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An evaluation of volume- and surface-based nonlinear registration of human brain MRI data

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INTRODUCTION

A recent evaluation of fully automated brain image registration methods included 16 participants from 11 institutions, 14 algorithms applied to 80 manually labeled brains, 4 different labeling protocols, and resulted in over 45,000 pairwise registrations (Klein et al. 2009; http://www.mindboggle.info/papers/).

Limitations of the Klein, et al. study include:

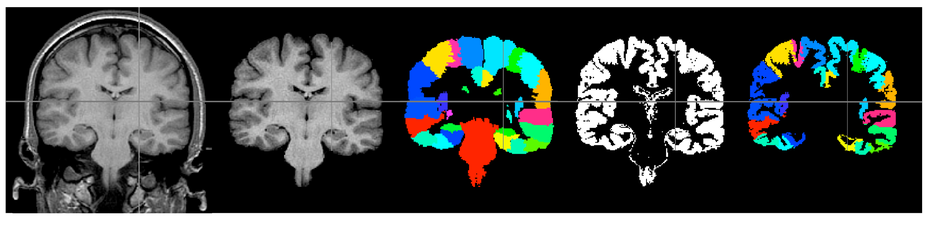
1. No surface-based registration methods were included.
2. No average template or atlas was used for nonlinear registration.
3. Only manually de-skulled images were used for most of the algorithms.
4. The top ranking algorithms, SyN and ART, have since been revised.
5. A separate linear registration step resulted in two interpolations.

The present study will address all of the above limitations, and is the first known to the authors that directly compares some of the most accurate volume-based and surface-based registration methods, as well as the first to compare registrations of whole-head and de-skulled brain images.

METHODS

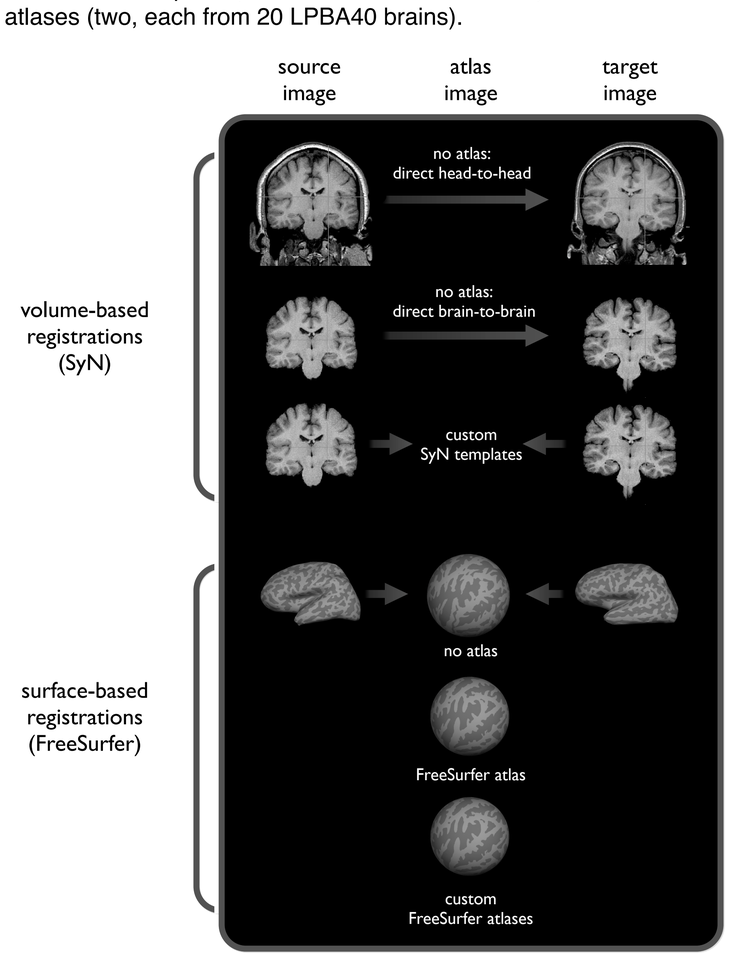
Data

Our data consist of the 40 individual manually labeled T1-weighted MRI volumes from the LONI Probabilistic Brain Atlas (LPBA40, Shattuck et al., 2008). We applied the LPBA40 tissue probability maps to extract just labels in gray matter. In the figure below, the left-to-right coronal images from one of the LPBA40 subjects include the head, manually edited skull-stripped brain, labels, gray matter, and gray matter labels:



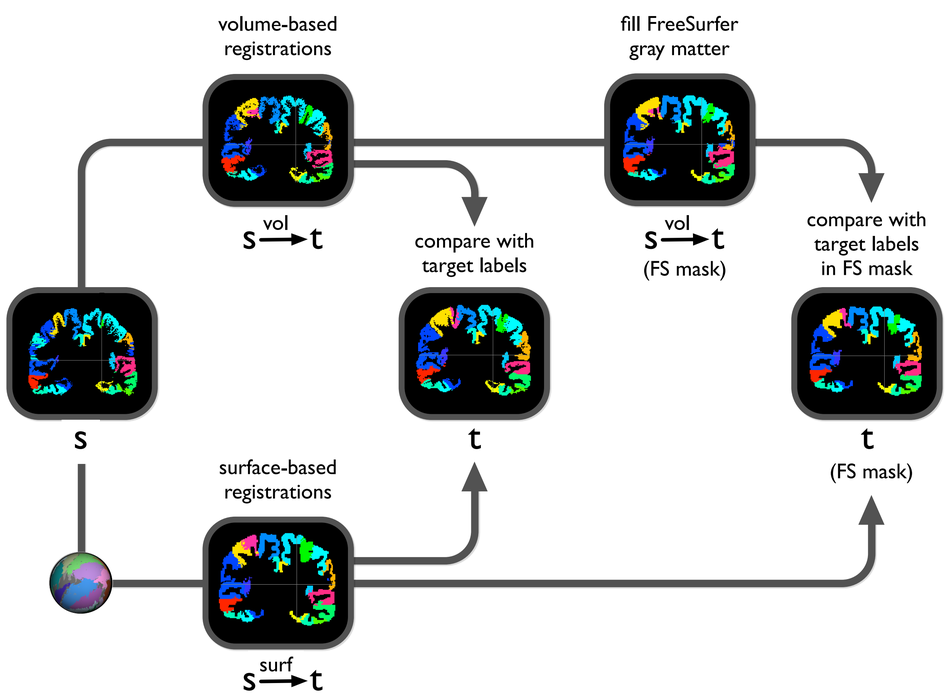
Registrations

The volume-based algorithm **SyN** (Symmetric Normalization) and the surface-based algorithm **FreeSurfer** nonlinearly registered each (source) MRI to each other (target) MRI, either directly from one brain image to one another or via tailored templates, according to the following six scenarios: SyN with and without skulls and via SyN-constructed templates, FreeSurfer without an atlas, via its default atlas, and via custom atlases (two, each from 20 LPBA40 brains).



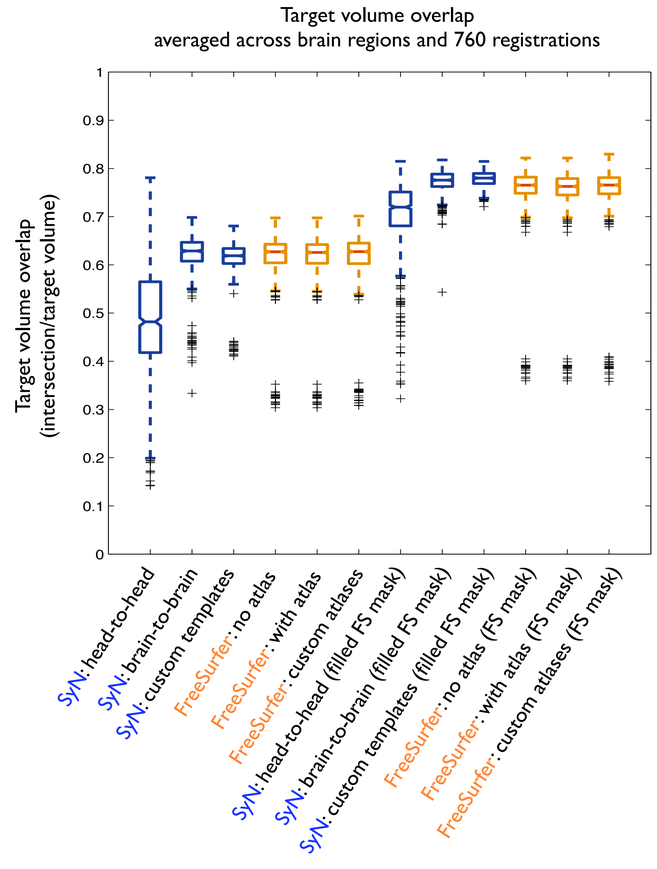
Evaluations

We applied the resulting source-to-target registration transforms to the source manual labels and compared the registered labels to target manual labels using overlap measures:

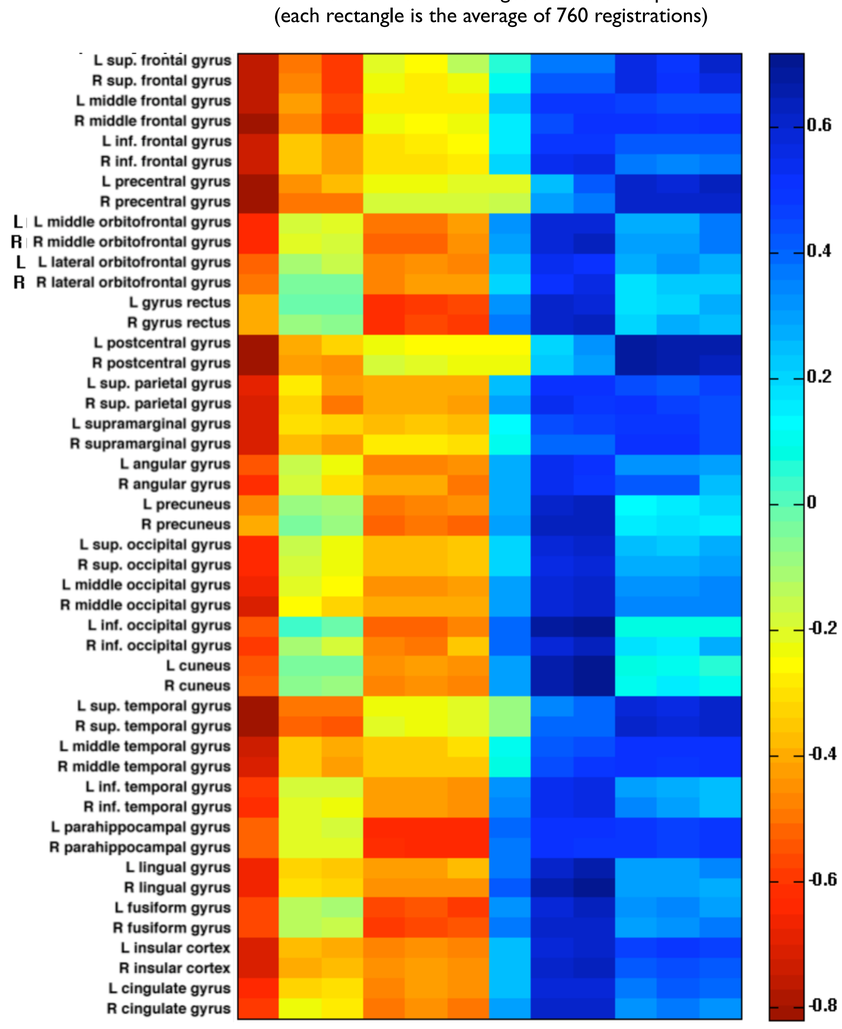


RESULTS and CONCLUSIONS

When the target overlap measures are averaged across all 56 brain regions and across all 760 registrations, proper skull-stripping appears to be crucial to volume-based registration, as does propagation of labels through the gray matter mask against which we are evaluating (performed by default by FreeSurfer, and performed here by a distance transform after running SyN). Almost all of the outliers resulted from the use of one of the 40 subjects (and does not affect the statistical results):



When we compare individual regions with the aid of the figure below (using indifference-zone ranking, as in Klein et al. 2009), we may also conclude that the methods (columns) perform consistently across regions (rows):



Permutation tests agreed with indifference-zone ranking of the methods. According to both of these analyses, SyN direct registration and SyN via a custom template obtained top rank (positive mean percentage lying within one standard deviation of the highest mean); second rank was obtained by FreeSurfer direct registration, via its atlas, and via custom atlases. If we analyze only those voxels on the target surface, permutation tests include FreeSurfer via a custom atlas in the top rank.

We are now analyzing results for the ART registration method, and will be evaluating overlap measures on the surface to test the effect of interpolation on registration accuracy. Updates will be posted on http://www.mindboggle.info/papers/ ...

REFERENCES

Arno Klein, et al. (2009), "Evaluation of 14 nonlinear deformation algorithms applied to human brain MRI registration", NeuroImage 46(3):786-802.
David W. Shattuck, et al. (2008), "Construction of a 3D probabilistic atlas of human cortical structures", NeuroImage 39:1064-1080.
SyN is part of the ANTS toolbox: http://www.picsl.upenn.edu/ANTS/
FreeSurfer: http://surfer.nmr.mgh.harvard.edu/