Cognitive control networks route task information to other networks via intrinsic functional connectivity pathways

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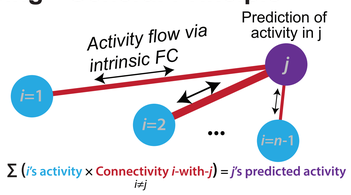
How is task information transferred between brain regions?

Recent evidence suggests that resting-state functional connectivity architecture describes the routes of activity flow for task-specific brain activations (Cole et al., 2016). However, the mechanism by which task information is transferred between functional brain components remains unclear. Shannon's information theory (Shannon, 1948) offers a framework by which communication channels transmit information between two receivers. Here, we extend the activity flow mapping framework as a large-scale mechanism and treat resting-state connectivity estimates as the channels that transfer information content between regions and networks. We use activity flow over resting-state connections as the underlying mechanism by which task information is transferred between regions.

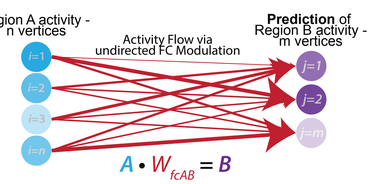
Activity Flow Mapping - General Principle

Activity of a region j is predicted by the linear weighted sum of all other regions' activity weighted by their intrinsic functional connectivity (resting-state functional connectivity) with region j

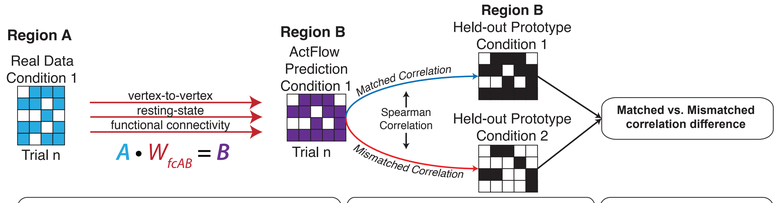


Region-To-Region Activity Flow Mapping

Activity patterns in Region B are predicted by computing the dot product between activity patterns in Region A and the intrinsic functional connectivity matrix between Region A and Region B



Information Transfer Mapping Procedure



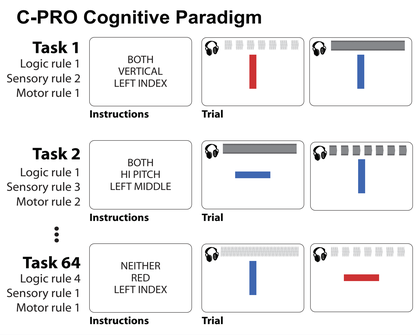
1) Region-to-region activity flow mapping

2) Predicted-to-actual activity pattern similarity tests

3) Information transfer estimate

Behavioral Paradigm

C-PRO Cognitive Paradigm



Rule set 1 description: *If BOTH stimuli are VERTICAL, press your LEFT INDEX finger*

Answer: TRUE (Left index finger)

Rule set 2 description: *If BOTH stimuli are HI PITCH, press your LEFT MIDDLE finger*

Answer: TRUE (Left middle finger)

Rule set 64 description: *If NEITHER stimulus is RED, press your LEFT INDEX finger* (other finger, same hand if false)

Answer: FALSE (Left middle finger)

Logic Rules
1. Both
2. Not Both
3. Either
4. Neither

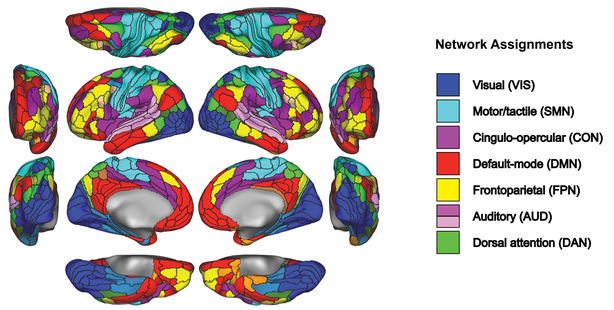
Sensory Rules
1. Red
2. Vertical
3. Hi Pitch
4. Constant

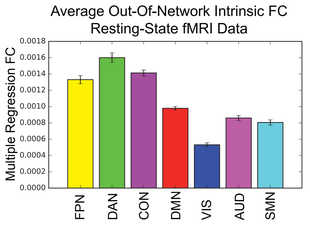
Motor Rules
1. Left Index
2. Left Middle
3. Right Index
4. Right Middle

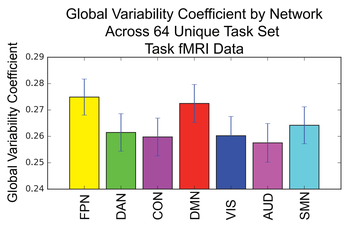
Resting-state connectivity as information flow channels

Hypothesis: Intrinsic topology of resting-state networks shapes the flow of task information between flexible hub networks (e.g., cognitive control networks) and task-related networks.

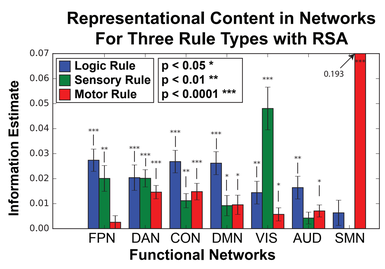
Network Definitions using parcels from Glasser et al. (2016)

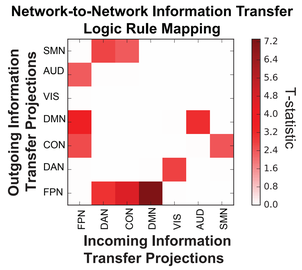


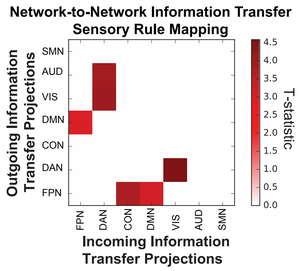


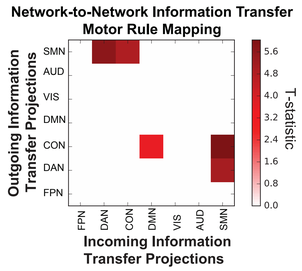


Network-to-network information transfer mapping





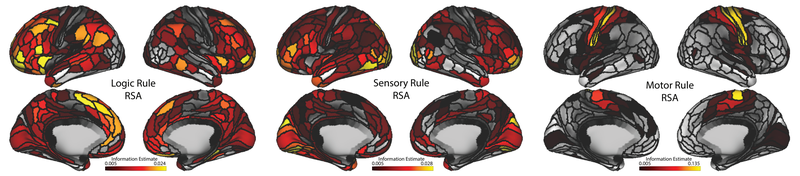




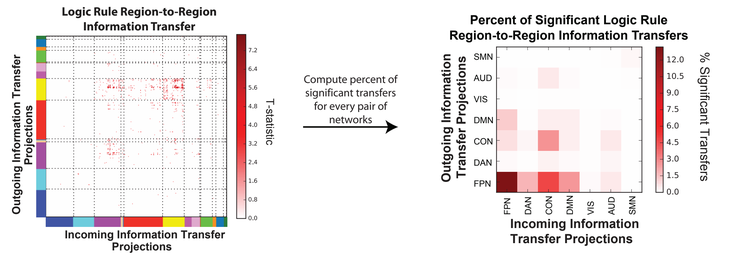
- Activity flow over resting-state networks transfer task representations to functionally relevant networks
- Higher-order, abstract task-rule information is more widely distributed than lower-order sensorimotor rule representations
- Cognitive control networks are involved in transferring task information across all rule domains

Region-to-region information transfer mapping

Representational content across three rule types for each region



Information transfer mapping between regions across three rule types



- Logic rule task representations are highly distributed across cortical regions, with significant transfers coming from frontoparietal regions.
- Sensory rule projections show less distributed representations, but higher specificity, with information transfer within visual regions and DAN regions.
- Motor rule projections show the highest specificity, with localized distribution of information in the motor network and some information transfer between the motor network and the DAN/CON.

Summary & Conclusions

- Resting-state network organization can ***shape the flow of task information*** at two levels of organization: functional networks and regions
- Resting-state connectivity describe the potential channels of communication between regions
- The information transfer framework can ***predict the computational transformation between task representations in regions***
- Cognitive control networks play an integral role in the transfer of task information between regions and networks

References

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