Diffusion tensor tractography demonstrates asymmetry in arcuate fiber density

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INTRODUCTION: There is a well known association between language tasks and increased neuronal activity in the left hemisphere in comparison with the right hemisphere. A growing body of evidence suggests that the brain may also be structurally asymmetric, particularly in regions that are functionally correlated with language. In the temporal lobe, for example, the planum temporale is larger on the left side. Furthermore, the size of the left planum temporale, but not the right, is correlated with the degree of activation detected during a language task. It has been suggested that functional asymmetry is a consequence of underlying white matter organization. This is supported by observations of white matter asymmetry in the temporoparietal regions associated with language. Indeed, an increased ratio of white matter to gray matter in the left parietal lobe has been correlated to improved performance on a language task. Diffusion tensor imaging (DTI) is a method of investigating white matter that takes advantage of varying degrees of anisotropy in the diffusion of water through different tissues.[1] The quantification of anisotropy provides a useful assessment of the microstructural integrity of white matter. In the temporal lobe, increased white matter anisotropy has been observed on the left side.[2] Additionally, abnormal anisotropy can be found in subjects with reading disorders. By using the directional information contained in the diffusion tensor, DTI can be extended to generate fiber maps for the purpose of anatomical classification. We used DTI fiber tracking to demonstrate anatomical differences in the left and right arcuate fasciculi. Increased fiber density was found on the left side, suggesting a structural correlate to functional observations regarding hemispheric specialization for language.

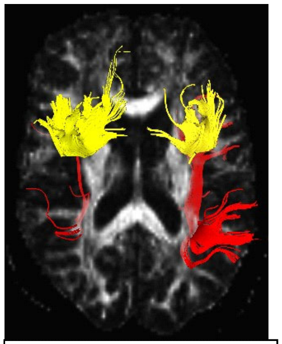

Figure 1: Arcuate fibers (red) are denser on the left side, while uncinate fibers (yellow) are symmetric.

METHODS: Diffusion tensor imaging (12-direction) was performed with a 3.0T scanner on 27 normal right handed subjects (14 male, 13 female, mean age: 30 years, age range: 21 – 51 years). Fractional anisotropy (FA) maps were produced using Volume One and diffusion TENSOR Visualizer (dTV) software. To generate arcuate fiber tracks, ROIs were manually placed in the posterior parietal lobe (seed) and posterior temporal lobe (target). Both cerebral hemispheres were analyzed independently using this protocol. The seed ROIs and the larger target ROIs were constrained to a standardized number of voxels in all subjects. Fiber tracking propagated from the seed ROI in the direction of the principal eigenvector of each traversed voxel and terminated when the FA of the fiber track fell below 0.18 or a predetermined length was reached. The arcuate fiber density was defined as the number of tracked fibers reaching the target ROI divided by the total number of fibers generated from the seed ROI. Since approximately the same number of fibers were generated in the seeds bilaterally in all subjects, this measure of fiber density avoided the need to register tensor maps when comparing results between subjects. Uncinate fiber tracks were produced with a similar procedure, using different ROIs. The shapes of the fiber tracks were inspected and in all cases conformed to known anatomical structures.

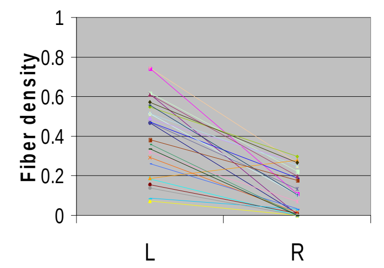

Figure 2: The arcuate fiber track density plotted for the left and right hemispheres of all subjects.

EXPERIMENTAL RESULTS: In the left hemisphere, the mean number of arcuate fiber tracks generated in the posterior parietal lobe was 677; of these 41% reached their targets in the posterior temporal lobes. In the corresponding location in the right hemisphere, in contrast, an average of 665 fiber tracks were generated of which only 13% reached their targets. In all but one subject, arcuate fiber density was greater on the left side than the right. In sixteen subjects, the fiber density of the left arcuate fasciculus exceeded three times the fiber density of the right arcuate fasciculus. In four subjects, no right-sided arcuate fibers were identified at all. In a single outlier subject, there was approximately 50% greater fiber density in the right arcuate fasciculus than the left. Arcuate fiber density was not significantly different in males and females in either the left or right hemisphere. Uncinate fibers did not exhibit significant asymmetry.

DISCUSSION: There is a significant asymmetry in the fiber density of the arcuate fasciculus. Previous studies have shown greater fractional anisotropy in the left temporal white matter than the right.[2] To our knowledge, this is the first study of hemispheric asymmetry to employ a fiber tracking algorithm, which makes use of directional information contained in the principal eigenvector of diffusion. Consequently, asymmetry in the arcuate fasciculus does not solely reflect white matter microstructure, but rather is more likely to represent anatomical differences in the underlying fiber pathways. Since cortical connectivity may be a factor in the ability to perform higher-level tasks, these results point to a possible structural explanation for the well-known left hemispheric dominance of language function. While it has been suggested that there are sex differences in hemispheric specialization, we do not find any significant difference in fiber density of males and females. These results demonstrate the ability of DTI fiber tracking to correlate functional data with a possible substrate in white matter anatomy.

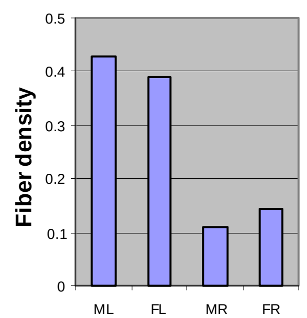

Figure 3: The average arcuate fiber track density shown in the left (ML, FL) and right (MR, FR) hemispheres for males (ML, MR) and females (FL, FR).

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1. Le Bihan, D. J. et al. "Diffusion tensor imaging: concepts and applications." *J. Magn Reson. Imaging* 13, 534-546 (2001).

2. Cao, Y., Whalen, S., Huang, J., Berger, K. L. & DeLano, M. C. "Asymmetry of subinsular anisotropy by in vivo diffusion tensor imaging." *Hum. Brain Mapp.* 20, 82-90 (2003).