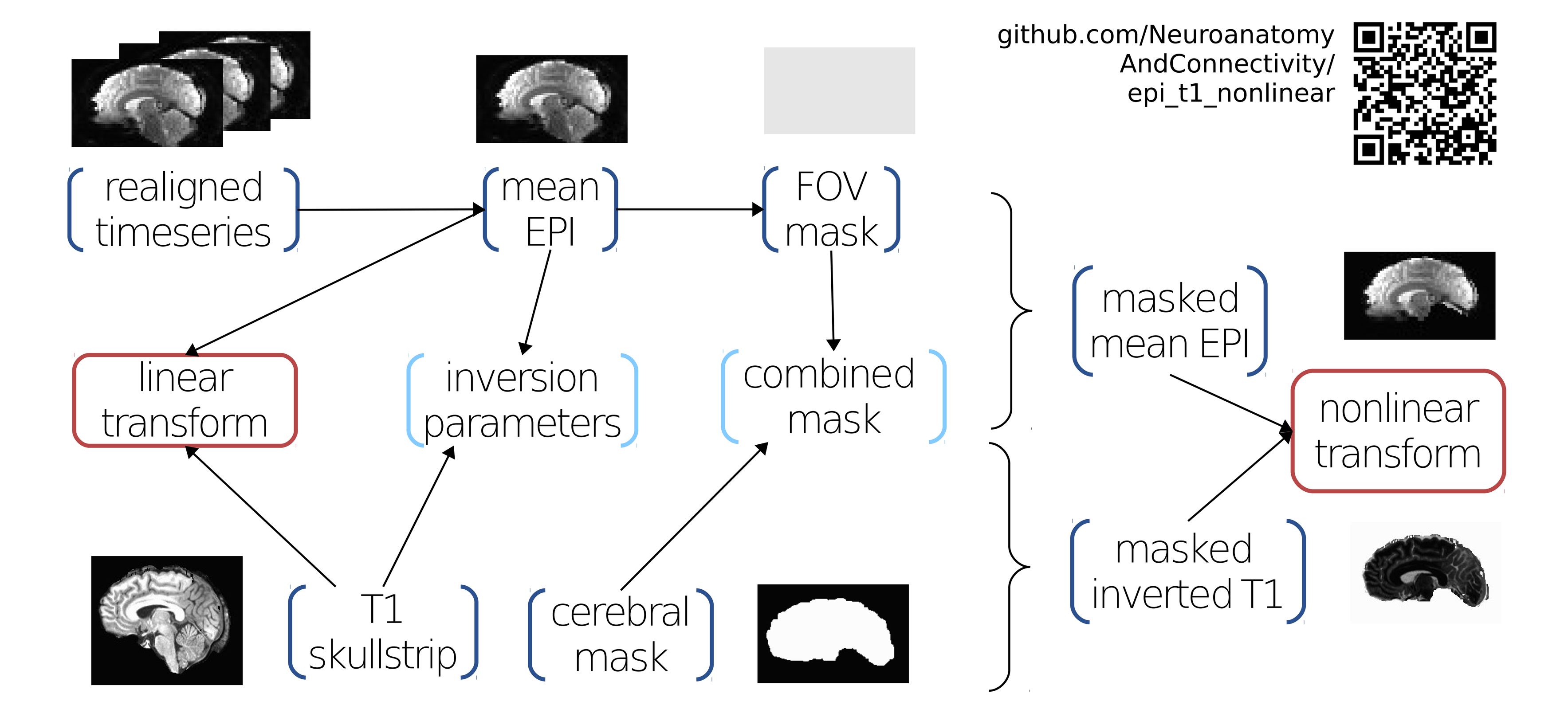
Methods

Common Processing

Motion correction EPI (FSL MCFLIRT)
Segmentation T1 (FreeSurfer)
Normalisation T1 → MNI152 (ANTs)

Compared Coregistration Methods

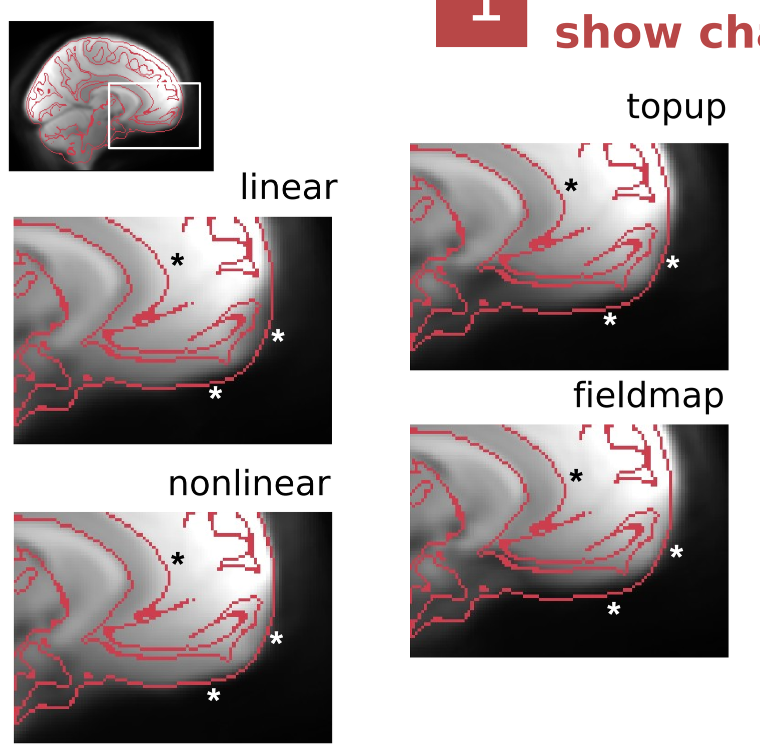
a Linear coregistration (FSL FLIRT & FreeSurfer BBReg)
b *plus* Nonlinear coregistration (ANTs SyN, see below)
c *plus* Fieldmap correction (FSL FUGUE)
d *plus* Reversed phase correction (FSL TOPUP)



Nonlinear coregistration pipeline. Nonlinear transformation with ANTs diffeomorphic algorithm SyN and fast cross-correlation [7] implemented in nipype [8]

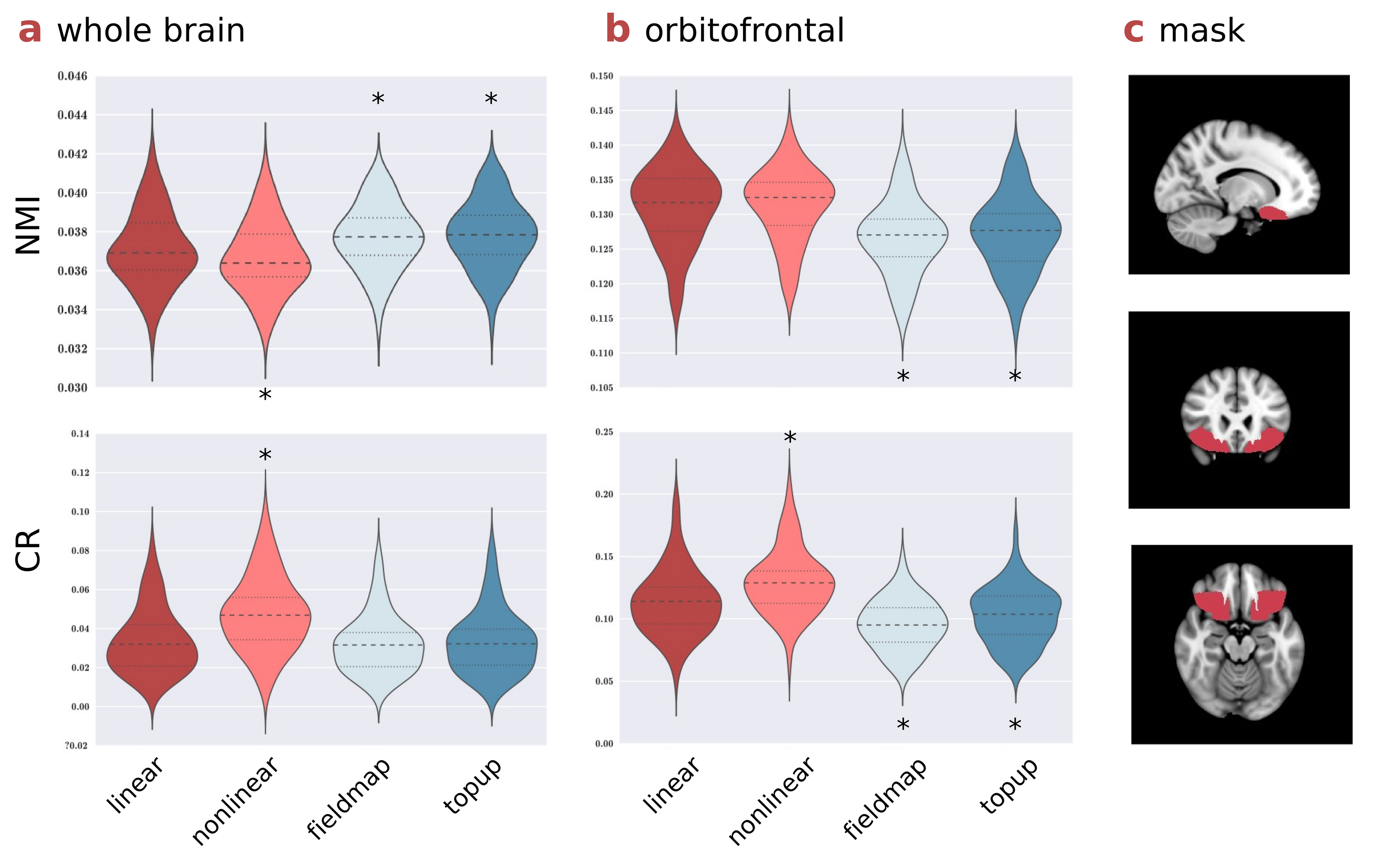
Results

1 Different methods for distortion correction show characteristic coregistration outcomes



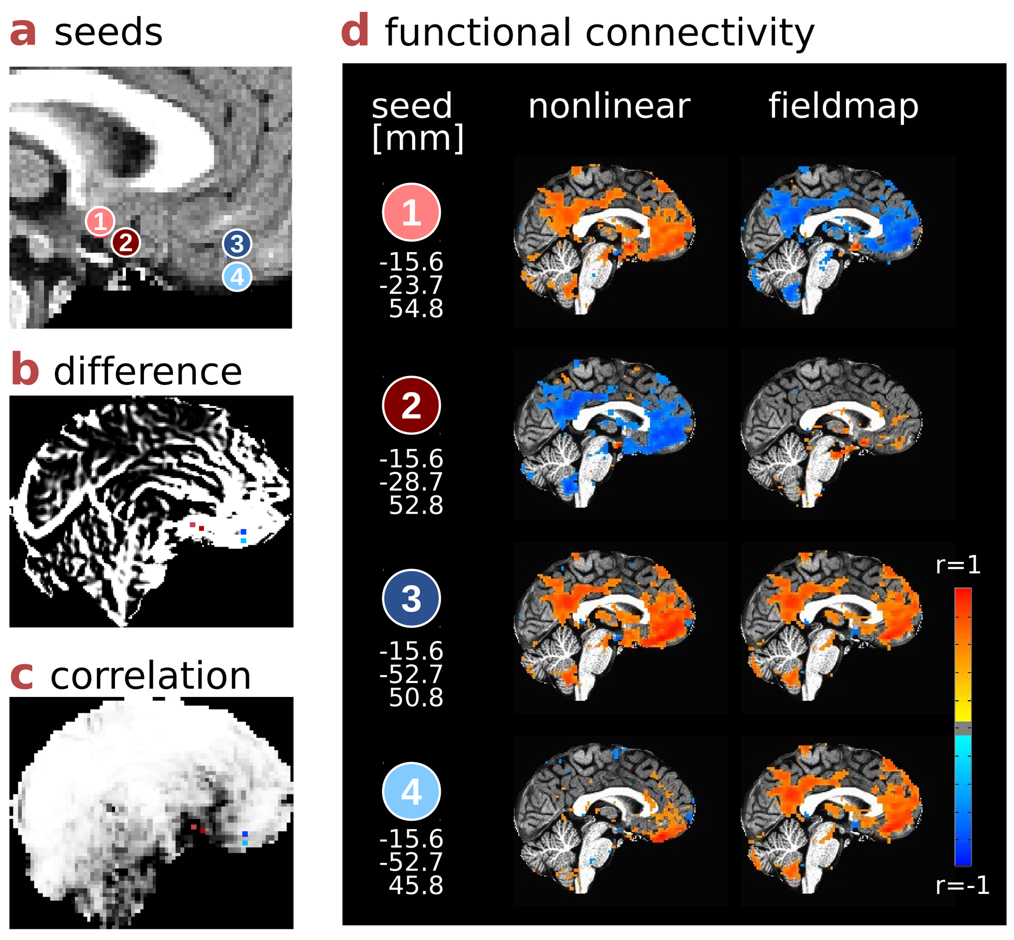
For each method, coregistered mean EPI images of all subjects were projected into MNI space, concatenated and averaged over the 4th dimension. The four detail images depict the white box outlined in the whole brain image for each method (x=-8mm). White matter and mask edges of the MNI152 standard brain are overlayed for anatomical reference. While nonlinear coregistration achieves a better fit of the brain outline in frontal regions (*white asterisks*), fieldmap and topup approach show superior performance in matching gray-white matter boundaries (*black asterisk*).

2 Similarity in orbitofrontal regions increases after nonlinear registration, but whole brain values are inconsistent



Normalised mutual information (NMI) and correlation ratio (CR) were calculated between MNI152 T1 and the coregistered, normalised mean EPI for each subject and method. Images were masked on whole brain (a) or orbitofrontal regions (b) as defined by the Harvard-Oxford probabilistic atlas (>25%) (c). Group distributions are shown, lines indicate mean and standard deviation. Whole brain outcomes are inconsistent across metrics, restricting interpretation. Orbitofrontal regions show increased CR values after nonlinear coregistration ($t(66)=19.51$, $p<0.001$), while CR and NMI decrease for fieldmap ($t_{NMI}(66)=-7.81$, $t_{CR}(66)=-7.00$, $p<0.001$) and topup ($t_{NMI}(66)=-6.20$, $t_{CR}(66)=-4.32$, $p<0.001$). While being in line with visual appearance (Fig.1), similarity values cannot readily be interpreted in terms of correct signal localisation.

3 Functional connectivity patterns suggest that meaningful signal is shifted differently by the compared methods



Seed based functional connectivity analysis, showcased for one subject. Four seeds (a) were chosen based on maps capturing differences between methods: difference of mean EPI after nonlinear and fieldmap correction (b, white indicates higher intensity for nonlinear); correlation between nonlinear and fieldmap corrected timeseries (c, white indicates high correlation). Seed 1 and 2 fall into regions of high intensity difference and correlation. Seed 3 and 4 lie in areas of high intensity difference yet high correlation. After additional preprocessing (removal of physiological noise (compcor), bandpass filtering 0.01-0.1 Hz, spatial smoothing FWHM=4mm) AFNI InstaCorr was used to assess the connectivity pattern for each seed (d, $p=1e^{-20}$ uncorrected). Seed regions with higher intensity after nonlinear correction mostly produce meaningful connectivity patterns (seed 1-3). Yet, only for seed 3 the pattern converges with the one observed after fieldmap correction. The seed 2 / nonlinear pattern closely resembles seed 1 / fieldmap, suggesting the same signal might be shifted differently by the compared methods.

Discussion

Nonlinear coregistration impacts on certain aspects of functional to anatomical fit. In particular, orbitofrontal regions show higher intensity (Fig. 1), which is corroborated by higher similarity in those regions (Fig. 2).

Functional connectivity from regions of higher intensity after nonlinear registration suggests the presence of meaningful signal (Fig. 3). The observed connectivity patterns are in agreement with previous findings [9] and present an approach to assess signal shift.

Improvement of the nonlinear coregistration pipeline is an ongoing endeavour. For instance, restricting an initial transformation step to regions typically affect by distortions will be interesting to explore.

As the outcomes for nonlinear coregistration differ from the fieldmap and topup approach, further careful investigation is required. It is unclear, if signal loss in orbitofrontal regions is disguised (Fig. 1,2) and if the signal is shifted properly (Fig. 3).

References

[1] Hutton et al., 2002. Image Distortion Correction in fMRI: A Quantitative Evaluation. NeuroImage, 16:217–240.
[2] Jezzard & Balaban, 1995. Correction for geometric distortion in echo planar images from B0 field variations. Magn Reson Med 34:65-73.
[3] Andersson et al., 2003. How to correct susceptibility distortions in spin-echo echo-planar images: application to diffusion tensor imaging. NeuroImage, 20:870–88.
[4] Kybic et al., 2000. Unwarping of unidirectionally distorted EPI images. IEEE Trans Med Imag , 19:80–93.
[5] Studholme et al., 2000. Accurate alignment of functional EPI data to anatomical MRI using a physics-based distortion model. IEEE Trans Med Imag , 19:1115–27.
[6] Gholipour et al., 2008. Cross-Validation of Deformable Registration With Field Maps, IEEE J Sel Top Sign. , 2:854–869.
[7] Avants et al. , 2008. Symmetric diffeomorphic image registration with cross-correlation: evaluating automated labeling of elderly and neurodegenerative brain. Med Imag Anal, 12:26–41.
[8] Gorgolewski et al., 2011. Nipype: a flexible , lightweight and extensible neuroimaging data processing framework in Python. Front Neuroinform, 5:13.
[9] Kahnt et al., 2012. Connectivity-based parcellation of the human orbitofrontal cortex. J Neurosci 32:6240–50.

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