Gray-matter morphometry using high-resolution fMRI

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Introduction

High-resolution functional MRI can reveal laminar patterns of BOLD activation in human visual cortex. These laminar profiles are well confined to the gray matter. By characterizing the variations of these profiles along the cortical surface, we gain an alternative means to study gray matter physiology and pathology. In particular, the root-mean-square width of the functional profiles can be compared with anatomic measures of gray-matter thickness based on T1-weighted imaging. Here, we describe methods to obtain BOLD laminar profiles and demonstrate their use for gray-matter morphometry.

Methods

MR imaging: Functional images were obtained on a 3T scanner using BOLD contrast, a spiral readout[1] and a 0.44-μL voxel (10-cm FOV, 0.7 × 0.7 mm effective pixel size, 11 0.9-mm slices, TE = 25 ms, TR = 1000 ms, 2 interleaves), and a custom 6-cm-diam receive-only surface coil. Nearly coronal slices were chosen to cover the most caudal portion of the occipital lobe (early visual cortex). High-resolution (0.6×0.6×0.9-mm voxels) T1-weighted anatomical images were obtained on the same slice prescription to facilitate subsequent registration. Protocol: Subjects (N=2) viewed 4-Hz flickering "checkerboard" patterns presented on a flat-panel display. The display alternated between an inner annulus (0.5—1.25º visual eccentricity), and an outer annulus (1.5—2.5º) with an 18-s period. Data analysis: After trend removal, the time series at each voxel in the volume was fit with a sinusoid to generate maps of amplitude and phase. The functional activity was registered with anatomical image volumes obtained for each subject in a separate session (0.6-mm voxels). This reference volume was segmented to identify the gray-white boundary. A distance map from this boundary provided a depth coordinate, *s*. We defined a functional thickness, $t_{BOLD} = 2\sqrt{\int (s-\bar{s})^2 A(s)\,ds}$, where $A(s)$ is the laminar profile of BOLD amplitude and $\bar{s}$ is the laminar centroid of the amplitude profile. The functional thickness was calculated across the cortical surface. For comparison, the thickness of the gray matter was also measured.[2]

Results

Laminar profiles indicate that the BOLD activity was generally confined to the gray matter (Fig. 1). In gyral gray matter, activity generally falls off toward the white matter and toward the CSF. In the sulci, activity likewise falls off toward the white matter, but sometimes the gray matter is so tightly packed that no drop in the functional activity can be resolved toward the CSF; in these cases the profile is terminated based on the segmentation. The red line segment below the curves illustrates the functional thickness calculated for the gyral profile. When measured across the surface of early visual cortex, the pattern of functional thickness (Fig. 2a) shows good correspondence to that obtained from an anatomical measure of gray-matter thickness (Fig. 2b). The thickness maps are overlaid on small portions of the flattened cortex, where the grayscale displays curvature; white regions are gyri while darker regions are sulci. By both measures, the gray matter is thicker (2—2.5 mm) on the gyri, and thinner (1—1.5 mm) on the banks of the sulci. The functional thickness tends to be somewhat (~20%) larger than the anatomical thickness.

Conclusions

When measured at high-resolution (<1-μL voxels) BOLD activity appears localized to the gray matter in early visual cortex. The laminar width of the functional activity profile therefore provides an alternative metric to characterize gray matter. In healthy, normal subjects, this functional thickness shows good correspondence to anatomical thickness. Accordingly, this form of morphometry could reveal pathologies that affect the laminar profiles of gray-matter function before they become anatomically evident.

Supported by NIH RR09784, NEI03164, Lucas Foundation and GEMS.

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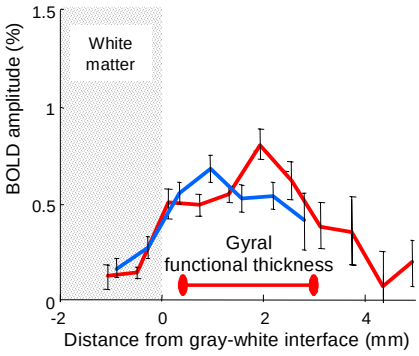

Figure 1: Typical laminar profiles of BOLD activity from early visual cortex; gyral profile in red, sulcal profile in blue.

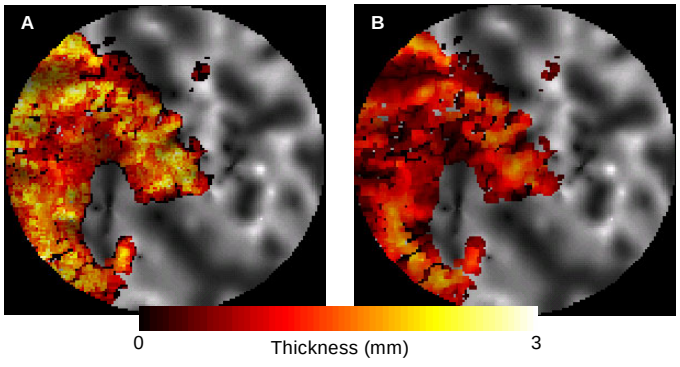

Figure 2: Thickness of gray matter in the posterior occipital lobe overlaid on a curvature image of flattened cortex. A: functional thickness. B: anatomical thickness