Eigenvector centrality mapping as a new model-free method for analyzing fMRI data

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Introduction. Functional magnetic resonance data acquired in a task-absent condition (``resting state'') require new data analysis techniques that do not depend on an activation model. Standard methods use either correlations with pre-specified seed regions or independent component analysis, both of which require assumptions about the source (seed-based) or validity (ICA) of a network. In this work, we introduce an alternative assumption- and parameter-free method based on a particular form of node centrality called "eigenvector centrality". Eigenvector centrality (Bonacich, 2007) attributes a value to each voxel in the brain such that a voxel receives a large value if it is strongly correlated with many other nodes that are themselves central within the network. Google's PageRank algorithm is a variant of eigenvector centrality. Thus far, other centrality measures – in particular so-called betweenness centrality - have been applied to fMRI data using a pre-selected set of nodes consisting of several hundred elements (Bullmore and Sporns 2009). Here, we propose to use eigenvector centrality instead of betweenness centrality. Because of its much greater computational speed it is possible to apply it to thousands of voxels in a region of interest covering the entire cerebrum which would have been infeasible using betweenness centrality. We tested eigenvector centrality mapping (ECM) on "resting state" data of 35 subjects.

Data and Methods. Functional MRI/EPI data were acquired of 35 normal volunteers on a 3T MRI scanner (Siemens Tim Trio) using TR=2.3 sec, TE=30ms, 3x3 mm^2 in-plane resolution, 3 mm slice thickness, 1 mm gap between slices. Each scanning session began with a task-absent scan (resting state) lasting 7.6 minutes during which subjects were asked to fixate a fixation cross. A second resting state scan with the same acquisition parameters followed about 10 minutes later within the same scanning session. In between these two scans, subjects were scanned in another task-absent condition using sagittal instead of axial slices. Data from this scan were not used for the present study.
All data sets were initially registered to an AC/PC coordinate system where the data were resampled to an isotropic voxel grid with a resolution of 3x3x3 mm^3. We manually defined a mask containing about 44,000 voxels covering the entire cerebrum. We then computed a correlation matrix containing pairwise correlations between fMRI time series. The entries of the normalized eigenvector belonging to the largest eigenvalue of the similarity matrix are a measure of node centrality provided all entries in the matrix are positive. Note that negative entries in the matrix may lead to multiplicities of eigenvalues so that the largest eigenvector is only guaranteed to be uniquely defined after adding +1 to all correlation values (see Perron-Frobenius theorem). For each subject, we thus obtained an eigenvector centrality map (ECM). Voxels having a large ECM value are highly correlated with many other voxels that are themselves well connected.

Results. Figure 1 shows group averages of eigenvector centrality in the two scans. A network of hubs including sensorimotor areas of the marginal ramus of the cingulate and mid-cingulate, thalamus, primary visual cortex, insula and operculum are common to both. Figure 2 shows results of a paired t-test contrasting the two scans. During the first scan, eigenvector centrality scores were significantly higher in left and right thalamus, and in the left parietal cortex. During the second scan, eigenvector centrality was larger in posterior cingulate, medial frontal and right opercular cortices.

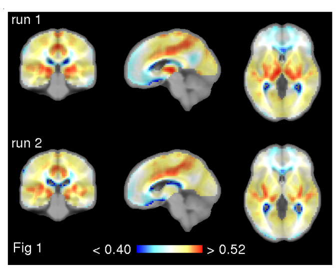

Figure 1: group averages

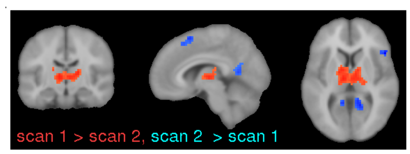

Figure 2: paired t-test

Discussion. We propose to use eigenvector centrality mapping for whole brain analysis of connectivity patterns. Previously used centrality measures such as betweenness centrality are not suitable for whole brain mapping due to their computational complexity. In comparison to betweenness centrality, eigenvector centrality has the additional advantage of not requiring thresholds on the correlation matrix. Note that eigenvector centrality is not equivalent to principal component analysis because the principal components may not be uniquely defined due to multiplicities of eigenvalues. In the experiment presented here we found that during a second resting state scan, eigenvector centrality highlighted specific regions that were differentially affected by the prolonged duration of the experiment. In particular, left and right thalamus had higher eigenvector centrality scores during the first scan. Thalamus has been implicated in mediating attention and arousal in humans (Portas et al. 1998) suggesting that subjects' attention and/or arousal may have declined with time spent in the scanner. On the other hand, posterior cingulate and medial frontal cortex appeared stronger in the second scan - regions that are associated with the so-called ``default mode network''. A possible explanation might be that subjects were more relaxed and more ``at rest'' during the second scan so that the typical ``default mode'' pattern emerged more clearly. Perhaps the mental effort of remaining motionless for a prolonged period of time may have played a significant role in this context.

References.
1. Bonacich (2007). Social Networks, 29:555-564.
2. Portas et al. (1998). J Neurosci, 18:8979-8989.
3. Bullmore, Sporns (2009). Nat Rev Neurosci, 10:186-198