A New Approach to Functional and Structural Connectivity in Human Brain Based on Anisotropic Correlations in Resting State MRI

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TARGET AUDIENCE

This work is relevant to researchers interested in developing MRI-based methods for studying the functional architecture of the human brain.

PURPOSE

Resting state functional MRI (rsfMRI) has been commonly used to measure functional connectivity between cortical regions[1, 2]. The underlying structural connections, however, have to be characterized with complementary imaging techniques such as diffusion tensor imaging (DTI)[3]. Recently we have proposed a concept of spatio-temporal correlation tensors on the basis of spatio-temporal analyses of rsfMRI signals, which holds the potential of depicting brain functional structure[4]. The purpose of this work is to develop robust techniques that allow visualization of major functional pathways of the brain, to explore biophysical mechanisms that underlie the proposed technique, and to compare anisotropy of resting state BOLD signals to DTI data.

METHODS

Image acquisition: MRI was performed on normal volunteers on a 3T Philips Achieva scanner (Best, Netherlands) with a 32-channel phased-array coil. Resting state fMRI: Images sensitive to BOLD (blood oxygenation level dependent) contrast were acquired using a multi-echo T_2*-weighted gradient echo, echo-planar imaging (EPI) sequence with the following parameters: TR=3 s, TE=11/31/51/71 ms, matrix size= 80×80 , FOV= 240×240 mm^2, 24 slices of 3 mm thick with zero gap, and 200 volumes. Subjects were instructed to close eyes without performing any functional tasks. Diffusion weighted MRI: A single-shot, spin echo, EPI sequence was used to acquire diffusion weighted signals with b=1000 s/mm^2, 32 diffusion-sensitizing directions, TR=10 s, TE=60 ms, SENSE factor=3, matrix size= 128×128, FOV= 256×256 mm^2, 68 slices of 2 mm thick with zero gap.

Image preprocessing: The rsfMRI data were corrected for slice timing, head motion and global time course using our standard protocol[4]. M0 and R2* images were computed by non-linear fitting. Each voxel time series was band-pass filtered to retain frequency of 0.01-0.08 Hz, and images were spatially smoothed with FWHM of 4, 6 and 8 mm respectively. Diffusion tensors were derived from the diffusion weighted MRI data using linear least square fitting[5], from which fractional anisotropy (FA) maps were computed.

Construction of resting state spatial-temporal correlation tensors: For each brain voxel V_i, a volume of interest (VOI) centered around the voxel was first chosen. For a voxel V_j in the VOI, a Pearson's linear correlation coefficient (C_{ij}) was calculated between the time course at V_i and that at V_j. Then the vector connecting V_i and V_j was computed and normalized into unit vector $\mathbf{n}_{ij}$, with which a diadic tensor $\mathbf{D}_{ij}$ was obtained[6] (Eq. 1). Here $\mathbf{n}_{ij,x}$, $\mathbf{n}_{ij,y}$, $\mathbf{n}_{ij,z}$ are respectively the 1st, 2nd and 3rd element of $\mathbf{n}_{ij}$. Finally, a resting state spatio-temporal correlation tensor $\mathbf{T}_i$ at voxel V_i was defined to be the sum of all diadic tensors in the VOI weighted by C_{ij}, (Eq. 2). The spatio-temporal correlation tensor $\mathbf{T}_i$ characterizes local profiles of correlational anisotropy, and similarly to diffusion tensors, its major eigenvector represents the direction of largest temporal correlation in resting state BOLD signals in both gray and white matters.

$$\mathbf{D}_{ij} = \begin{pmatrix} \mathbf{n}_{ij,x}\bullet\mathbf{n}_{ij,x} & \mathbf{n}_{ij,x}\bullet\mathbf{n}_{ij,y} & \mathbf{n}_{ij,x}\bullet\mathbf{n}_{ij,z} \\ \mathbf{n}_{ij,y}\bullet\mathbf{n}_{ij,x} & \mathbf{n}_{ij,y}\bullet\mathbf{n}_{ij,y} & \mathbf{n}_{ij,y}\bullet\mathbf{n}_{ij,z} \\ \mathbf{n}_{ij,z}\bullet\mathbf{n}_{ij,x} & \mathbf{n}_{ij,z}\bullet\mathbf{n}_{ij,y} & \mathbf{n}_{ij,z}\bullet\mathbf{n}_{ij,z} \end{pmatrix} \quad [1]$$

$$\mathbf{T}_i = \sum_j C_{ij}\mathbf{D}_{ij} \quad [2]$$

RESULTS

Figure 1 shows color-coded principal eigenvector maps computed from resting state BOLD signals acquired at four different TEs. The spatio-temporal correlation tensors were constructed with signals spatially smoothed at FWHM of 6mm and a VOI radius of 9 mm. Among these maps, the map at TE=31ms exhibits best directional consistency with that in the DTI map. The map from M0 image appears only to contain random blobs, and that from R2* images show similar patterns to that at TE=31 ms.

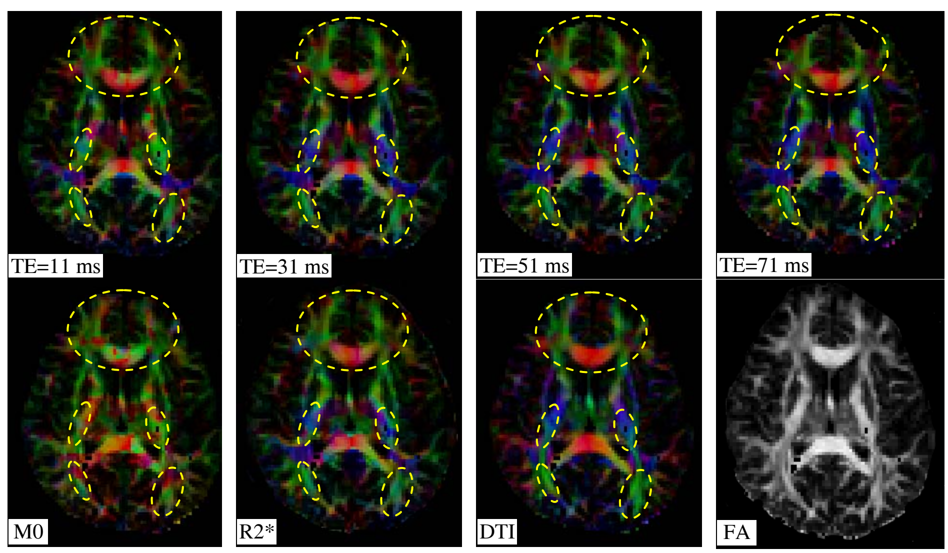

Figure 1. A slice of color-coded tensor major eigenvectors. Image types are labeled in individual panels. All vector maps are weighted by the FA map and the color scheme follows DTI conventions. Circled regions show nearly identical anisotropy patterns between BOLD image at TE=31 ms and DTI data.

DISCUSSION AND CONCLUSIONS

This study demonstrates that resting state MRI signals obtained using conventional BOLD-sensitive acquisitions in brain white matter possess anisotropic correlations, with patterns in many regions grossly consistent with those revealed by DTI. Our findings that R2* but not M0 images exhibit these patterns suggest that local hemodynamic effects, presumably associated with neural activity, may account for the contrast that drives the patterns observed.

In principle, because white matter fibers are carriers of neural activity, the anisotropic correlations of MRI signals implicate information propagation. Thus the spatio-temporal correlation tensor may characterize a local functional structure (as opposed to anatomic structure defined by, e.g., DTI), which offers the potential of being used to map directly structure-function relations in the human brain.

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