Network Modularity Maps Reveal Sub-Components of the Default-Mode Network

LCBN
Laboratory for Complex Brain Networks

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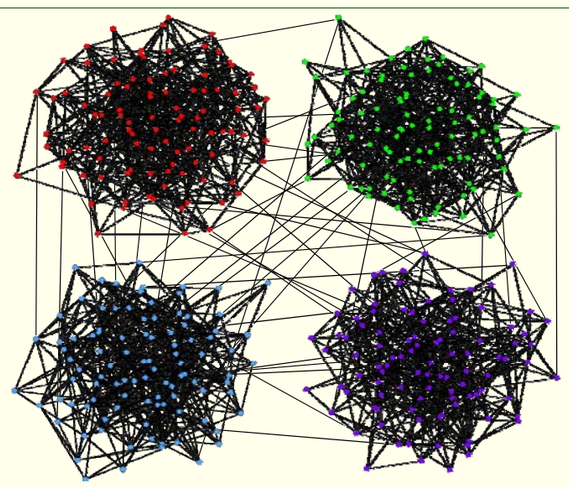
Introduction

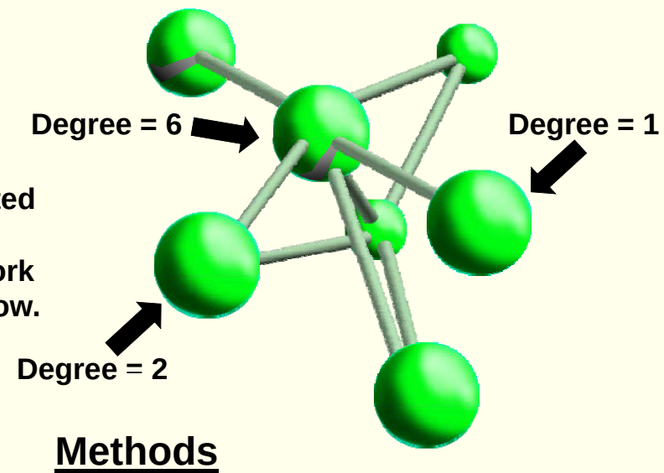
Network science has revealed astonishing similarities and relationships between many naturally occurring and self-organized networks. The application of network theory to the brain is able to evaluate the whole brain rather than functional subdivisions (Bullmore and Sporns 2009). Modularity analyses identify neighborhoods in a network. Neighbors in a module are more connected with each other than with members of other neighborhoods. Modularity analyses can identify neighborhoods that are consistent with known structure/function relationships in the brain (Sporns et al, 2007; Schmitt et al, 2008). The goal of the work presented here was to examine modules in the resting brain on a voxel-wise level. Particular attention was focused on the interconnections between default mode network (DMN) areas during visual fixation and when participants viewed a video with sound.

Figure 1. Network Modularity



Functional connectivity is able to assess connectivity to a singe seed area. Modularity (Newman 2004) identifies highly interconnected neighborhoods within an entire network. The example in figure 1shows a network with 4 distinct communities.

Figure 2. Node degree and network hubs



Hubs are the most connected nodes in a network. These nodes are critical for network stability and information flow.

Methods

SUBJECTS. A total of 14 adult volunteers (age 22-35) participated in the study. **MRI ACQUISISTION.** BOLD MRI was collected during continuous rest or watching a video over 7 minutes. **ANALYSES (see Figure 3).** Functional connectivity analyses were performed between each voxel and every other voxel in the brain. A voxel-wise cross correlation matrix was created after regressing head motion, global signal and average CSF and white matter signals. The correlation matrix was thresholded to yield networks with an average node degree of 30. The adjacency matrix was analyzed using a spectral graph partition method developed by Ruan (2008) to optimize modularity (Q).

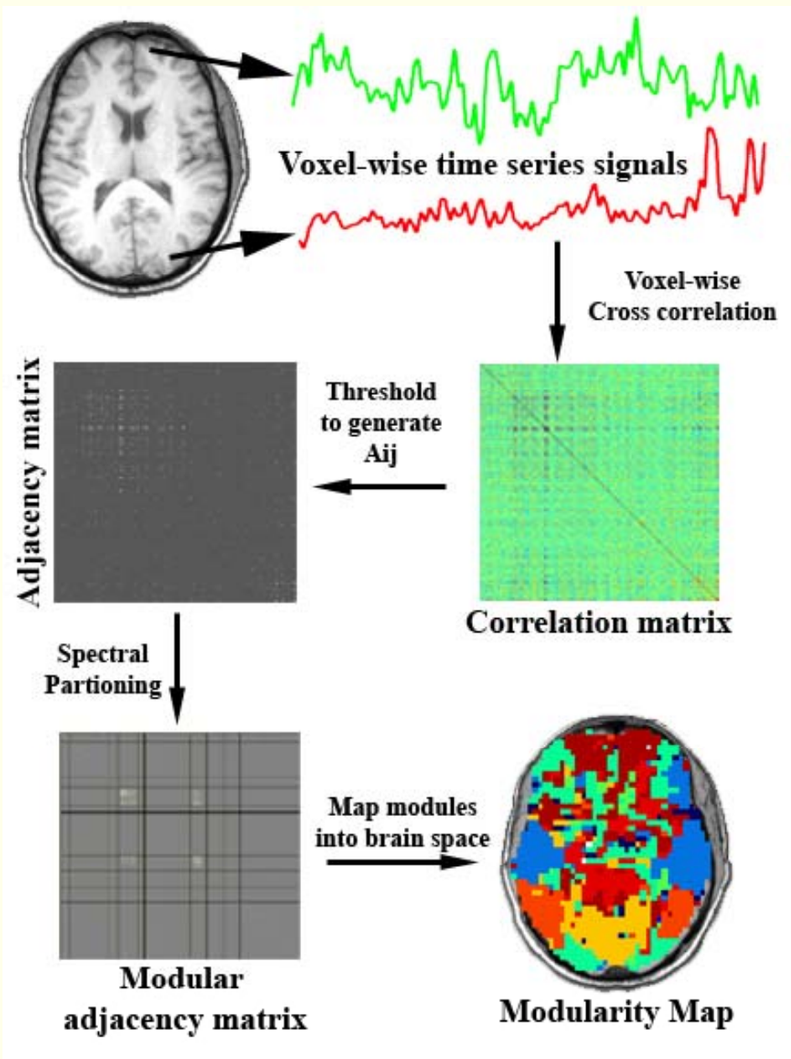
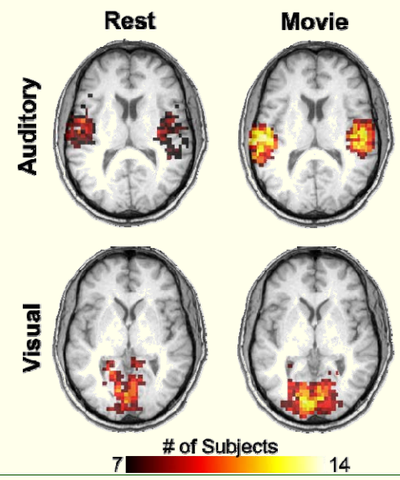


Figure 3. Flow diagram showing methods for network analyses

Results

Figure 4. Modular organization of visual and auditory cortices



These "overlap" maps show the number of subjects (total of 14) that have a particular voxel in the visual and auditory modules. During the resting state (visual fixation), the visual and auditory regions are moderately consistent across subjects. When watching a movie with sound, the visual and auditory modules exhibit high spatial specificity.

Figure 5. Hub structure at rest and while watching a video

These maps show the number of subjects that had any particular voxel as the top 20% of connected voxels. Note that at rest the DMN areas are highly connected. While engaged in the video, the visual and auditory cortices become prominent hubs. Connectivity of the DMN is reduced. However, the inferior medial frontal cortex remains highly connected.

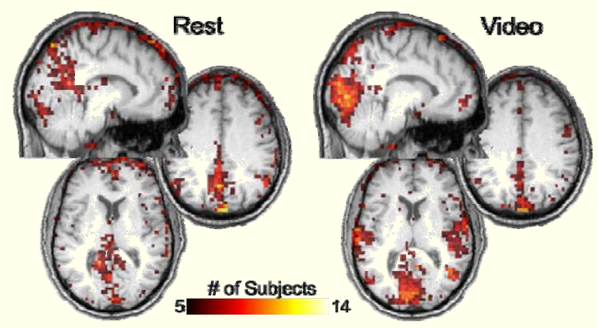
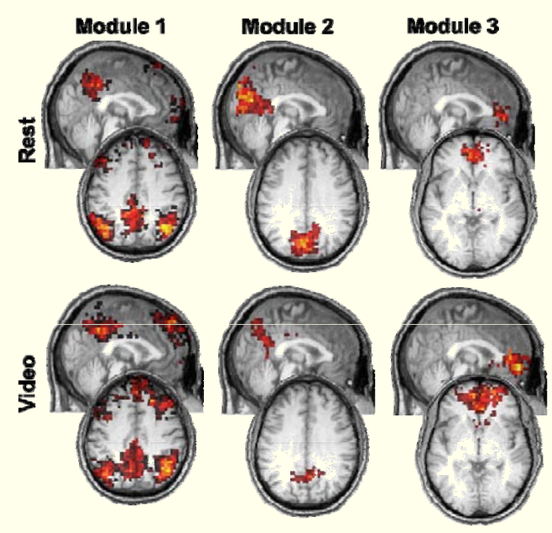


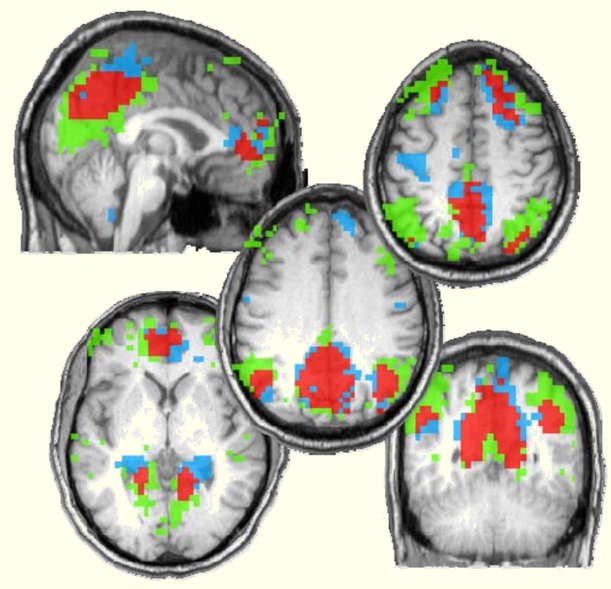
Figure 6. Modular organization of the default mode network



Overlap maps demonstrate that the DMN is actually comprised of 3 distinct modules. When engaged in watching a movie, the DMN exhibits subtle changes but maintains the same overall community organization. Calibration same as Figure 3.

Figure 7. DMN overlap with Default-mode modules

A mask of the DMN, as identified by deactivation under visual and auditory stimulation from a different study of 60 subjects (Peiffer et al 2009), is overlaid with a mask of the 3 DMN modules shown at rest in Figure 6.



DMN deactivated during task
DMN from modularity analysis
Overlap

Conclusions

- **The DMN is comprised of 3 distinct network modules**
- **Task engagement does not change the DMN community structure**
- **Task engagement does change highly connected nodes (hubs)**
- **The inferior medial frontal module does not relinquish its hub status during an engaging task**
- **Modularity effectively identifies community structure in whole-brain data**
- **Studies of brain disorders may want to consider the modular structure of the DMN**

References

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