LCBN
Laboratory for Complex Brain Networks

Network Analyses of Multisensory Processing

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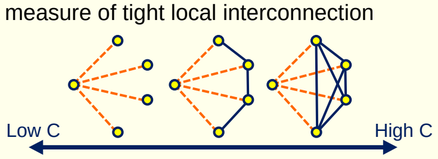
Introduction

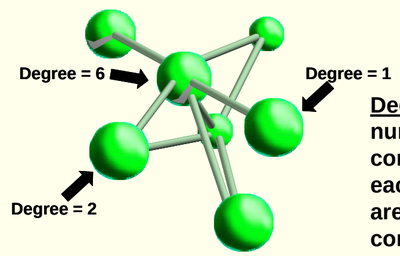
The brain is a complex network and multisensory processes occur within the framework of this highly integrated system. A comprehensive understanding of multisensory processes may be achieved through studies of the brain as a complex network. The current study was designed to evaluate network properties in the human brain under various multisensory conditions. Brain hub structure exhibited significant changes during visual and multisensory stimulation. The community structure of the brain was also sensitive to unisensory and multisensory conditions. Identification of network neighborhoods that dynamically change with sensory conditions can provide insight into the functional organization associated with multisensory processing.

Figure 1. Network metrics and analyses

Clustering coefficient (C):

A measure of tight local interconnection

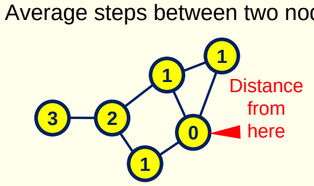




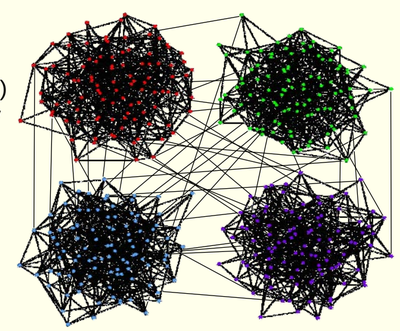
Degree is the number of connections for each node. Hubs are the most connected nodes.

Path length (L):

A measure of efficient long-distance communication
→ Average steps between two nodes



Modularity (Newman 2004) identifies highly interconnected neighborhoods within an entire network.



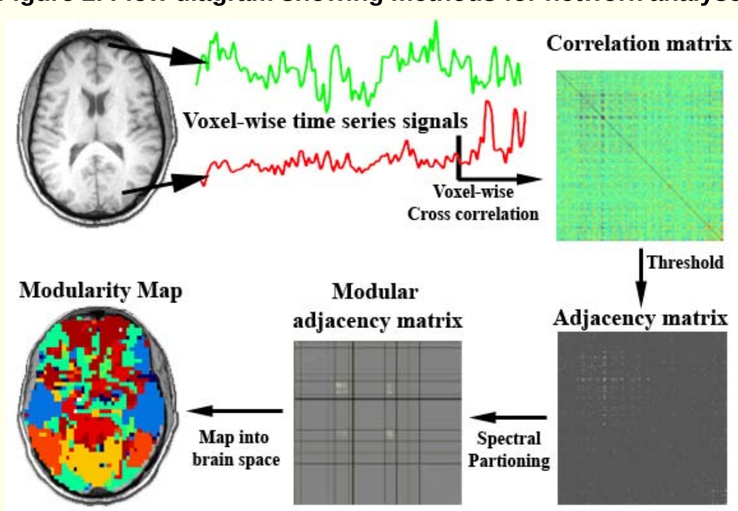
Efficiency:

Alternative metrics to C & L
- Local efficiency E_{loc}: for local interconnection
- Global efficiency E_{glob}: for long-distance communication

Methods

SUBJECTS. A total of 14 adult volunteers (age 22-35) participated in the study. **MRI ACQUISISTION.** BOLD MRI was collected during continuous rest, during viewing of a silent movie, and while watching a video with sound. All data was collected during continuous task performance over 7 minutes. **ANALYSES (see Figure 2).** 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 global metrics were based on his network and were averaged across all nodes. The adjacency matrix was also analyzed using a spectral graph partition method developed by Ruan (2008) to optimize Q and identify neighborhoods.

Figure 2. Flow diagram showing methods for network analyses



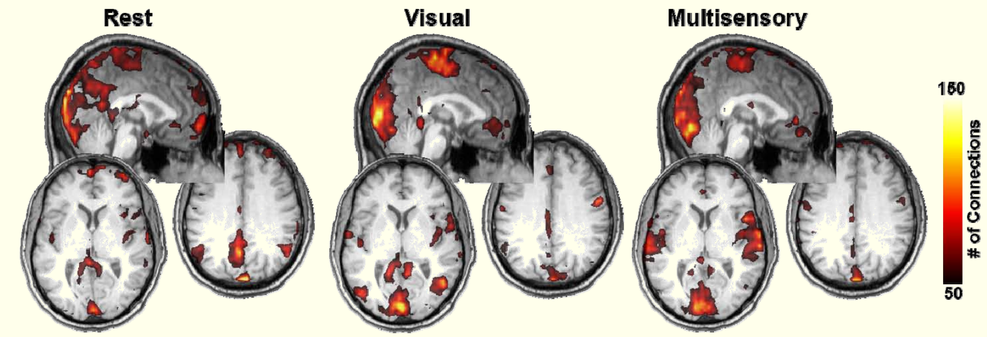
Results

Table 1. Global network metrics do not distinguish stimulation condition

	C	L	Eloc	Eglob
rest	0.29 (.011)	5.50 (.197)	0.43 (.009)	0.20 (.006)
visual	0.29 (.007)	5.34 (.156)	0.44 (.007)	0.21 (.005)
multisensory	0.29 (.012)	5.43 (3.19)	0.44 (.009)	0.21 (.007)

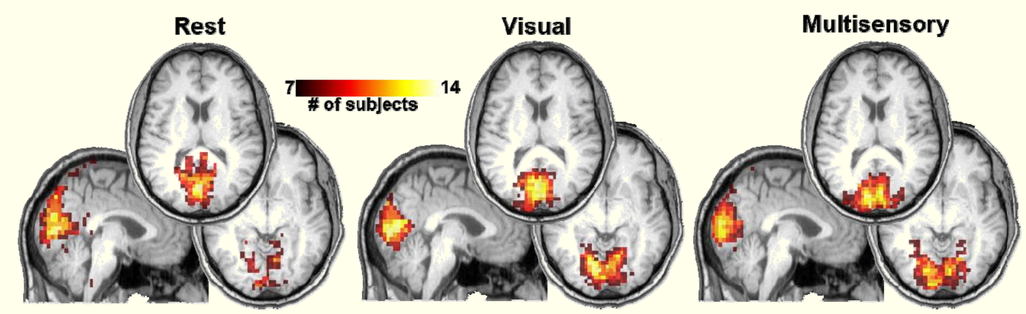
Mean clustering coefficient (C) and path length (L) are virtually identical across the 3 stimulation conditions. Metrics of global and local efficiency parallel the traditional measures showing no condition effects.

Figure 3. Hubs structure across conditions



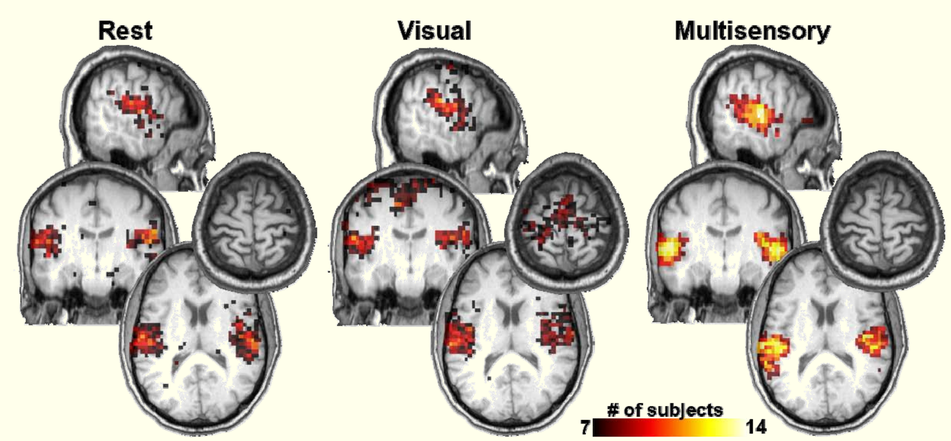
Hub maps show the average number of connections at each voxel across the 14 subjects. The maps have been thresholded to isolate the most connected nodes (hubs). At rest medial and lateral parietal cortex are the primary hubs. During viewing of a silent movie the visual cortices become hubs and the connectivity of the parietal cortex is reduced. During the multisensory movie the visual and auditory cortices are the hubs. The lateral occipital areas loose hub status during the multisensory condition.

Figure 5. Modular organization of the visual cortex



These "overlap" maps show the number of subjects (total of 14) that have a particular voxel in the visual cortex module. During the resting state (visual fixation), early visual cortex clearly visible. During the silent movie the visual module is expanded and more consistent across subjects. Multisensory stimulation results in a modest expansion of this module.

Figure 6. Modular organization of the auditory cortex



Overlap maps demonstrate that the organization of the auditory cortices. During the resting state (visual fixation), the auditory regions are moderately consistent across subjects. When watching a silent movie with sound, the auditory module includes sensorimotor areas (note areas axial slice through the upper cortex). During multisensory stimulation the auditory module is highly spatial specific and consistent across subjects.

Conclusions

- **Network analyses provide a novel view of multisensory processing**
- **Brain hubs shift from default-mode regions to the stimulated sensory cortices**
- **Community structure:**
  - **Visual cortex consolidates during viewing a silent or multisensory movie**
  - **Auditory cortex shares a community with sensorimotor during viewing a silent movie**
  - **During the multisensory movie auditory cortex exhibits strong consolidation and consistency**

References
Newman, M. E. & Girvan, M. (2004) Phys Rev E Stat Nonlin Soft Matter Phys 69, 026113; Ruan, J. & Zhang, W. (2008) Phys Rev E Stat Nonlin Soft Matter Phys 77, 016104.

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