

Determining aging trajectories through hyperbolic embeddings of MEG brain networks

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Abstract

Background: Investigating age-related changes in MEG brain networks offers significant potential for comprehending aging trajectories and unveiling anomalous patterns associated with neurodegenerative disorders, such as Alzheimer's disease. In this study, we extended a deep learning model called Fully Hyperbolic Neural Network (FHNN) to embed MEG brain connectivity graphs into a Lorentz Hyperboloid model for hyperbolic space. Through these embeddings, we then explored the impact of aging on brain functional connectivity across multiple decades.

Method: We analyzed data from 587 participants enrolled in the Cambridge Centre for Ageing and Neuroscience (Cam-CAN) longitudinal study. Notably, we introduced a unique metric—the radius of the node embeddings—which effectively proxies the hierarchical organization of the brain. We leveraged this metric to (i) assess whether we can decode age-related information, and (ii) characterize subtle hierarchical organization changes of various brain subnetworks attributed to the aging process.

Result: Our decoding results revealed that the hyperbolic radius carries substantially more age-related information compared to all other conventional graph-theoretic measures examined, underscoring the effectiveness of employing hyperbolic embeddings to characterize the aging process. An examination of hyperbolic radius alteration patterns across decades exposed numerous subnetworks showcasing a decline in hierarchy during aging, with some displaying gradual changes and others undergoing rapid transformations in the aging brain (illustrated in Figure 1cde).

Conclusion: Overall, our study presented the first evaluation of hyperbolic embeddings in MEG brain networks, introduced a novel measure of brain hierarchy, and used this measure to highlight aging trajectories in the large cohort of the Cam-CAN dataset. A prominent finding was the reduction of hierarchy across a substantial number of subnetworks throughout the aging brain. This hierarchy reduction could imply a shift in the brain network configuration impairing cognitive processes.

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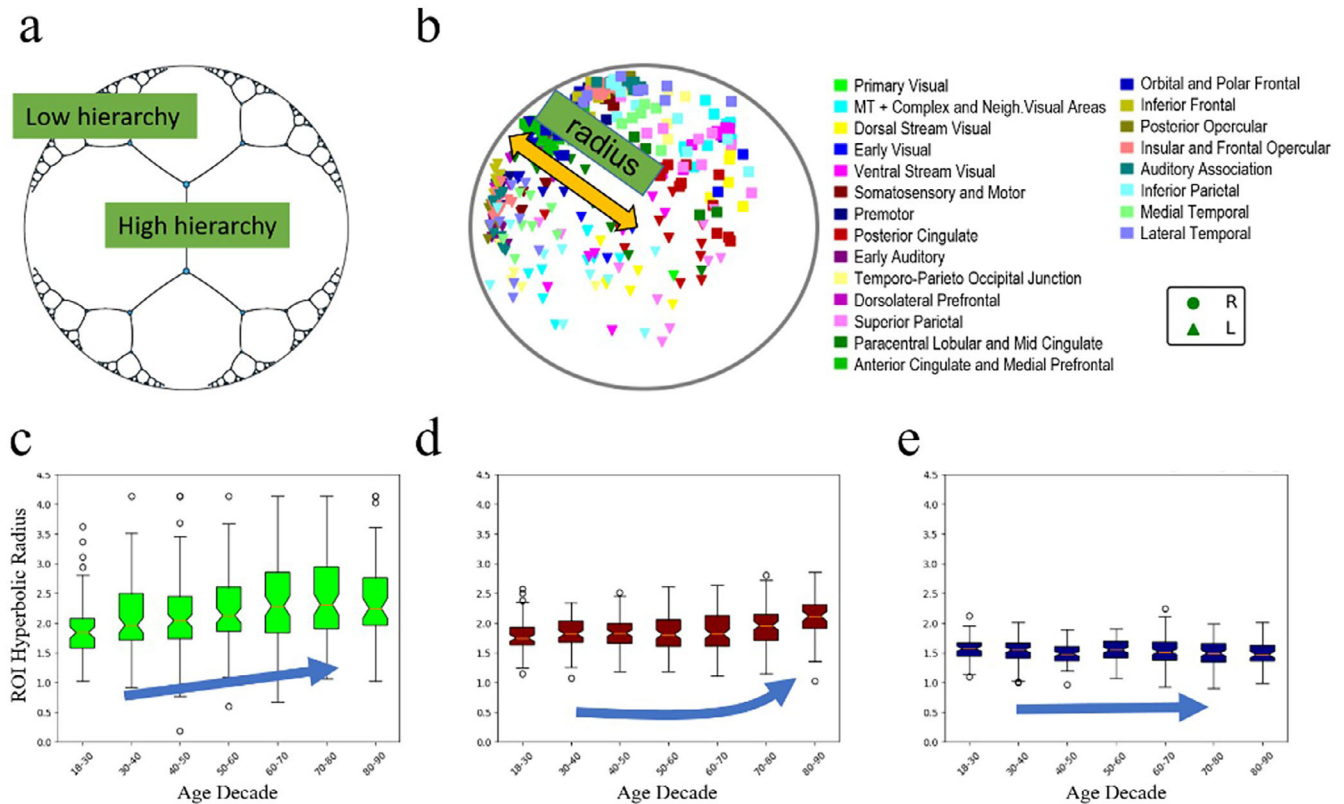


Figure 1: Hyperbolic embeddings of brain networks reveal aging trajectories. (a) Example hyperbolic embedding of a binary tree. Hyperbolic space expands non-linearly from center due to its negative curvature, enabling embeddings with minimal distortion. (b) Example hyperbolic embedding of the MEG network of a Cam-CAN participant. The hyperbolic radius effectively proxies the hierarchical organization of the brain. (c-d-e) Hyperbolic radius of left primary visual cortex, right orbital and polar frontal, and left paracentral lobular and mid cingulate, respectively. Each ROI undergoes a different trajectory across decades.