Task-specific Interactions of Overlapping Networks Across Key Cognitive Domains

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Introduction

- Human cognition is organized in distributed networks in the brain.
- While distinct specialized networks have been identified for different cognitive functions, previous work also emphasizes the overlap of some key cognitive domains in higher level association areas[1].
- Among these functions, **attention**, **language**, and **social cognition** represent three key human-defining facets that are central for environmental interaction and successful communication.
- A better understanding of the overlap, interaction, and dissociation of these networks during different cognitive tasks may provide insight into how resources are flexibly redistributed during cognition.
- Choice of window length in dynamic connectivity analysis is still poorly understood, and applying the analysis in multi-task fMRI may provide additional guidelines for method selection

Methods

Experiment:

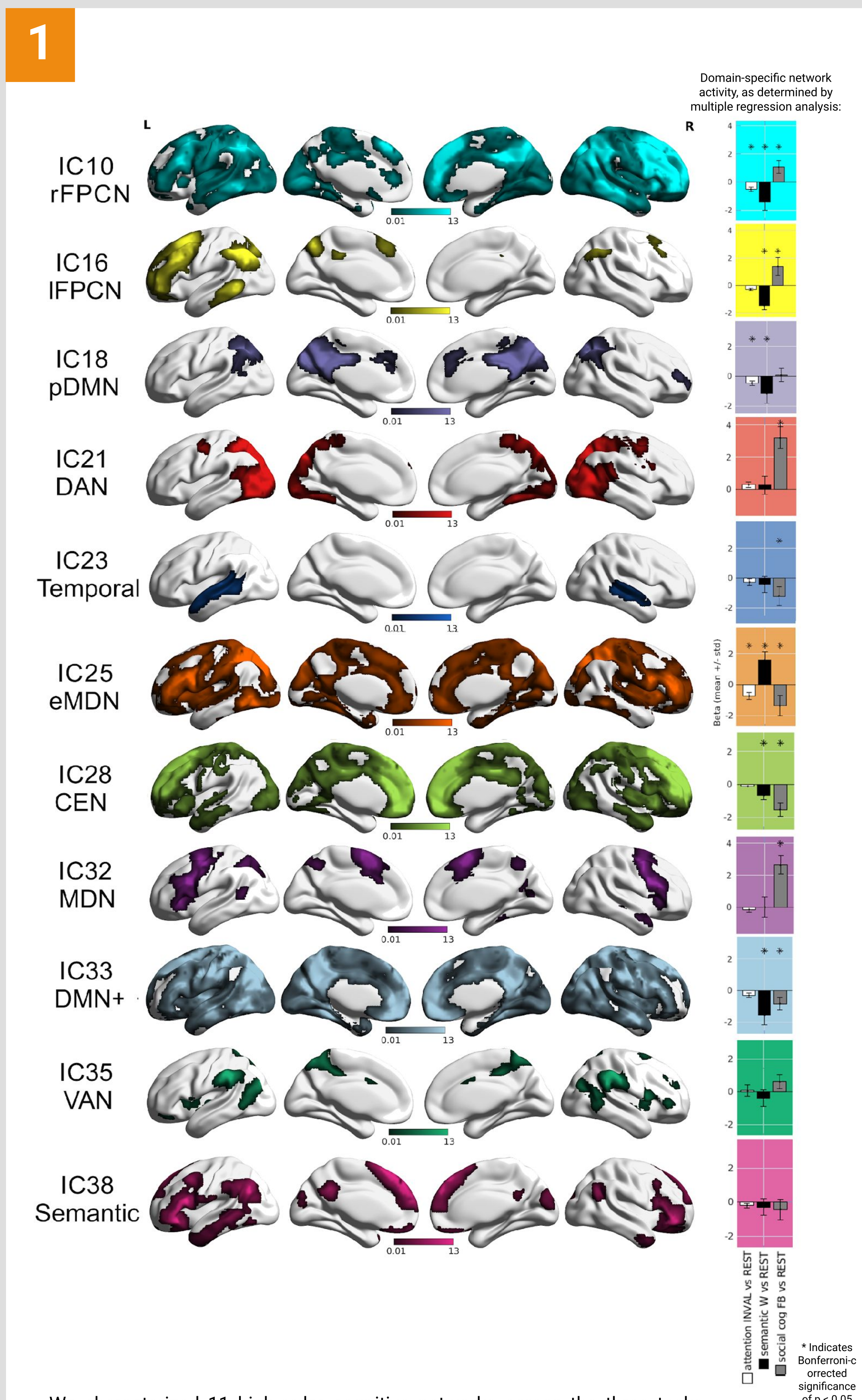
- 22 healthy, native German speakers (11 female, mean age 27.9 ± 3.28 years)
- Multi-task fMRI experiment combining three prototypical tasks of larger domains:
  - Attention – Posner-like attentional reorienting
  - Language – lexical decision making (semantics)
  - Social cognition – perspective taking (Sally Anne task)
- 12 experimental runs performed across three different days, each including all tasks
- Whole-brain coverage with 0.5 second TR acquisition rate

Analysis:

- Group-wise spatial independent component analysis (sICA) with multiple-regression assessment of network task activity
- Correlational psychophysiological interaction analysis[2] (cPPI) to quantify task-specific network interactions
- Dynamic functional network connectivity (dynFNC) analysis:
  - Six window lengths: 20, 40, 60, 80, 100, and 120 seconds
  - Task-based dynamic connectivity correlation as implemented in GIFT toolbox[3], following Sakoğlu et al. , 2010[4]

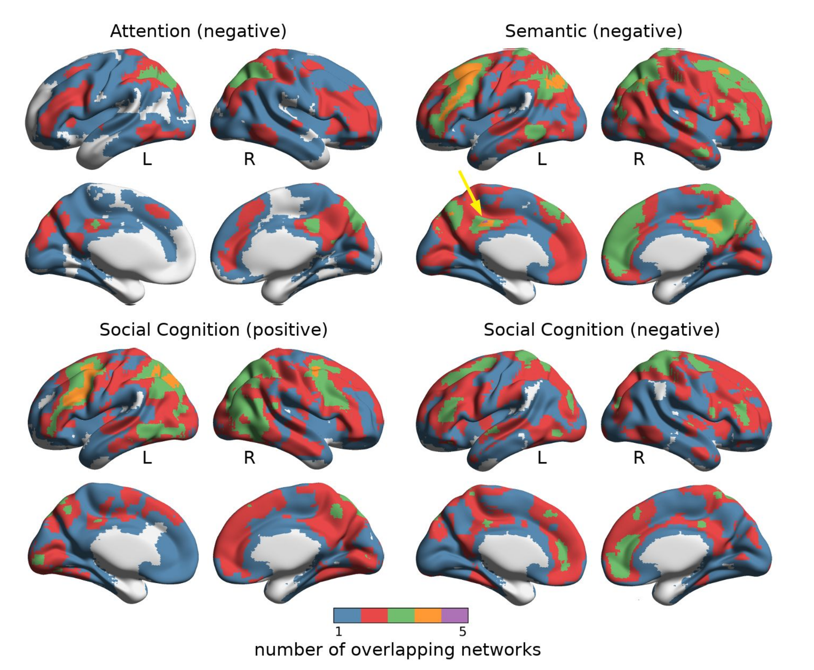
Results

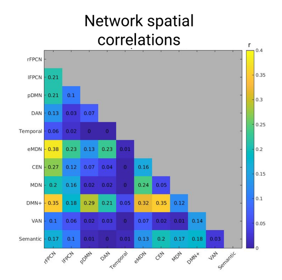
1



We characterized 11 high-order cognitive networks across the three tasks. The spatial distributions of the networks comprise both typical **resting-state intrinsic connectivity networks** – the right and left lateralized fronto-parietal control networks, dorsal attention network, default mode network subsystems: posterior DMN, temporal lobe, and the classical DMN, with extensions across the cortex, and central executive network – and **task-evoked functional connectivity networks** – the multiple demand and extended multiple demand networks, ventral attention network, and the semantic network. Multiple regression of each network's activity to task-based predictors reveals the strength of the networks' activity in each cognitive domain.

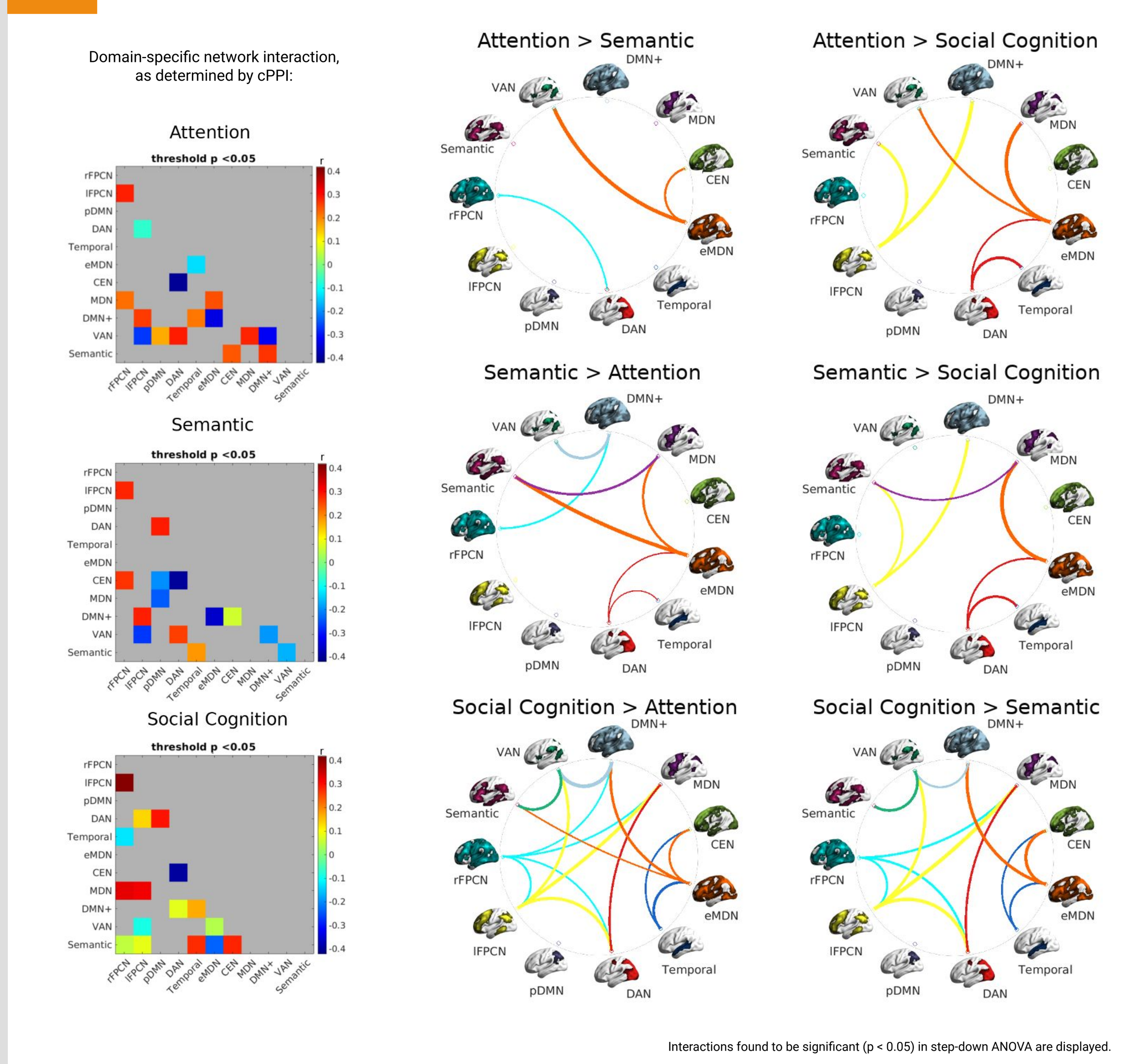
2





Spatial correlations between the networks ensure their distinct distributions. However, for each domain, plotting all networks with significant activity associated with the task reveal the significantly overlapping nature of simultaneously active networks during attention, semantics, and social cognition.

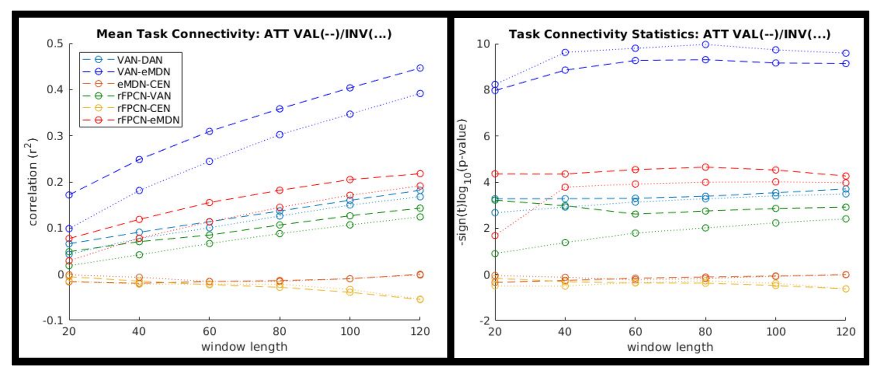
3



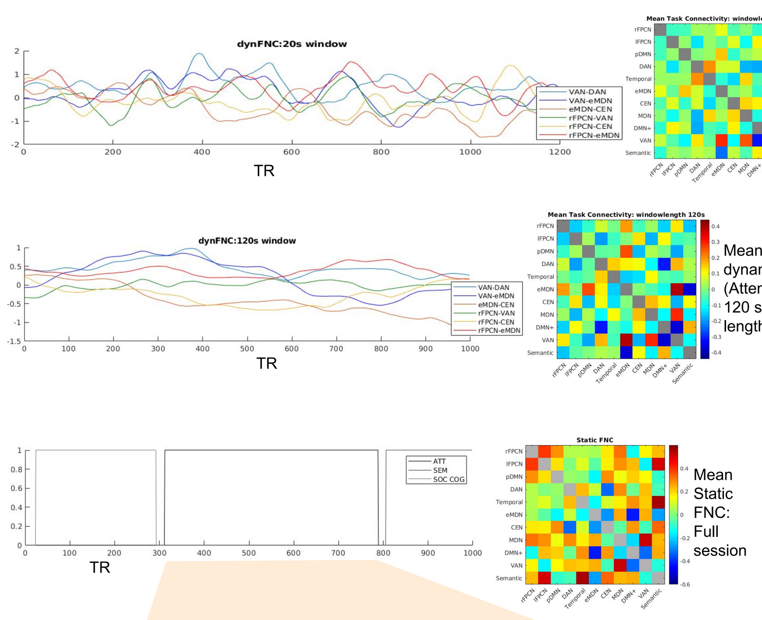
Correlational PPI analyses show interactions between the selected networks that distinguish each domain from the other. Comparing interactions between domains shows consistent involvement of the multiple demand, dorsal attention, and right and left fronto-parietal control networks, while also highlighting the strength of domain-specific network interactions, such as VAN for attention and the semantic network in its respective language domain task.

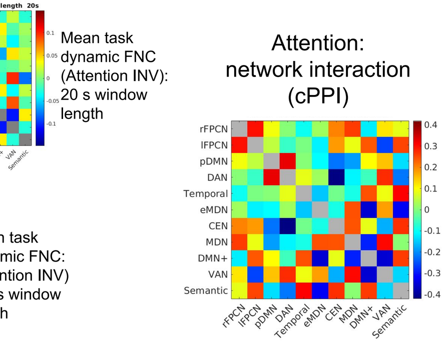
4

Task-based dynamic connectivity assessed across time windows for the **attention task** in network pairs whose cPPI-based interactions were significantly stronger than in the semantic task.



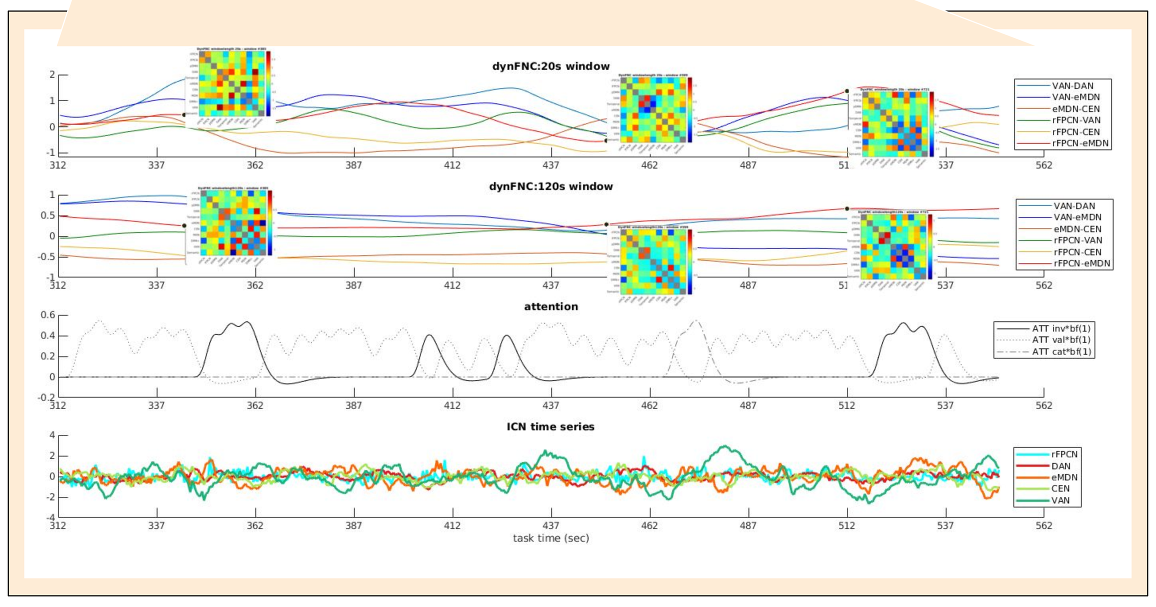
Mean correlation implies that dynamic functional network connectivity increases with window size, while t-test results show different network pairs to have more significant connections in different time windows. Network interaction significance also varies between the target (attention: invalid) and control (attention: valid) conditions.





While task correlation values are lower with 20 s window length (upper left matrix), overall network interaction appears similar in 120 s window dynamic analysis (middle left). Static connectivity across all tasks (lower left) more strongly resembles attention task-based cPPI interactions (above) than task-based dynamic network connectivity.

Attention task:
single subject, single session inspection



Visual inspection of a single session shows the evolution of dynamic connectivity across the attention task conditions (third line plot). Dynamic connectivity for selected network pairs (attention>semantic, cPPI) for shortest (20 s, top line plot) and longest (120s, second line plot) window lengths, along with whole brain network connectivity snapshots, reveal diverse network connectivity motifs that generally resemble one another in corresponding time windows. These snapshots bear less resemblance to task-based correlation or cPPI matrices. Time series of single ICA networks comprising the set of selected pairwise interactions (bottom line plot) show that task-dependent fluctuation of network activity varies in frequency across networks, thus influencing measurement of dynamic interactions in different window lengths.

Discussion

- We have built upon our previously inferior parietal lobe-focused results of whole brain connectivity[5].
- In line with recent multi-task fMRI studies[6,7], we show a common functional structure across tasks.
  - Interaction patterns demonstrate a common core structure across domains, including the multiple demand network, default mode subnetworks, and two lateralized fronto-parietal networks, as well as dissociable domain-specific activity and connectivity, that is, ventral attention network specific to attentional reorientation, semantic network specific to lexical decision making, and several domain general networks to social cognition.
- Functional network interactions increase with increasing cognitive complexity of the three domains, from attention to semantics to social cognition.
- While it has been shown that node connectivity differs across functional networks for different window lengths in dynamic analysis[8], inspecting time series interactions of whole networks spatially resolved in a data-driven manner allows insight about task-elicited network-specific activity.
- Initial results of temporal dynFNC show condition-specific variation of task-based connectivity significance across time windows that also differs across network pairs.
- Dynamic connectivity snapshots reveal network interactions not captured by task-based correlation or cPPI interaction, as such other dynamic connectivity quantification methods (e.g., state-based) should be considered for multi-task data.
- Inspecting ICA network time series shows that variable network frequencies may interact with quantification of dynamics across time windows, as such, alternative quantification methods incorporating multiple window lengths or correlations with moments of supra-threshold activity should be considered. Also, alternative frequency or phase-based connectivity measures (e.g., wavelets) should be considered.

References

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