A spotlight on network hubs: cutting-edge analyses and clinical applications

Thursday, Jun 21: 8:00 AM - 9:15 AM
1968
Symposium
Thursday - Symposia AM

Our community has contributed to a shift in neuroscientific inquiry, which emphasizes the relevance of studying large-scale networks to understand the organization of the healthy and diseased brain. The purpose of this symposium is to shed light on hubs, crucial building blocks of those networks that ensure efficient communication between the individual elements and sub-modules of the network. Given their relevance in maintaining network stability, the identification of hubs is crucial for our understanding of network architecture and their mapping may provide a synoptic view on macroscale structural as well as functional organization. Moreover, numerous studies have suggested large-scale network reorganization in disease and, in particular, high susceptibility of hub regions to pathology.

The proposed symposium will shed light on the importance of hubs for overall brain network topology and their vulnerability in disease. We will provide an update on state-of-the-art methodologies to identify hubs and cover work that supports their significant clinical relevance.

Our first speaker (Shi Gu) will cover controllability analysis on structural networks, a novel framework to simulate functional dynamics from a diffusion MRI derived connectome and to identify hubs that can steer whole-brain dynamics in healthy brain function and traumatic brain injury. Our second speaker (Işık Karahanoğlu) will overview recent approaches fMRI analyses to construct spatially and temporally overlapping brain networks and to situate core nodes within these representations. Thirdly, Kangjoo Lee will present her k-hubness framework, a methodology able to identify hubs, the underlying networks associated to each hub and the analysis of hub typical reorganizations for patients with epileptic lesions. Finally, Nicolas Crossley will overview his work on integrating meta-analytical techniques with network centrality mapping, which supports a preferential susceptibility of hub regions across numerous clinical conditions. Our symposium will end with a discussion panel with our speakers and the audience on this important question: should we consider connector hub for clinical studies?

Objective

This morning workshop is designed to develop participants' understanding of:
• The concept of hub regions in structural and functional networks
• Cutting-edge methodologies (graph theory, sparse modeling, control theory, dynamic systems) to characterize connector hubs
• The role of hubs in healthy brain organization
• The relevance of hub analysis to study brain pathology

Target Audience

This workshop targets a broad audience, including neuroimagers, network neuroscientists, clinicians, mathematicians, and everyone interested in the use of advanced system analysis to improve our fundamental knowledge of brain connectivity and network architecture. The analyses of structural and functional neuroimaging data will be covered, and the audience will also learn about cutting-edge applications of the concept of network hubs to characterize pathological brain activity.

Co Organizer

Boris Bernhardt, McGill University

Organizer

Christophe Grova, PERFORM Center - Concordia University

Presentations

Controllability Analysis on Structural Brain Networks (index.cfm?do=ev.viewEv&ev=1665)

The complexity of neural dynamics stems in part from the complexity of the underlying anatomy. Yet how white matter structure constrains how the brain transitions from one cognitive state to another remains unknown. Here we address this question by drawing on recent advances in network control theory to model the underlying mechanisms of brain state transitions as elicited by the collective control of region sets. Our results suggest that densely connected areas, particularly in the default mode system, facilitate the movement of the brain to many easily reachable states. Weakly connected areas, particularly in cognitive control systems, facilitate the movement of the brain to difficult-to-reach states. Areas located on the boundary between network communities, particularly in attentional control systems, facilitate the integration or segregation of diverse cognitive systems. Further, we find that previously identified attention and executive control systems are poised to affect a broad array of state transitions that cannot easily be classified by traditional engineering-based notions of control. This theoretical versatility comes with a vulnerability to injury. In patients with mild traumatic brain injury, we observe a loss of specificity in putative control processes, suggesting greater susceptibility to neurophysiological noise. These results offer fundamental insights into the mechanisms driving brain state transitions in healthy cognition and their alteration following injury.

Presenter

Shi Gu, University of Electronic Science and Technology of China

---

Time-resolved fMRI analysis reveals rich dynamics of large-scale brain networks in health and disease (index.cfm?do=ev.viewEv&ev=1666)

Spontaneous brain activity measured by functional magnetic resonance imaging (fMRI) provide a novel window onto the organizational principles of brain function. New dynamic models enable to capture the spatiotemporal structure of large scale functional networks and offer a new understanding of the complex network interactions. I will talk about these recent developments on resting-state fMRI analyses to construct spatially and temporally overlapping brain networks, and how their dynamic properties and interactions help to better characterize brain function and provide clinically relevant information in the presence of disease

Presenter

Fikret Işık Karahanoğlu, Massachusetts General Hospital

SParsity-based Analysis of Reliable K-hubness (SPARK): A new analysis of individually reliable functional connector hubs and its application to epilepsy (index.cfm?do=ev.viewEv&ev=1667)

In brain networks, hubs are brain regions with dense connections to other regions. Connector hubs participating in inter-network connectivity promote long-range communications. Hubs are often identified using the hubness metrics in graph theory, such as degree centrality, which counts the number of all pairwise significant correlations between voxels up to several thousands. However, the identification of hubs from functional data is more complex than that from structural data, notably because of the inherent problem of multicollinearity between temporal dynamics within a functional network. We recently developed a “SParsity-based Analysis of Reliable K-hubness (SPARK)” to study connector hubs using resting state functional MRI. SPARK handles the multicollinearity based on a sparsity assumption that a voxel can be involved in more than one but not all resting state networks. It proposes a new measure of hubness by counting the number (k) of networks involved in each voxel: k-hubness, featuring the unique ability to identify which networks are actually involved in each hub. The robustness and test-retest reliability of SPARK were validated using realistic simulations and real data. Using SPARK, we studied the reorganization of connector hubs in mesial temporal lobe epilepsy (mTLE). mTLE is characterized by recurrent seizures originating in the mesial Temporal Lobe (mTL), however, recent studies suggest abnormal reorganization of brain networks involving distant brain regions. Within the mTL structures and default mode network, we compared the k-hubness values estimated using SPARK in individual patients to those estimated consistently in healthy controls. We found pathological hub disruptions where brain regions corresponding to connector hubs in the control group become non-hubs in individual patients. We also found the characteristic emergence of new hubs in each patient from brain regions corresponding to non-hubs in controls, suggesting a candidate biomarker of mTLE lateralization. SPARK also identified several important epileptic networks involving the pathological hippocampus in individual patients. Our results suggest that SPARK is a promising tool to study hub reorganization in epilepsy and also in different neurological disorders and conditions.

Presenter

Kangjoo Lee, McGill University

Testing the universality of hub vulnerability through meta-analysis (index.cfm?do=ev.viewEv&ev=1668)

Theoretical work has shown that networks with a heavy-tailed degree distribution, containing nodes with a high number of connections or hubs, are resilient to random attack but vulnerable to targeted attacks to hubs. Brain networks have hubs, and therefore should also follow this behavior. I here will present the use of meta-analysis to test this hypothesis, using meta-data to explore the hub vulnerability across multiple brain disorders, as well as across different functional MRI tasks. I will show that this specific property of the brain organization modulates how it is affected by brain disorders, and discuss how this is compatible with many pathophysiological mechanisms.

Presenter

Nicolas Crossley, King's College London