Comparative Analysis of Brain Functional Networks: Pre vs Post-Learning

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Networks (Dr. Philip Knight)

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Background of Study

- In past, researches on networks in neuroscience has focused primarily on static situations.
- Based on **Mantzaris et al. (2013)** (1),
- 20 participants learned finger-tapping task over 3 days.
- Brain was modeled as a network of 112 regions (nodes).
- Edges are undirected and represent strong correlations (0.06–0.12 Hz) in activity between regions.
- **Aim of this project**: To track how the brain network changes over time during learning, by comparing brain networks from Day 1 to Day 3.

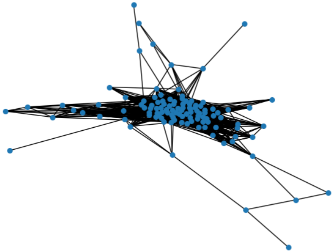
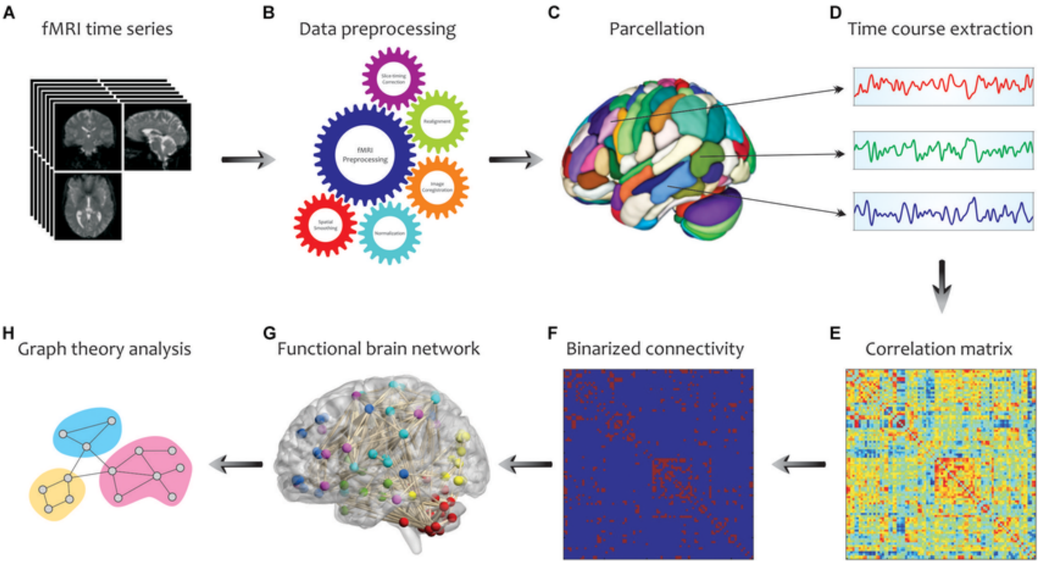


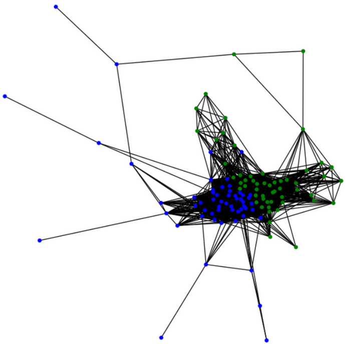
Figure: Brain network at day 1.

Background of Study

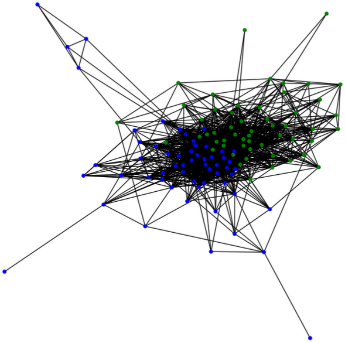


Community Structure

- **Interpretation:** As learning progresses, the brain network evolves from a more globally integrated state towards increased modularity.



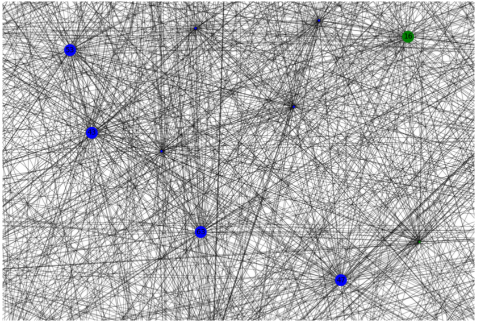
Communities at day 1.



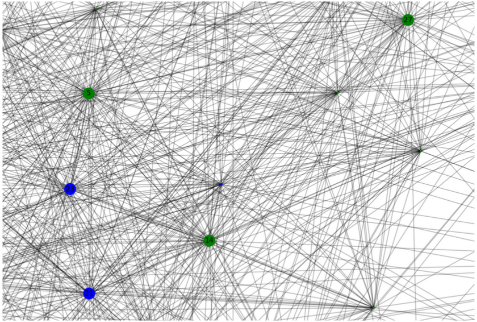
Communities at day 3.

Degree Centrality

- **Interpretation:** The most important nodes from day 1 become less important in day 3, as the brain gets better at the task.



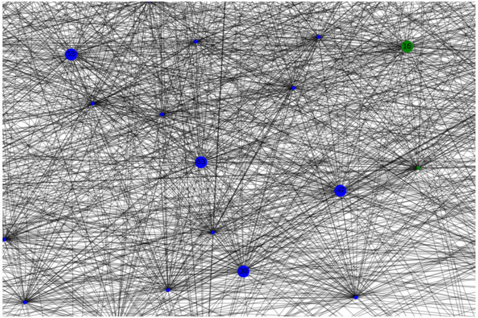
Day 1 Top 5 Nodes: [16, 47, 63, 53, 43]



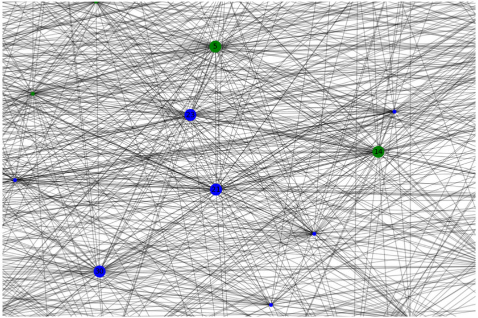
Day 3 Top 5 Nodes: [5, 14, 23, 21, 27].

Closeness Centrality

- **Interpretation:** Node 30 appears to be consistent from day 1 to day 3, implying it's importance in facilitating faster information flow throughout the learning process.



Day 1 Top 5 Nodes: [16, 63, 47, 30, 53]

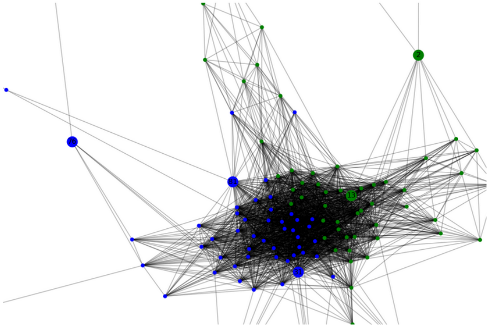


Day 3 Top 5 Nodes: [5, 14, 21, 23, 30]

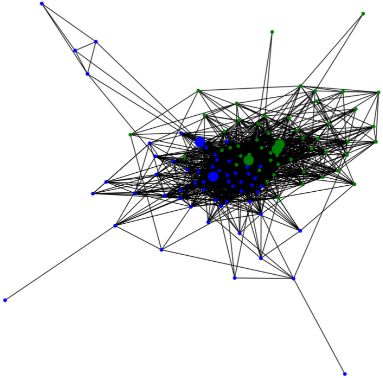
Betweenness Centrality

The top 5 nodes in day 1 and 3 act as bridges, providing the most efficient communication between communities.

- **Interpretation:** The reorganization of these bridges during learning, likely reflects optimization of information flow between specialized brain regions.



Day 1 Top 5 Nodes: [2, 31, 76, 13, 81]



Day 3 Top 5 Nodes: [0, 22, 5, 33, 6]

Comparison to Erdős–Rényi Random Graph

- Both brain networks are clearly non-random, showing strong small-world structure and rich motifs.
- The brain's wiring is highly organized, with dense clusters and short loops that support efficient, small-world communication.

Metric	Day 1 (Brain1)	Day 3 (Brain3)	Random Graph (ER)
Edges	~2500	1540	matches edges of real
Clustering Coefficient	0.7565	0.5671	0.4022 (Day1) 0.2465 (Day3)
Triangles (count)	38.026	~11.3457 (est.)	14803.6 (avg) (Day1) 3420.6(Day3)
Squares (Count)	1680411	327139.9	534086.2 (Day 1) 88340.9(Day 3)

Figure: Comparison of day 1 and 2 datasets with random graph models.

Summary of Statistics.

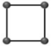
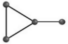
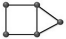
Metrics	**Day 1**	**Day 3**
Number of closed walks of 4	1.36×10^7	2.67×10^6
Number of closed walks of 5	8.16×10^8	1.03×10^8
Community 1 edges	**(57)** 839	**(58)** 529
Community 2 edges	**(55)** 702	**(54)** 486
Edges between communities	959	525
	3.80×10^4	1.13×10^4
	1.68×10^6	3.27×10^6
	7.03×10^6	1.43×10^6
	8.54×10^7	9.23×10^6
	3.27×10^8	3.31×10^7

Table: Summary of network statistics and motif counts for Brain1 (Day 1) and Brain3 (Day 3).

Conclusion

Our project shows that the brain reorganizes its connections as we learn a new skill. Using brain network analysis, we found that the brain reduces unnecessary links and strengthens communication within closely related areas. Over time, the network becomes more organized and efficient. Some brain regions lose their central role, while others become more important. Even with fewer connections, the brain still keeps a balanced structure that supports both local and global communication. These findings help us understand how the brain improves its function during learning.

References

[1] A. V. Mantzaris, D. S. Bassett, N. F. Wymbs, E. Estrada, M. A. Porter, P. J. Mucha, S. T. Grafton, and D. J. Higham, "Dynamic network centrality summarizes learning in the human brain," *Journal of Complex Networks*, vol. 1, no. 1, pp. 83–92, 2013.