Analyzing Structural and Functional Imaging Data on the Cortical Surface

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Introduction: Traditionally, structural and functional neuroimages have been analyzed in three-dimensional volumes. However, greater precision can be obtained by utilizing the cortical surface due to better inter-subject alignment, especially in patient populations that have different cortical folding patterns (e.g., William's Syndrome). Surface-based alignment, as implemented in CARET [1], uses six-core landmarks to align individuals, but retains the original folding patterns for structural analyses. Here we demonstrate that the cortical surface can be used to examine the relatedness between diffusion tensor imaging parameters and cortical gross morphology. In addition, we also demonstrate the accuracy of using the cortical surface in functional data mapping. The improved precision and common analysis space will allow an understanding of how structure and function are related.

Methods/Results:

It has been hypothesized that the tension in inter-region connectivity is a driving force behind brain folding patterns [2]. Based on this hypothesis, we investigated the relationship between cortical folding and white matter diffusion measurements. Diffusion parameters of anisotropy (A_σ) and mean diffusivity (MD) were computed from diffusion weighted images in a single individual. The diffusion parameters were then transformed into spatial register with the high-resolution T1-weighted image. Next, a bispectral (T1W/T2W) fuzzy clustering algorithm classified voxels as white matter, grey matter, or cerebral spinal fluid. Using CARET, a representation of the cortical surface was created from the T1-weighted image. During the creation of the cortical surface, sulcal depth and surface curvature values were computed at each node [1]. Additionally, the nearest white matter voxel to each node was identified and the diffusion parameters for that voxel mapped to that surface node. Thus, the nodal values represent diffusion parameters in the white matter subjacent to the cortical surface (Figure 1). A multiple linear regression analysis revealed that cortical depth and curvature accounted for about 15% of the variation in A_σ. However, depth and curvature accounted for less than 3% of the variation in MD. This dichotomy suggests that the directionality of tracts, and consequently inter-region connectivity, and not their density may be a driving factor in cortical folding patterns.

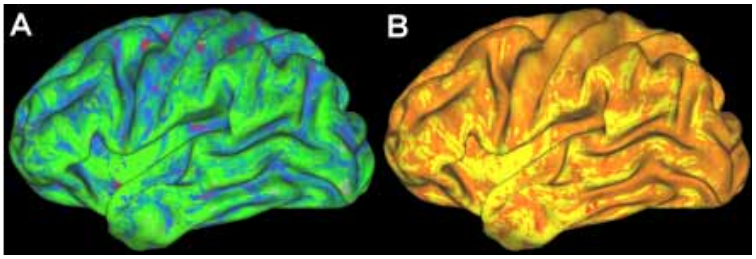

Figure 1: Lateral view of the individuals inflated left hemisphere cortical surface. A: A_σ of the subjacent white matter, A_σ=.05 (light green) to A_σ>.5 (purple). B: MD of the subjacent white matter, MD=0 (yellow) to MD=1.5 (dark orange). Note that only A_σ, not MD, follows the sulcal patterns and is highest at the sulcal fundi.

It has also been shown that there is significant variability in the cortical folding patterns of normal adults [1]. Thus, we used CARET's surface-based mapping techniques in an attempt to better align homologous areas between individuals. Surface-based analyses of functional data show greater localization of significant activity and decreased variability in group average time courses. Using event-related fMRI, we examined significant cortical responses during a divided vibrotactile attention task in twelve individuals. First, clusters of multiple comparison corrected significant activity were determined from the task F-statistic in each individual; the voxels in the clusters were binary coded. The binary coded images were then mapped to the individual's cortical surface using CARET and aligned to the PALS-B12 surface atlas. Next, we defined regions of interest based on a conjunction between individuals (threshold was N≥6) on the cortical surface and computed regional statistics. Specifically, we compared the conjunction map used to create the regions to a conjunction map created from the volume images and then mapped to an average fiducial surface. The degree of overlap between individual data was significantly higher when CMs were created directly on the surface compared to the volumes (p=.0390). In addition, surface-based CMs revealed distinct differentiable peaks (e.g., two peaks in BA7, figure 2). In addition, a preliminary analysis suggests decreased variance in the time courses of data mapped to surface-based regions.

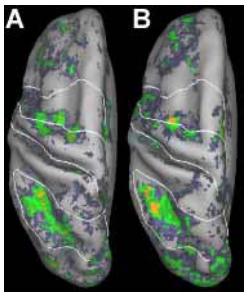

Figure 2: Dorsal view of the PALS inflated surface. White lines indicate the borders of Brodmann Areas 6, 4, and 7, from anterior to posterior, respectively. A: Surface conjunction map thresholded at N≥6. B: Volume conjunction map thresholded at N≥6. The maximum on both surfaces is 12 (orange color). Note that at the border of Brodmann Areas 4 and 6, there are three distinct clusters of activation in the surface conjunction and only one clear cluster in the volume conjunction map. A similar pattern is found in Brodmann Area 7.

Conclusions/Future Directions: The diffusion parameters in the white matter subjacent to the cortical surface reveal a relationship with gross morphology. And by conducting functional analyses on the cortical surface, the results can be directly compared with high precision and reliability to available anatomical data. Thus, we can integrate structural and functional imaging data, using the cortical surface, to reveal differences between patient and control groups. Most importantly, we plan to develop diffusion tensor imaging in white matter subjacent to the cortex in hopes of developing a model for atrophy in Alzheimer's Disease and cortical changes after traumatic brain injury. The use of the cortical surface and diffusion tensor imaging will potentially elucidate the basis for the aforementioned structural differences as well as possible functional changes, thereby creating a holistic model for disease states and progression.

1. Van Essen, D.C., *A Population-Average, Landmark- and Surface-based (PALS) atlas of human cerebral cortex.* NeuroImage, 2005. **28**(3): p. 635-62.
2. Van Essen, D.C., *A tension-based theory of morphogenesis and compact wiring in the central nervous system.* Nature, 1997. **385**(6614): p. 313-8.