Published in final edited form as:
Trends Cogn Sci. 2013 December ; 17(12): . doi:10.1016/j.tics.2013.10.001.

Fronto-parietal network: flexible hub of cognitive control

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Abstract

A recent study shows that the fronto-parietal network (FPN), and subregions therein, alters its functional connectivity with nodes of other networks based on task goals. Moreover, FPN patterns of connectivity not only reflect engagement of specific tasks, but also serve as a code that can be transferred to facilitate learning novel tasks.

Neuroimaging techniques, such as functional MRI (fMRI), have permitted unique insights into the structure and function of the human brain, and have helped advance the now pervasive view that the brain operates via functional interactions between distributed regions, or neural networks. Importantly, a plethora of neuroimaging research has identified multiple functional neural networks that may be generalized into ‘processing’ or ‘control’ network categories [1]. Whereas processing-type networks are considered more modular and static, control-type networks are hypothesized to be dynamic and flexible, with an ability to adapt to a wide variety of tasks. One such control network, the fronto-parietal network (FPN), includes portions of the lateral prefrontal cortex and posterior parietal cortex, and is thought to be involved in a wide variety of tasks by initiating and modulating cognitive control abilities [2]. Yet, it is unclear how the FPN can generalize its function to many different tasks, regardless of whether the task is practiced or novel.

Recently, Cole and colleagues [3] tested the hypothesis that the FPN is composed of brain regions that, according to task requirements, flexibly and rapidly alter their functional connectivity with other neural networks that are more task specific, such as processing-type networks. Moreover, Cole and colleagues [3] assessed whether network connectivity patterns during practiced tasks could be transferred to novel tasks (exhibiting compositional coding), thereby providing a functional network basis to understand rapid instructed task learning. To achieve this, a unique paradigm was implemented that permuted 12 task rules into 64 novel task states. The 12 task rules were created to assess three distinct cognitive domains (four rules per domain): logical decision, sensory semantics, and motor response. On each trial, three task rules were presented (one from each cognitive domain). Participants practiced four of these tasks for two hours on a separate day preceding the fMRI session. Then, during fMRI data acquisition, 60 novel tasks and four highly practiced tasks were assessed, each with a 50% trial-wise probability. By manipulating the task rules on each trial, Cole and colleagues [3] were able to assess whether the FPN, compared to other neural

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networks, exhibited greater task-specific connectivity patterns and whether such compositional coding may be reused to implement novel tasks.

The fMRI data were parcellated into 264 putative functional areas and assigned to one of ten major functional neural networks [1]: fronto-parietal, cingulo-opercular, default, dorsal attention, ventral attention, salience, motor, visual, and auditory. Cole and colleagues [3] calculated a global variability coefficient (GVC) for each of the 264 regions by assessing the variance of functional connectivity (across the 64 tasks) with the other 263 regions, and network GVC was calculated by averaging GVC from regions within each network. This procedure enabled a global variable connectivity metric that averages GVCs across networks, whereas pairwise comparisons between networks yielded mean variable connectivity measures. As hypothesized, the FPN, compared to the other nine networks, exhibited a greater GVC globally (averaged across networks), whereas pairwise GVC comparisons between networks showed that the FPN exhibited the most variable functional connectivity with each of the other nine networks. These results suggest that the FPN may serve as a flexible hub that alters its functional connectivity with other neural networks based on the specific task.

To address whether the FPN may transfer functional connectivity patterns from practiced tasks to novel tasks (thereby exhibiting compositional coding), multi-voxel pattern analysis (MVPA) was used to decode task state. Classifiers were trained on the novel tasks across subjects (to counterbalance the number of trained rules) and tested on the practiced tasks. The classification results yielded accuracies significantly better than chance, suggesting that the FPN functional connectivity patterns not only reflect task state, but may also be transferred between practiced and novel tasks. Importantly, such classification performance was not observed in other networks, underscoring the importance of the FPN in initiating and adjusting cognitive control. Together, these results suggest that the FPN contains flexible hubs, whose connectivity patterns are systematic and structured, reflecting compositional coding that enables an immediate transfer of knowledge to novel tasks.

Similar to how the conceptualization of neural networks have advanced our understanding beyond a modular view of the brain, dynamic multi-network interactions may enhance the framework by which we understand cognitive function. Notably, flexible hub theory may prove instrumental in characterizing the functional connectome of the human brain. Previous research has recognized the dynamics of neural networks, such that networks may reorganize in response to changes in sensory input, task, cognitive load, or learning (e.g., [4, 5]). The work of Cole and colleagues [3] extends previous work to show that network reorganization is a structured process, based on task goals, that involves integrating information across multiple networks, thus supporting recent perspectives on the role of network hubs [6]. Interestingly, the notion of FPN flexibility supports findings that neural perturbation of the FPN may utilize contralateral homologues to uphold task performance [7, 8]. Moreover, the ability of the FPN to use compositional codes to facilitate learning novel tasks provides a mechanism for recent findings that suggest that a common core in cognitive control may underlie transfer-of-benefits following cognitive training [9].

Flexible hub theory may help explain why ‘temporal functional modes’ exist, in which a neural region may be coupled with a certain network at one time, and a different network at another time [4, 10]. However, it remains unclear what information is transferred between the FPN and other cognitive control networks. Dosenbach *et al.* [2] proposed that the FPN may serve to initiate and adjust cognitive control, whereas another control-type network, the cingulo-opercular network (CON), provides stable set-maintenance. Although Cole and colleagues [3] helped to solidify the role of the FPN as predicted, many questions remain regarding the interaction between the FPN and the CON, such as whether compositional codes are transferred to the CON for task set-maintenance. Overall, characterizing the dynamic role of the FPN and how it interacts with other major networks, such as the CON and default mode, will be critical towards understanding the neural basis of cognition and structure–function relationships, and enhancing prognostic/diagnostic abilities in clinical populations.

Acknowledgments

Supported by NIH grant R01MH096861.

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