Evaluating the accuracy of cortical registration using landmark-based and automatic methods

Dimitrios Pantazis[1,6], Anand Joshi[1], Jiang Jintao[2], David Shattuck[3], Lynne E. Bernstein[2,4], Hanna Damasio[5,6], Richard M. Leahy[1]

[1]Signal and Image Processing Institute, University of Southern California, Los Angeles
[2]Division of Communication and Auditory Neuroscience, House Ear Institute, Los Angeles
[3]Laboratory of Neuro Imaging, Department of Neurology, David Geffen School of Medicine at UCLA, Los Angeles
[4]Psychology Department & Neuroscience Graduate Program, University of Southern California, Los Angeles
[5]Dornsife Cognitive Neuroscience Imaging Center, University of Southern California, Los Angeles
[6]Brain and Creativity Institute, University of Southern California, Los Angeles, CA 90089

Introduction: Surface-based registration methods differ mainly in the features or similarity metrics that are used when aligning cortical surfaces. One general approach uses manually or automatically defined landmark contours to constrain the registration. The second approach allows automatic registration by optimizing the alignment of shape metrics, such as sulcal depth and cortical convexity, computed over the entire cortical surface. In this work we evaluate the performance of our landmark-based method (Joshi et al., 2007) against two automatic surface registration methods, implemented in two popular software packages, FreeSurfer (Fischl et al., 1999) and BrainVoyager (Goebel et al., 2006).

Methods: We introduce a cortical delineation protocol comprising 26 well defined and consistent landmarks spanning the entire cortical surface. The cortical surfaces of 12 normal subjects (6 male, mean age 26 years) were extracted using FreeSurfer. One of them was selected as a target, and the remaining 11 subjects were registered to it using the 26 curve landmark-based method and the two automatic methods. The curvature maps and the 26 protocol curves of each subject were mapped to the target, allowing us to investigate the accuracy of each method in aligning the curvature and the 26 curves.

Results: The average curvature map as a function of cortical location across all 11 coregistered surfaces is shown in Figure 1a for all methods. Areas for which gyri are mapped to sulci, or the original cortical surfaces are locally flat (for example sulcal banks) have average curvature close to zero and are represented in white. FreeSurfer pursues curvature overlap much more aggressively than the landmark-based and BrainVoyager methods, as indicated by less white regions. This is also indicated in Figure 1b, which shows the histogram of the average curvature after registration (black), and the average of the curvature histograms before registration (gray). The landmark-based method and BrainVoyager distort the histograms, whereas FreeSurfer preserves the histogram reasonably well. However, as expected, the landmark-based method produces substantially closer alignment of the 26 curves than the FreeSurfer and BrainVoyager automatic methods (Figure 2). The automatic methods show poorer registration of the traced curves in most cortical regions.

Conclusions: We have demonstrated that each method performs best in its own similarity metric, i.e. our landmark-based method achieved better alignment of the traced contours, even if it was not as accurate in matching curvature, with the opposite being true for FreeSurfer and BrainVoyager. However, since a great deal of evidence points to sulci as the best landmark to discern comparable anatomical regions, such as underlying cytoarchitectonic regions, the fact that curvature is aligned at the expense of misaligned sulci seems to point to a problem with curvature-driven automatic alignment methods: corresponding cortical areas that are bounded by standard sulcal curves will not be aligned in those cases where the curvature matching constraint results in the misalignment of sulci.

References:

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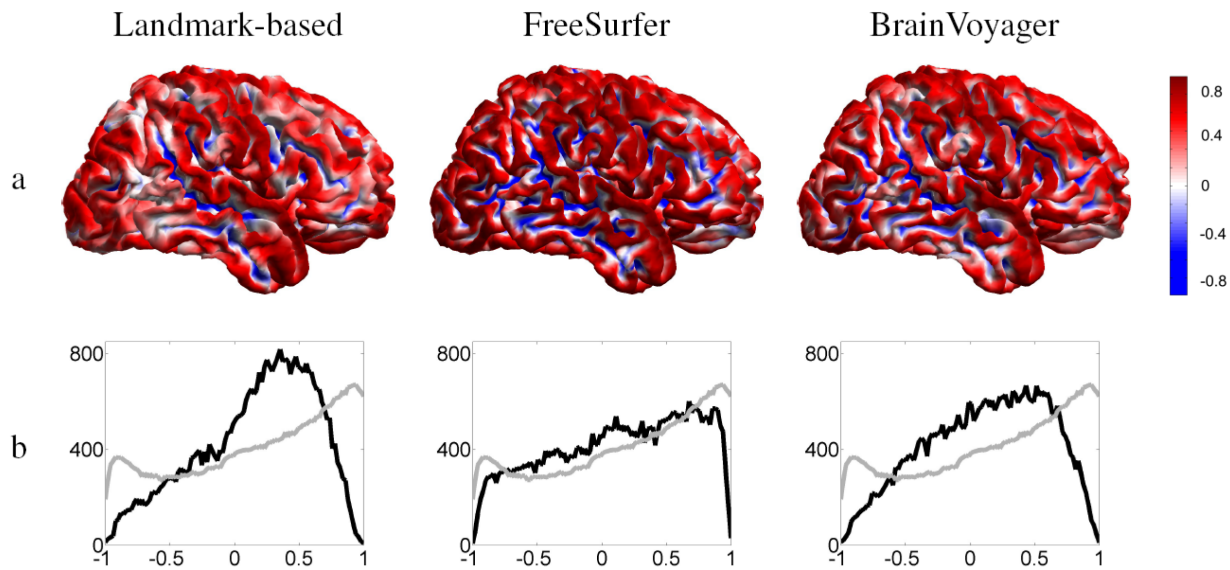

Figure 1: a: Average curvature of the 11 subjects on the target brain; b: Histogram of the average curvature after registration (black), and average of the curvature histograms before registration (gray). In other words, black denotes the histogram of the curvature map displayed in row (a), and gray the typical curvature histogram a cortical surface has before registration.

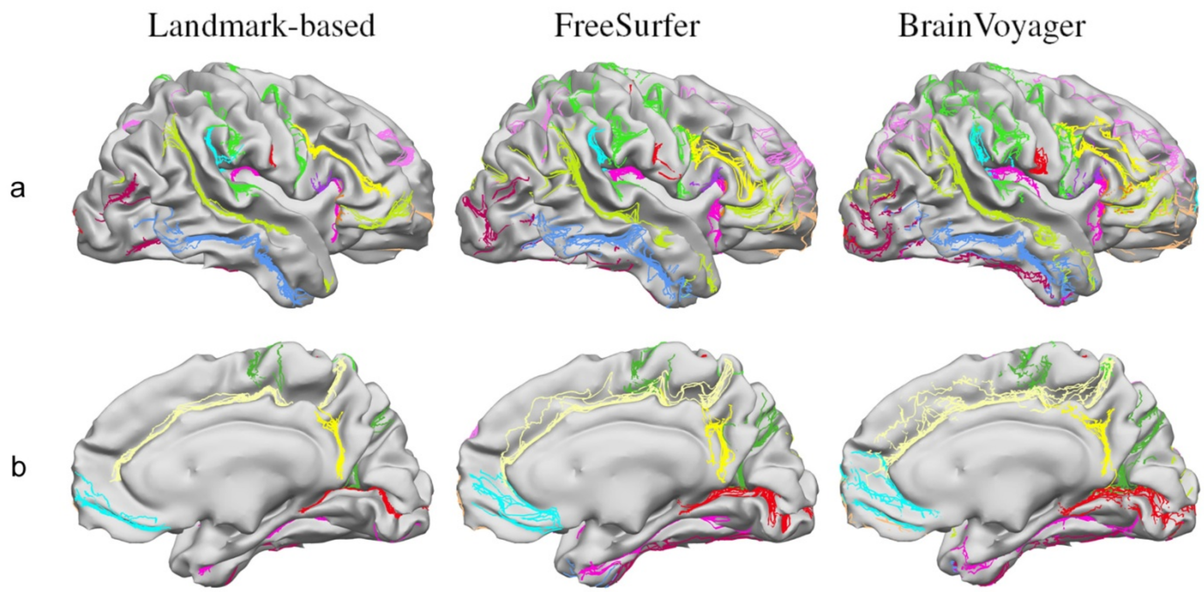

Figure 2: Protocol curves for the 11 subjects mapped onto the target surface using landmark-based registration, FreeSurfer, and BrainVoyager.