New ways of understanding brain neurocircuitry

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Abstract

Inside the brain, neural regions dynamically interact at multiple spatial and temporal scales through a highly structured and adaptive neurocircuitry. Comprehensive maps of brain connectivity have led to the emerging field of connectomics. Graph theory methods are interesting tools to improve our understanding of the brain as a complex interconnected system.

Keywords: *neurocircuitry; connectome; graph theory method; mental disorder*

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The brain is definitely the most complex human organ. Neurons are linked by a large number of connections that can be analyzed across several orders of spatial, as well as temporal, magnitude. Indeed, functional brain networks are intrinsically dynamic on multiple timescales. To add another level of complexity, brain functional networks also spatially overlap and interact with each other. Moreover, such network interactions may temporally evolve. Even during the resting state, the brain undergoes dynamical changes in functional connectivity. The structural and functional study of these networks remains crucial to the understanding of brain organization, dynamics, and cognition or behavior by quantitative description of the temporal evolution of spatial overlaps/interactions of connectome-scale brain networks.[1] For example, Kottaram et al (2018)[2] have studied spatio-temporal dynamics of resting state brain networks in the prediction of schizophrenia diagnosis (see also Marek and Dosenbach in this issue, p 133).

An essential tool used to understand functional brain networks is functional magnetic resonance imaging (fMRI), which allows the indirect study of brain neural activity using the hemodynamic relationship between blood flow and neural firing. It is often used to examine contrasts between different cognitive conditions or changes in functional signal amplitudes and connectivity associated with different behaviors.

Comprehensive maps of brain connectivity have given rise to the emerging field of connectomics. Collin and Keshavan, in this issue (p 101), have explored how disruptions in these processes could lead to abnormal brain network architecture and organization and, thereby give rise to mental disorders such as schizophrenia.

The connectome is the complete structural wiring diagram of the brain. A better knowledge of its organization is an important and challenging question. Interareal connectomes are wiring diagrams of white matter pathways (also called mesoscale or macroscale connectomes). Previous studies have described modules, hubs, module hierarchies, and rich clubs, as structural characteristic of these wiring diagrams. Modules are densely intraconnected areas which constitute functionally specialized systems; hubs are connected areas which integrate information between these systems. Module hierarchies are nestings of smaller modules within larger ones; while rich clubs are highly connected groups of hub nodes which reflect the dense connectivity between association areas. One important rich club is the structural substrate of the default-mode network (for review see Rubinov, 2016).[3] In this issue, Griffa and Van den Heuvel (p 121) will review recent neuroimaging, computational, and cross-species comparative literature to provide an insight into the function and origin of rich clubs and the core brain architecture, while discussing the relevance of rich clubs to human cognition and behavior as well as vulnerability to brain disorders.

A number of emerging trends to identify central network elements that facilitate communication and signal transfer are the growing use of generative models, dynamic (time-varying) and multilayer networks, as well as the application of algebraic topology. The mathematical basis in which one can represent and study networks of nodes and connections is called graph theory which is crucial to study brain complexity. Using this latter theory, the analysis of brain resting state using fMRI has shown several interesting pathways of healthy and dysfunctional brain network organization.[4] In this issue, Sporns reviews some of the most relevant graph theory methods and illustrated their application in various neurobiological contexts (p 111). Calhoun (p 87) will also discuss the synergistic relationship between brain structure and function to link together macroscopic structural and functional MRI data. This latter author will provide a selective review of data-driven approaches with a focus on independent component analysis approaches for capturing multivariate relationship both within and between brain structural and functional measure with multiple analytic examples. ❑

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