Comparison and Reproducibility of Atlas-based Brain Parcellation Methods

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Target audience: Researchers working on brain volumetric measurements.

Introduction: The automatic brain parcellation in different anatomical or functional regions is an important processing step for comparative morphological studies and is often required as an initialization of regional functional analyses using multi-modal MRI datasets. Brain parcellation can, for example, be automatically performed in terms of non-linear registration of brain atlases in which the brain regions of interest are defined. Different non-linear registration methods may lead to different spatial displacement fields that may crucially influence the volume and shape of the atlas brain regions transformed to a specific subject. For example, Klein et al. performed a comparison of 14 non-linear registration algorithms using cross-sectional manually labeled brain regions for ground truth comparison[1]. However, the usage of manual segmentations may introduce additional variability in the comparison of different algorithms. The aim of this study is to evaluate the robustness of three state-of-the-art nonlinear registration frameworks, by applying them to a large number of high-resolution T1-weighted datasets acquired multiple times from the same subjects, requiring no manual segmentations of the brain for reliability comparison purposes.

Material and Methods: ***Data*** **-** A publicly available dataset consisting of a total of 120 3D T1-weighted volumes acquired from 3 healthy volunteers (40 scans/subject) over one month was used for this study[2]. This dataset is unique, in that each subject was scanned twice on each study day, but was repositioned between the two scans so that all scans can be treated as separate measurements. Imaging was performed using an ADNI-recommended T1-weighted sequence (Sagittal 3D IR-SPGR, TR=7.3ms, TE=3.0ms, 11° flip angle, 256x256 matrix size, 192 slices, in-plane FOV 27x27cm, 1.0x1.0x1.2mm^3 spatial resolution, accelerated factor 1.75 with ASSET; 5:37mins acquisition time). All scans were performed in the same 3T MRI scanner (GE MR750) with an 8-channel head coil.

Analysis **-** Automatic brain parcellation was performed by registration of the 152 MNI brain atlas to each subject and subsequent transformation of the Harvard-Oxford (HO) subcortical brain regions defined in MNI space. Overall, three different registration method were used in this work to determine the displacement field for each dataset. All three methods have in common that the MNI atlas is first pre-aligned with each T1-weighted dataset using an affine transformation, which is then used as an initialization for a subsequent non-linear registration. The affine transformation and non-linear displacement field are then used for transforming the HO subcortical brain regions to each subject and subsequent volume determination. The following registration frameworks, which differ regarding the implementation details for determining the displacements field, were used in this work: 1) NiftyReg[3], which uses the normalized cross correlation and mutual information metric as well as cubic B-splines for deformation field determination; 2) FSL[4], which uses the sum-of-squared difference metric and a deformation model based on cubic B-splines; 3) ANTS[5], which uses a fast cross correlation metric, a diffeomorphic transformation and Gaussian regularization. After non-linear registration of the MNI atlas and transformation of the HO subcortical brain regions using the three different registration methods, the regional volume for cerebral white matter, cortical gray matter, subcortical gray matter, ventricle, hippocampus, and thalamus were determined for each subject and registration method. All registrations were performed on the same Linux server (Centos 6, 64GB Memory, 32 Core Intel(R) Xeon(R) CPU 2.7GHz).

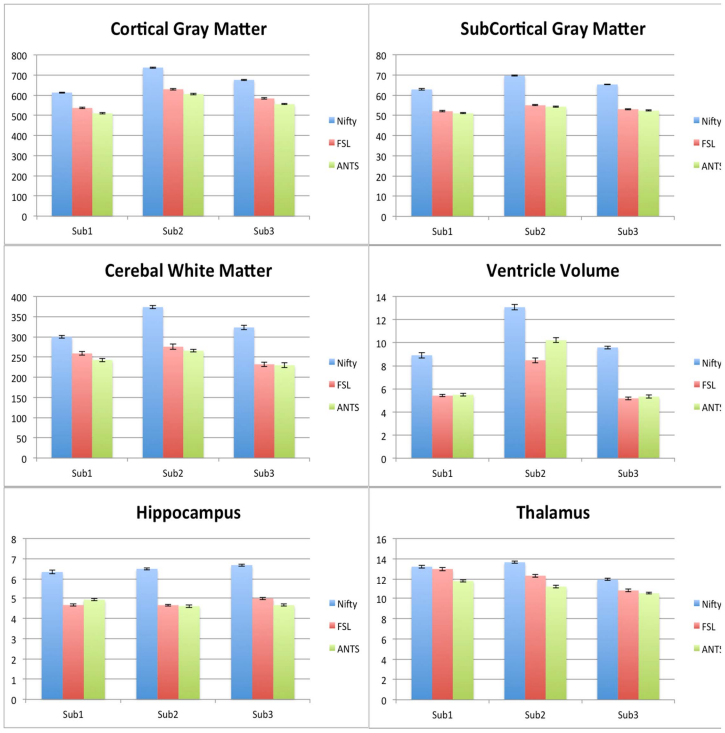

Fig. 1: *Comparaison of Nifty, FSL and ANTS registration methods.*

Results: The volumetric results of this study revealed that all methods are robust in terms of low standard deviations of the regional brain volumes for scans of the same subject. The single-subject coefficients of variation, defined as the ratio of the standard deviation to the mean, were below 1% for all registration methods and brain regions, except for ventricle segmentation, for which a coefficient of 2.5% was found. However, comparing the volumes of corresponding brain regions determined by the different registration methods reveals that the volumetric results are not comparable. NiftyReg tends to produce larger regional brain volume estimations, which may be due to the interpolation method used for deformation of the HO subcortical brain regions. FSL and ANTS produce rather similar volumetric results for the white matter, cortical gray matter, subcortical gray matter, and hippocampus structures. More discrepancy between NiftyReg, FSL and ANTS was found for the ventricle and thalamus (see Fig. 1), which is in line with the results of the study reported in [2] using only FreeSurfer on the same dataset[2]. The run time is approximately 15 minutes for NiftyRef, 1:20 hours for FSL, and 1 hour for ANTS.

Discussion & Conclusion: This work shows that all registration methods lead to robust brain parcellation results in longitudinal datasets. However, the parcellation results generated by using different non-linear atlas registration methods should not be mixed together. Future work will comprise evaluation of more registration methods and more detailed parcellation regions.

References: [1] Klein. et al., NeuroImage. 2009. 46:786-802. [2] Maclaren. et al., ISMRM 2013. #2867. [3] Modat M et al. Comput Meth. Prog. Biomed. 2010. 98:278-84. [4] Jenkinson, et al. 2001. Med. Image Anal. 5:143-156. [5] Avants. Med. Image Anal. 2008. 12:26-41. **Acknowledgements:** NIH (5R01EB011654, 5R01EB008706, 5R01EB002711, P41 RR009784), the Center of Advanced MR Technology at Stanford (P41 EB015891), Lucas Foundation.