Inter-subject variability of structural network: a DTI study

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Introduction: Recently diffusion MRI has been successfully applied in the study of structural network of the human brain[1,2]. In this technique, the brain anatomy is first parcellated into small regions called nodes of the network. The links between pairs of nodes is characterized by the white matter tracts that can be obtained by fiber tracking from the diffusion imaging data. Structural network reveals the topological architecture of neural wiring and macroscopic pathways of signal transmission within the brain, making structural network analysis a valuable tool to characterize brain function. To better understand its possible alterations in diseases, it is important to know the common features of normal structural network as well as its variability across healthy subjects. To this end, we have applied the network analysis on relatively homogeneous samples, with the networks constructed from diffusion tensor imaging (DTI) data.

Methods: Fifty-six male young adults with an average age of 24.0±3.2 years were included in this report. They are all healthy volunteers with no history of neurological and psychiatric disorder. The MR data were acquired on a 3.0 T TIM Trio scanner using a 12 channel head coil. A SE-EPI DTI sequence was performed using parameters: matrix=128x128; FOV=256x256mm; TE/TR=77/8300ms; 68 transversal slices with 2mm thickness; 48 diffusion directions with gradients b=1000s/mm^2, and 8 samplings at b=0. In addition, each session included a high resolution T1-weighted MRPRAGE imaging as anatomical reference for subsequent parcellation. The DTI data was preprocessed with FDT toolbox of FSL (http://www.fmrib.ox.ac.uk/fsl/) to correct for motion artifacts and Eddy current distortion. Tractography was performed on Diffusion Toolkit (http://trackvis.org/) using FACT algorithm with 40 initial random seeds. The stop angle threshold was set to 35 degree. Anatomical parcellation was done using FreeSurfer (http://surfer.nmr.mgh.harvard.edu/) on MPRAGE image to obtain 68 ROIs of gray matter, which will then be coregistered with the b0 image of DTI data. A track is considered to connect two ROIs if and only if its end points fall in the two ROIs. The corresponding weighted networks were then constructed according to $w_{ij} = 2/(n_i + n_j)\sum_m (1/L_{ij})$ with n_i the number of voxels in ROI$_i$ and L_{ij}^m the length of the m^{th} track between ROI$_i$ and ROI$_j$. A backbone network was also generated as the product of all the binary networks converted from the weighted networks ($w_{ij} = 1$ *if* $w_{ij}>0$). Various topological properties are computed for each of the network, including node degree, node strength, betweenness centrality, maximized modularity (qsc), optimal number of modules (msc), average clustering coefficient (gam), average path length (lam), small worldness (smi), assortativity (ass), global efficiency (gef), and average connection strength (avw), using the brain Connectivity Tool Box in Matlab[3].

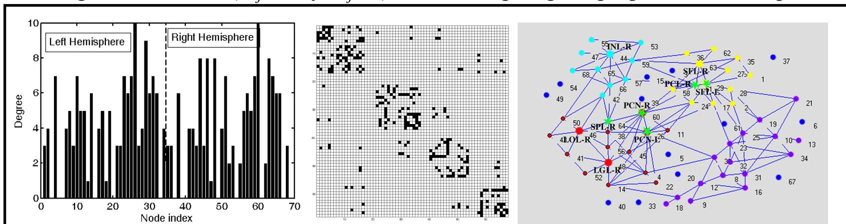

Fig. 1 a b c

Results: The results of the backbone network are shown in Fig. 1. Fig. 1a shows the distribution of the degree for all the nodes, which indicates some degree of asymmetry between left hemisphere and right hemisphere. Figure 1b is the matrix representation of the network clustered into four different modules. A different representation of the network in nodes and links is shown in Fig. 1c. The nodes of the four different modules are displayed in different colors. The nodes with degree greater than 7 are represented by larger circles, including left and right precuneus (PCN-L and PCN-R), right insula (INL-R), right lateraloccipital (LOL-R), right lingual (LGL-R), left and right superiorfrontal (SFL-L and SFL-R). The nodes with large betweenness centrality are considered hubs of the network (represented by green stars), including PCN-L and PCN-R, SFL-L, right paracentral (PCL-R), and right superiorparietal (SPL-R).

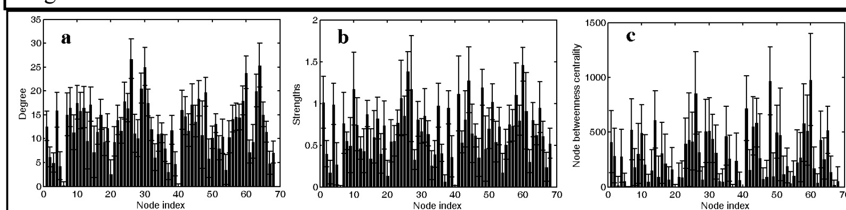

Fig. 2. Node degrees, strengths, and betweenness centrality of the backbone network.

The mean value of node degrees, node strengths, and node betweenness centrality for each node are shown in Fig. 2 along with their standard deviation across all the subjects. It can be seen that the variation of these quantities are very large on a node basis, suggesting that the local structural connectivity may be very individualized. The variations of some of the global measures are listed Table 1. The average clustering coefficient is 0.016, while the average clustering coefficient for a comparable random network with the same number of nodes, edges, and degree distribution is 0.0043. The average path length is 40.7, while the average path length for a comparable random network is 29.1. Therefore, the structural network exhibits a small-world topology, with the mean small worldness index of 2.56. In contrast to the large variation of local properties, some of the global measures have very small variability. For instance, the maximized modulariy is less than 4%, the global efficiency is also less than 6%. The assortativity has the largest variation.

Table 1. Means and standard deviations of some network properties across 56 subjects

	qsc	msc	gam	lam	swi	ass	gef	avw
mean	.634	6.98	.016	40.7	2.56	.036	.505	.053
std	.021	1.67	.004	19.9	0.56	.050	.027	.008

Discussion: Basic features of the structural network as well as the inter-subject variations were investigated on a homogeneous subject pool. It was found that the backbone network can be clustered into four communities. Some of hubs such as precuneus and superior frontal cortex are in good agreement with other literature despite a different parcellation scheme[1]. Although some global measures of the network are less fluctuated, the structure of the network may have a large degree of freedom from subject to subject, as indicated by the variations of node degrees, node strengths, and node betweenness centrality. However, how much variation is caused by noise and errors in fiber tracking needs further investigation.

References: 1. Gong H. et al., Cerebral Cortex, 2009;19:524—536. 2.Hagmann P. etl al., PloS ONE. 2007;2:e597. 3. Rubinov M. et al., Neuroimage. 2010;52:1059-69.