Brodmann's Area Template for ROI Selection in White Matter Tractography Studies

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Introduction

The aim of this study is to determine the efficacy of using a template, based on Brodmann's Areas, for the selection of regions-of-interest (ROIs) in white matter tractography studies. The technique provides automation for the time-intensive process of ROI selection by using a registered template to select targeted cortical regions. The Brodmann's Areas divide the cerebral cortex into regions based on cytoarchitectural features in a normalized space. The Brodmann regions appear to be related to specific brain function, and are used extensively to indicate specific brain locations in fMRI analyses. Previous studies have shown that fMRI response is constrained by anatomical connectivity [1]. The selection of white matter tracts that terminate in Brodmann's Areas provides insight into the anatomical connectivity of defined cortical areas with known associated function. The processing technique was performed on the DTI and T1W data of sixteen subjects.

Method

DTI Data Acquisition and Pre-processing: DTI studies were performed on 16 healthy adult subjects using a 3-Tesla GE SIGNA and a quad birdcage head coil. Scan parameters included b=1000s/mm^2; 12 encoding directions, voxel size = 2x2x3 mm. Eddy current distortion correction was performed using 2D affine coregistration in AIR [2]; B0 distortion correction was applied using a field map. Data was interpolated to 0.9375 mm isotropic dimensions. 3D maps of the DT, and FA were calculated.

Template Registration: A standard template based on Brodmann's Areas (available with MRIcro software, C. Rorden; www.mricro.com) is registered to each subject's FA map through a 3D affine image registration program (flirt from FSL; FMRIB, Oxford, UK; www.fmrib.ox.ac.uk/fsl/). All resulting data is presented in MNI space.

White Matter Tractography: Fiber trajectories were generated using the streamline algorithm, with a second-order Runge-Kutta integration method [3]. The following criteria were used for fiber termination: a voxel with fractional anisotropy less than 0.2, or an angle between adjacent steps of greater than 45°. Initial white matter fiber trajectories were created using a "whole brain" ROI by selecting all voxels above a designated FA threshold (0.4) to be part of the seeding region.

Tract Selection: Specific white matter tracts were selected using the registered Brodmann's Areas template. Fiber trajectories determined to terminate in a chosen Brodmann Area were selected. This allowed for the separation of the generated white matter fibers based on connectivity to a specified Brodmann's Area. Trajectories that were determined to be anatomically implausible were removed.

Tract Probability Maps: A mask of the voxels intersected by the selected tracts of a given area was generated for each subject. The masks common to a particular Brodmann Area were averaged together, and the resulting average mask overlaid on an anatomical image. The average mask corresponded to the between-subject probability of Brodmann connection. A probability threshold was applied to the average masks to remove potentially spurious voxels with low tract probabilities. To improve the correspondence between the tract masks from different subjects, the analysis was repeated with dilated individual masks (2 mm in this case).

Results and Discussion

An illustration of the methods for creating tract probability maps of Brodmann's Area 10 is depicted in Fig 2. Area 10 is an anterior medial cortical area, which has white matter projections through the corpus callosum, cingulum, thalamus, and occipital brain regions. Some of the tract probabilities were greatly increased after each single subject mask was dilated by 2 mm (Fig. 2c). In particular, fronto-occipital projections are much more clearly visualized. The mask dilation helps to account for differences that result from imperfect co-registration between data sets (especially since the normalization was affine), small differences in white matter organization between subjects, and variations in tractography results that arise from noise and partial volume averaging. The variability of actual Brodmann's Areas across subjects can also degrade the accuracy of the results. Although results are shown for only area 10, the methods can easily be adapted to other Brodmann's Areas or cortical area masks. Note that our mask was not strictly limited to the cortex, but also to the subcortical white matter, which is important for tract selection. The results from multiple areas can be combined for mapping relative connectivity patterns (Figure 3). In voxels where tracts from multiple areas were present, the voxel was assigned to the area with the highest probability. Despite some limitations associated with Brodmann parcellation, it is attractive because many neuroimaging study results are reported using Brodmann's Area labels. One potential application is to use the probability maps as ROIs for quantitative analysis associated with specific cortical regions. Improvements in tractography algorithms and image normalization will further improve the localization of these tracts. However, despite these limitations, there appears to be good between-subject correspondence with anatomically plausible results.

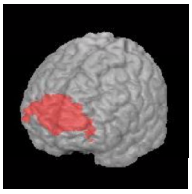

Figure 1: 3-D view of selection ROI for BA 10

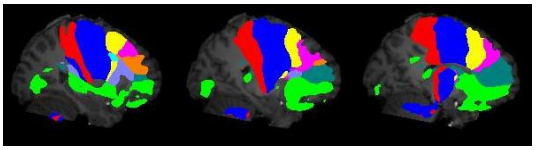

Figure 3: Composite map of several Brodmann's Areas in the frontal lobe. Voxel color was assigned according to BA maximum probability (e.g. BA 4 is red).

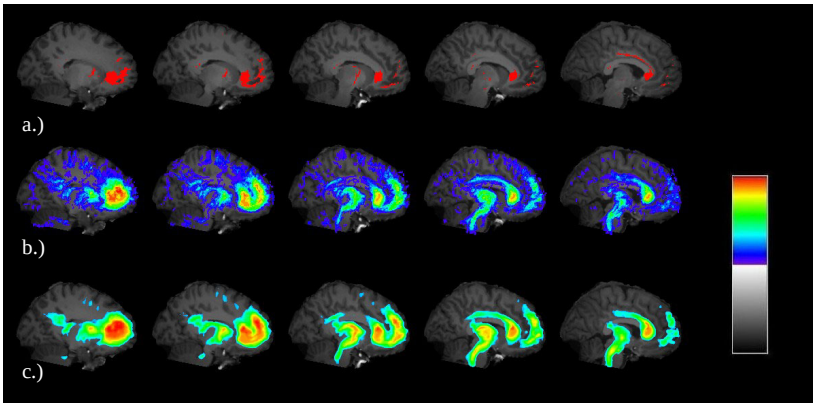

Figure 2: Building Tractography Probability Maps for Brodmann's Areas
a.) Individual subject result (mask) for area 10. **b.)** Average results for area 10 (sixteen subjects) **c.)** Averaged results after smoothing with a minimum 25% threshold. The blue to red colors indicate increased probabilities (e.g., yellow & red are very high probabilities).

References: [1]Toosy et al. NI 21:1452(2004) [2] bishopw.loni.ucla.edu/AIR5/
[3] Lazar M et al. NI 2:1140(2003) [4]Ciccarelli et al. NI 19:1545 (2003)