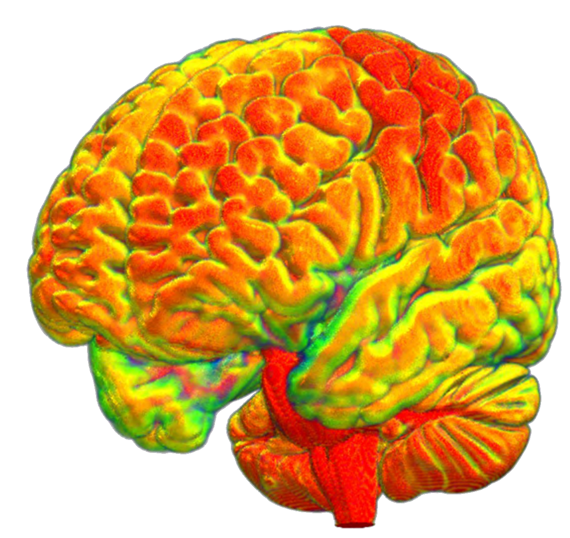
When Less is More: Multi-Task Brain Network Reconfiguration and its Inverse Relationship with General Intelligence

Jonas A. Thiele[1], Joshua Faskowitz[2], Olaf Sporns[2], Kirsten Hilger[1]

[1]University of Würzburg, Würzburg, Germany; [2]Indiana University, Bloomington, USA



Introduction

What is general intelligence?

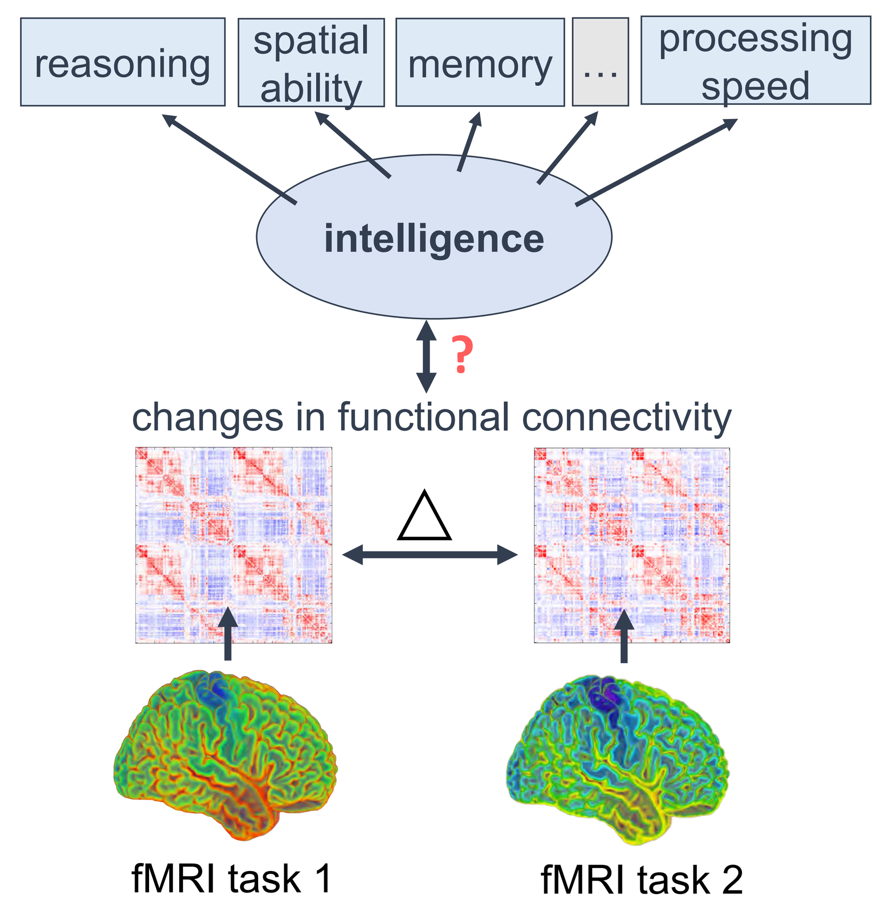
- *g*-factor theory = existence of underlying latent factor influencing performance in all different cognitive tasks [1]
- Crucially implicated in effective adaption to environmental demands

How is intelligence manifested in the human brain?

- Individual differences in intelligence relate to variations in brain structure and brain function [2]
- Brain network reconfiguration = changes of functional brain connectivity between resting and task state; recently proposed as correlate of differences in intelligence [3]
- Multi-task brain network reconfiguration has not yet been investigated

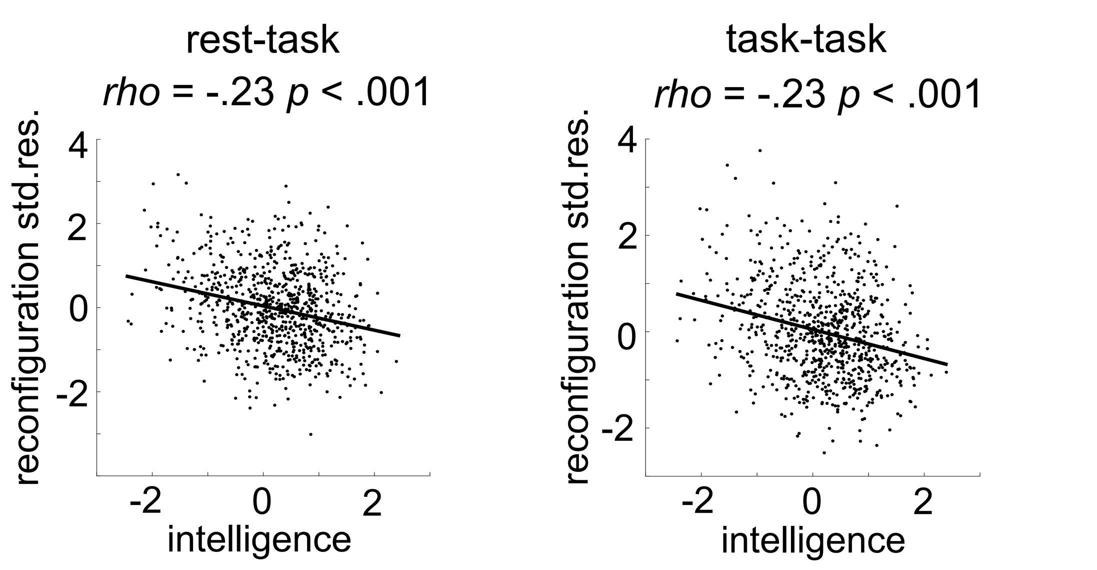
Hypotheses

- Higher levels of general intelligence = less brain network reconfiguration?
  - In reaction to different cognitive demands?
  - On various spatial scales?



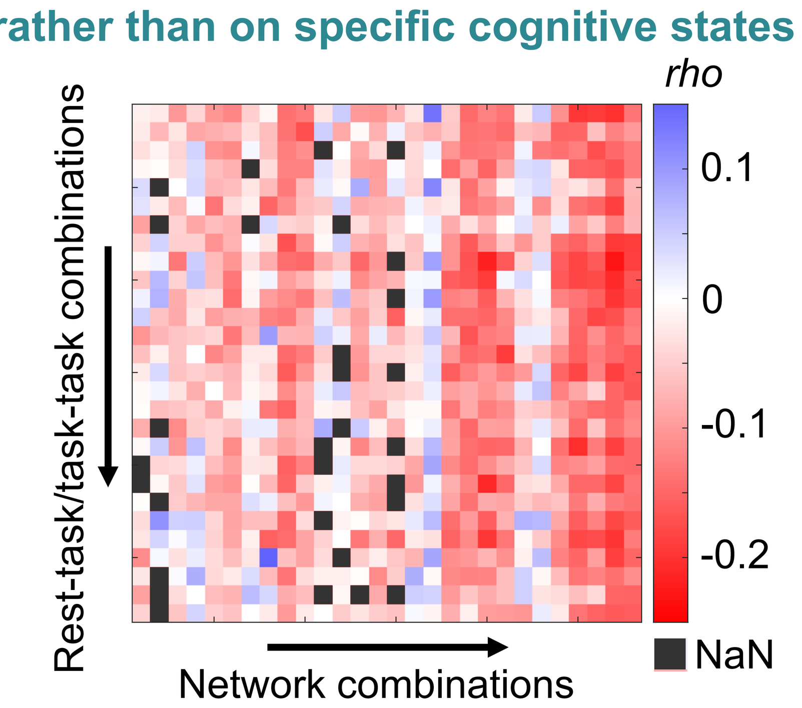
Results

Less brain network reconfiguration is associated with higher intelligence



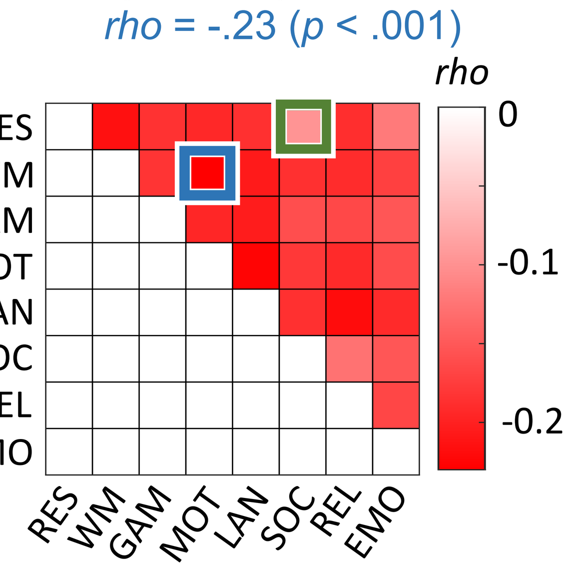
Spearman partial correlations, controlled for age, sex, handedness, and in-scanner head motion; for multiple comparisons, *p*-values were FDR corrected ($\alpha = 0.05$)

Relation between reconfiguration and intelligence depends on different functional brain systems rather than on specific cognitive states

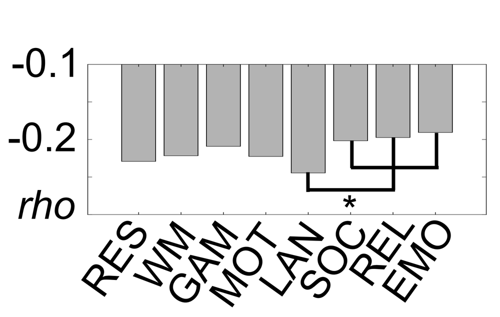


Higher intelligence relates to less reconfiguration across all different cognitive demands

- resting state - social recognition: *rho* = -.10 (*p* = .006)
- working memory - motor task: *rho* = -.23 (*p* < .001)



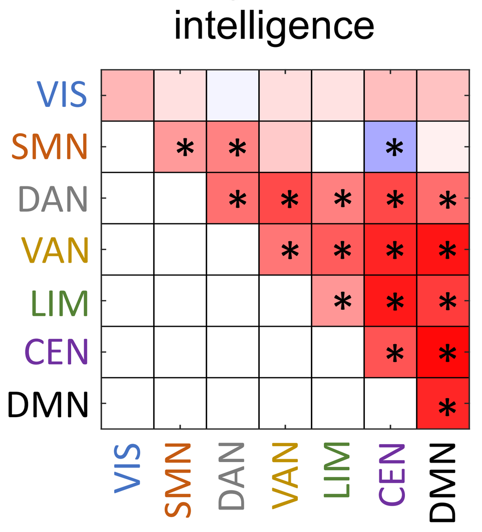
- averaged association for each state



* = significant differences

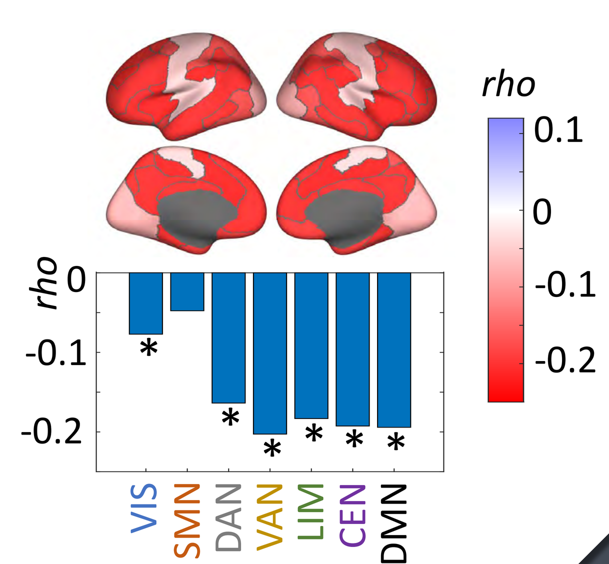
Higher intelligence relates to less reconfiguration across different spatial scales

- task-general within and between network reconfiguration and intelligence



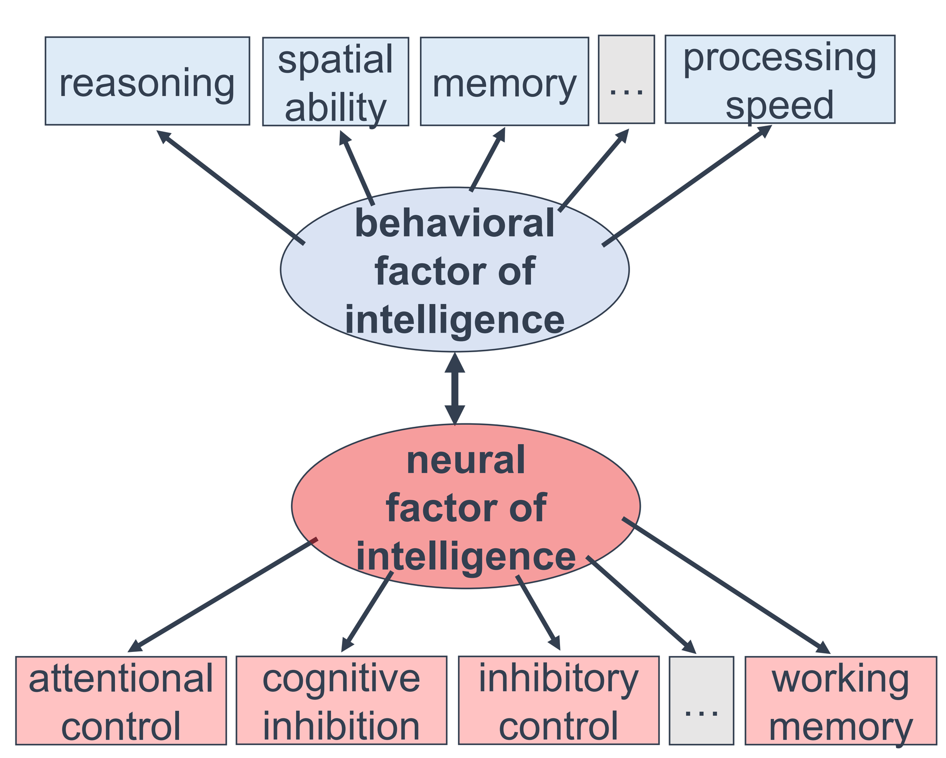
* = significant

- network-specific reconfiguration and intelligence



Discussion

- Intrinsic network architecture of people with higher intelligence scores closer to **network architecture as required by various cognitive demands**
- Results support **neural efficiency** theories [9] of cognitive ability
- Intelligent-relevant reconfiguration emerges **from a distributed brain network**
- Contributions of major networks and brain regions suggest **interplay of multiple specific cognitive abilities** in intelligent-related processing
- **Multi-task brain network reconfiguration may reflect the neural equivalent of the behavioral positive manifold that constitutes the foundation of a universal construct of cognitive ability**



Methods

Samples

Main sample:

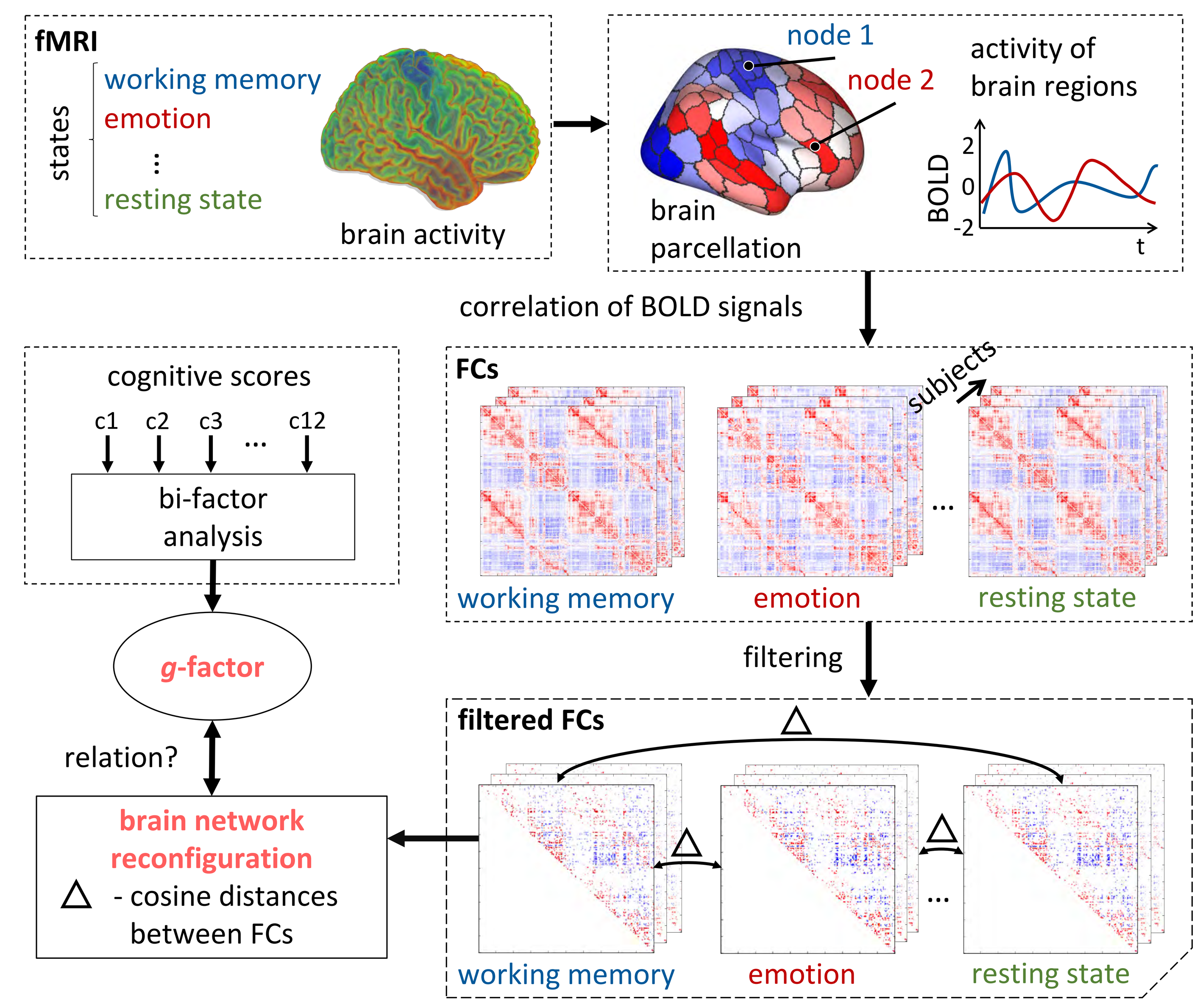
- Human Connectome Project [4] (*N*=812)
- Intelligence = *g*-factor from 12 cognitive tasks
- fMRI = resting state and task-related fMRI data (7 task states)

Replication samples:

- The Amsterdam Open MRI Collection [5] (*N* = 138, *N* = 184)
- Intelligence = SPM [6]
- fMRI = resting state and task-related fMRI data (5,3 task states)

(Pre)processing

- Parcellation: 200 cortical nodes [7]
- Functional connectivity (FC): Fisher z-transformed Pearson correlations
- Functional connectivity filtering
- FC reconfiguration: cosine distance between the filtered FCs of two states
- 7/17 functional brain networks [8]



States: resting (RES), working memory (WM), gambling (GAM), motor (MOT), language (LAN), social cognition (SOC), relational processing (REL), emotion processing (EMO); **Networks**: visual (VIS), somatomotor (SMN), dorsal attention (DAN), salience/ventral attention (VAN), limbic (LIM), control (CEN), default mode (DMN)

References & Acknowledgements

[1] Spearman, C. (1904), 'General Intelligence, Objectively Determined and Measured', *Am. J. Psychol.,* 15, 201.

[2] Basten, U. (2015), 'Where smart brains are different: A quantitative meta-analysis of functional and structural brain imaging studies on intelligence', *Intelligence,* 51, 10–27.

[3] Schultz, D.H. (2016), 'Higher intelligence is associated with less task-related brain network reconfiguration', *J Neurosci*, 36(33), 8551-8561.

[4] Van Essen, D.C. (2013), 'The WU-Minn Human Connectome Project: An overview', *Neuroimage*, 80, 62-79.

[5] Snoek, L. (2021), 'The Amsterdam Open MRI Collection, a set of multimodal MRI datasets for individual difference analyses', *Sci. Data,* 8, 85.

[6] Raven, J. (1998), 'Manual for Raven's progressive matrices and vocabulary scales'.

[7] Schaefer, A. (2018), 'Local-Global Parcellation of the Human Cerebral Cortex from Intrinsic Functional Connectivity MRI', *Cereb Cortex*, 28(9), 3095-3114.

[8] Yeo, T.B.T. (2011), 'The organization of the human cerebral cortex estimated by intrinsic functional connectivity', *J Neurophysiol*, 106(3), 1125-1165.

[9] Neubauer, A.C. (2009), 'Intelligence and neural efficiency: Measures of brain activation versus measures of functional connectivity in the brain', *Intelligence*, 37, 223–229.

The research leading to these results has received funding from the **German Research Foundation** (grant no. HI 2185 - 1/1) assigned to K. Hilger. The authors thank the **Human Connectome Project [4]** funded by the National Institute of Health for providing data of the main sample and all contributors to **The Amsterdam Open MRI Collection [5]** for providing data of the replication samples.

Julius-Maximilians-UNIVERSITÄT WÜRZBURG

DFG

jonas.thiele@uni-wuerzburg.de