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Graph-theoretical analysis of resting-state functional networks in mild cognitive impairment.

Hannah Vogel*

Department of Neurology, Berlin Institute of Brain Research, Germany.

*Correspondence to: Hannah Vogel, Department of Neurology, Berlin Institute of Brain Research, Germany, E-mail: hannah.vogel@neuro.uni-berlin.de

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Introduction

Graph-theoretical analysis has emerged as a powerful approach for investigating alterations in resting-state functional networks in individuals with mild cognitive impairment (MCI). MCI is widely considered a transitional stage between normal aging and Alzheimer's disease, characterized by subtle but measurable cognitive deficits that do not significantly impair daily functioning. Resting-state functional magnetic resonance imaging (rs-fMRI) provides a non-invasive method for assessing spontaneous neural activity, capturing intrinsic connectivity patterns between brain regions when individuals are not engaged in specific tasks. By representing these connectivity patterns as graphs composed of nodes (brain regions) and edges (functional connections), graph theory enables quantitative characterization of the brain's topological organization. This framework offers valuable insights into how network integration, segregation, and efficiency are altered in MCI, potentially revealing early biomarkers of neurodegenerative processes [1].

Key graph-theoretical metrics, such as clustering coefficient, characteristic path length, modularity, and global and local efficiency, are commonly employed to describe the functional architecture of resting-state networks. In healthy brains, these networks exhibit small-world properties, characterized by high clustering and short path lengths that support efficient information processing. In MCI, however, studies have reported disruptions to this optimal small-world balance, often manifesting as reduced clustering, increased path length, and diminished efficiency. Such alterations suggest a decline in the brain's capacity to integrate and segregate information effectively, potentially contributing to cognitive decline. In particular, changes in hubs—highly connected and central nodes in the network—are of particular interest, as these regions, such as the posterior cingulate cortex and precuneus, are critical for global communication and are among the earliest affected in Alzheimer's disease [2].

Resting-state networks, including the default mode network (DMN), executive control network, and salience network, show characteristic patterns of disruption in MCI. Graph-theoretical analysis has revealed decreased connectivity strength and altered community structure within these networks, with the DMN being especially vulnerable. The DMN, implicated in self-referential processing and memory consolidation, exhibits reduced intra-network connectivity and weakened hub integrity in MCI, which correlates with episodic memory impairments. Moreover, compensatory increases in connectivity in other networks, such as the frontoparietal control network, have been observed in some individuals, potentially reflecting adaptive responses to underlying pathology. These network-level changes highlight the complex interplay between degeneration and compensation in the early stages of cognitive decline [3].

Methodologically, graph-theoretical analysis of rs-fMRI data in MCI involves several key steps. First, the brain is parcellated into a set of regions of interest (ROIs) using anatomical or functional atlases. Time series data are extracted from each ROI, and pairwise correlations between them are computed to construct functional connectivity matrices. These matrices are then thresholded to define the edges in the graph, and various network metrics are calculated. Advances in preprocessing, noise reduction, and motion correction are crucial for ensuring the reliability of connectivity estimates, particularly in older populations where motion artifacts can be more prevalent. Additionally, emerging techniques, such as multilayer network analysis, dynamic connectivity modeling, and integration of multimodal imaging data, are expanding the scope of graph-theoretical approaches and providing deeper insights into the temporal and cross-modal aspects of network alterations in MCI [4].

Despite its promise, graph-theoretical analysis of resting-state functional networks in MCI faces several challenges. The choice of preprocessing steps, parcellation schemes, and thresholding methods can significantly influence network metrics, making standardization across studies essential for reproducibility. Variability in rs-fMRI acquisition parameters across research sites can further complicate comparisons, emphasizing the need for harmonized protocols. Moreover, while group-level differences between MCI patients and healthy controls are well-documented, translating these findings into reliable individual-level biomarkers remains challenging due to inter-individual variability and overlapping connectivity patterns. Longitudinal studies are needed to establish the predictive value of graph-theoretical metrics for conversion from MCI to Alzheimer's disease. Integrating graph theory with machine learning approaches may help address these limitations by identifying multivariate patterns that better capture the complexity of network alterations in MCI [5].

Conclusion

Graph-theoretical analysis of resting-state functional networks offers a robust framework for characterizing the subtle but significant alterations in brain connectivity associated with mild cognitive impairment. By quantifying changes in network topology, efficiency, and hub structure, these methods provide valuable insights into the neural mechanisms underlying early cognitive decline. While methodological challenges remain, advances in imaging protocols, analytical techniques, and computational modeling are enhancing the reliability and interpretability of these measures. As research progresses, graph-theoretical metrics derived from rs-fMRI may contribute to the development of sensitive, non-invasive biomarkers for early detection and monitoring of neurodegenerative diseases, ultimately improving diagnosis, prognosis, and intervention strategies in at-risk populations.

References

1. Veerapandiyan A, Connolly AM, Finkel RS, et al. Spinal muscular atrophy care in the COVID?19 pandemic era.. Muscle & nerve. 2020;62(1):46-9.
2. Goetschius DJ, Kim Y, Kumar A, et al. A comprehensive review of neuromuscular manifestations of COVID-19 and management of pre-existing neuromuscular disorders in children. J Clin Med. 2022;11(4):934.
3. Stratton AT, Roberts Iii RO, Kupfer O, et al. Pediatric neuromuscular disorders: Care considerations during the COVID-19 pandemic. . J Pediatr Rehabil Med. 2020;13(3):405-14
4. Kim Y, Walser SA, Asghar SJ, et al. A comprehensive review of neurologic manifestations of COVID-19 and management of pre-existing neurologic disorders in children. J Child Neurol. 2021;36(4):324-30.
5. Paybast S, Gorji R, Mavandadi S. . Guillain-Barré syndrome as a neurological complication of novel COVID-19 infection: A case report and review of the literature. Neurologist. 2020;25.

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