Networks of Impulsivity: Evidence from Meta-Analyses and Functional Connectivity Modelling

Martin Gell[1,2], Robert Langner[2,3], Vincent Küppers[2], Edna C. Cieslik[2,3], Theodore D. Satterthwaite[4] Simon B. Eickhoff[2,3] and Veronika I. Müller[2,3]

1 Department of Psychiatry, Psychotherapy and Psychosomatics, Medical Faculty, RWTH Aachen University, Aachen, Germany
2 Institute of Neuroscience and Medicine (INM-7: Brain & Behaviour), Research Centre Jülich, Jülich, Germany
3 Institute of Systems Neuroscience, Heinrich Heine University Düsseldorf, Düsseldorf, Germany
4 Department of Psychiatry, Perelman School of Medicine, University of Pennsylvania, Philadelphia, PA, USA
m.gell@fz-juelich.de

Introduction

Impulsivity

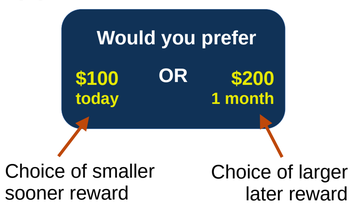
Multidimensional construct referring to diverse behaviours such as response inhibition and discounting of future rewards[1].
Most investigations of its neural correlates only focus on individual dimensions or behaviours.

Aim

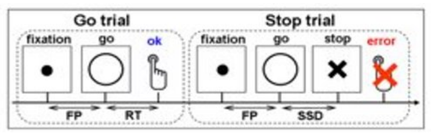
Delineate and characterize a brain network associated with impulsivity focusing on two dimensions:

A) Delayed consequence sensitivity (delay discounting)
B) Response inhibition (stop signal, go/nogo tasks)

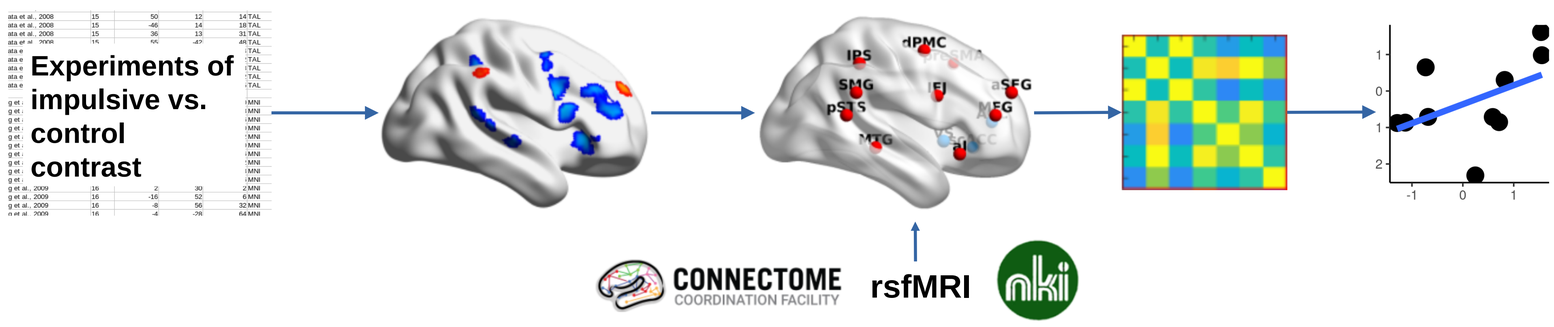
A



B



Methods



1) Meta-analysis

ALE meta-analyses[2] for impulsive vs control processes within delayed consequence sensitivity (**47** experiments):

- Smaller sooner vs larger later rewards
- Larger later vs smaller sooner rewards
- Subjective value

and response inhibition (**126** experiments):

- Error vs correct inhibition (meta-contrast)
- Correct inhibition vs error (meta-contrast)

2) Community detection

Resting-state functional connectivity between meta-analytic seeds and rest of the brain in data from Human Connectome Project[3] (n=332) and Nathan Kline Institute[4] (n=608). Louvain community detection[5] and gradient decomposition[6] (PCA).

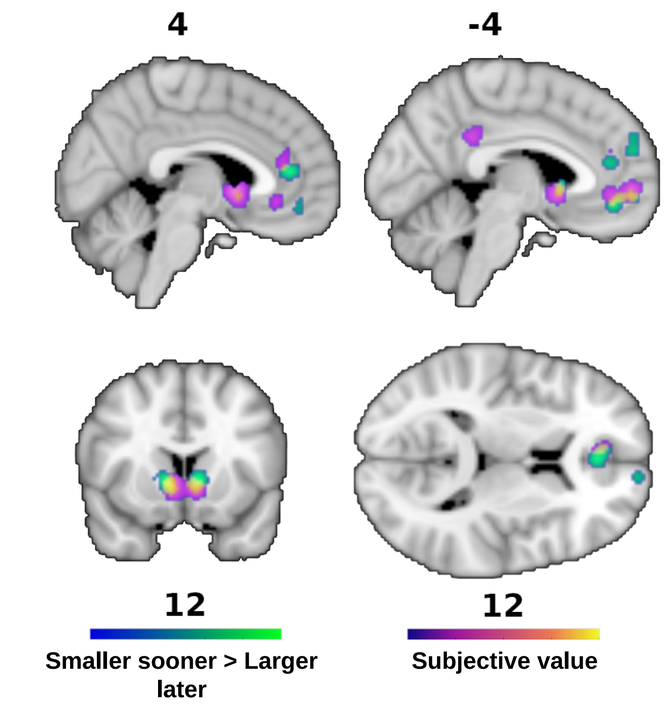
3) Neuromodulation

Correlation between network measures of integration/segregation and PET receptor density of serotonin, dopamine and norepinephrine[7].
Significance was tested using spatial permutation.

Results

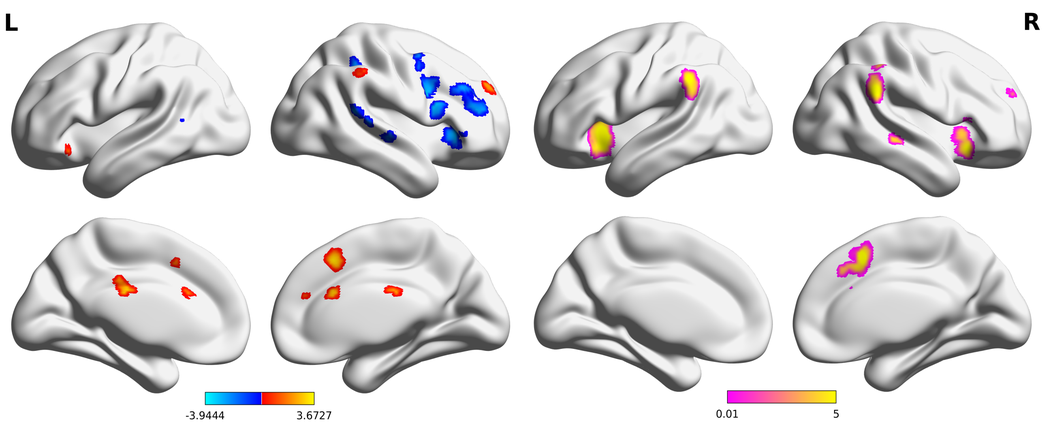
Meta-analysis

A) Delayed consequence sensitivity meta-analyses



No convergence was found for contrast larger later > smaller sooner

B) Response Inhibition meta-analyses



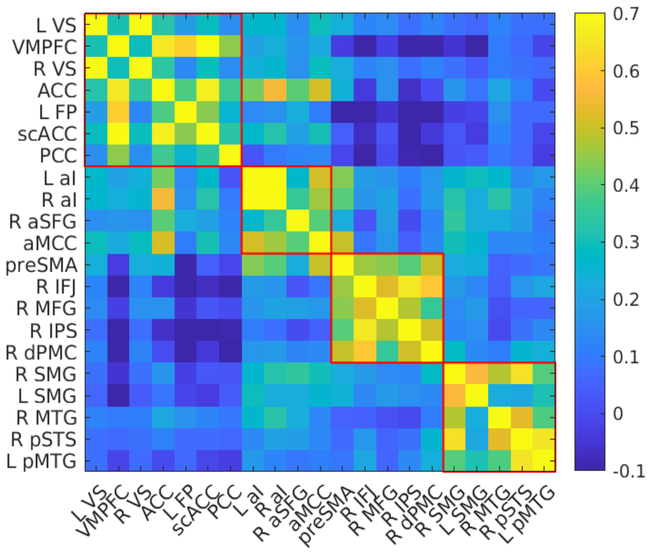
Network community detection

A) Louvain community detection

Identified four functional subsystems which replicated in both datasets:

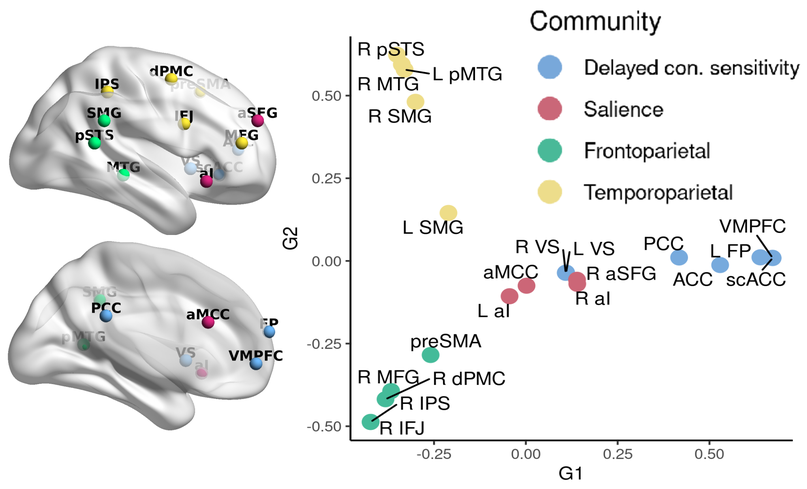
1) All Delay-related regions
2) Salience network regions
3) Frontoparietal regions
4) Temporoparietal regions

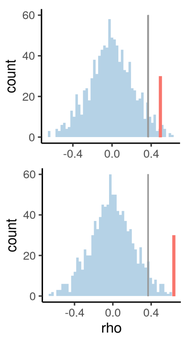
Response inhibition



B) Seed-voxel connectivity gradients

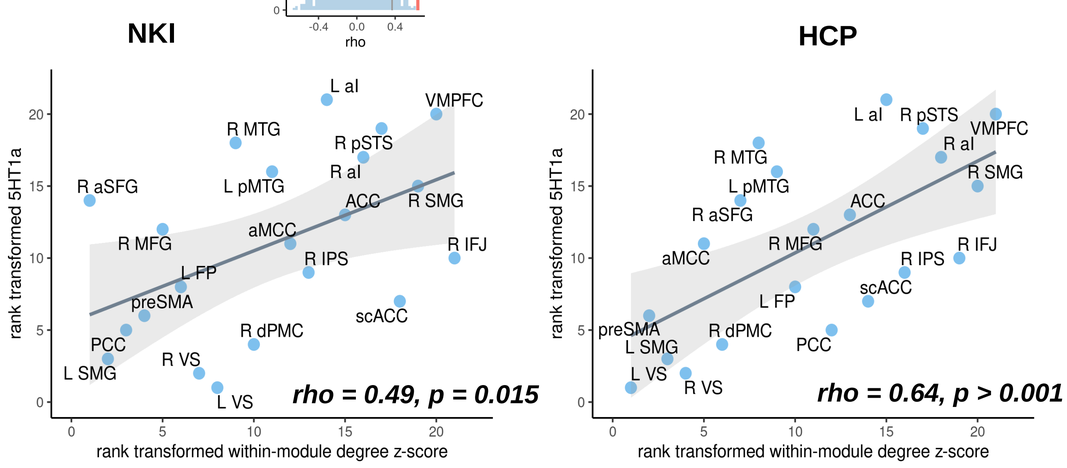
Complementary whole-brain analysis was in strong agreement with community detection results.





Community Neuromodulation

Only serotonin 5HT1a receptor density displayed a positive correlation with network integration (within-module degree z-score) in both datasets. Segregation was not correlated with receptor density.



Discussion

Two non-overlapping meta-analytic networks, one (A) associated with goal-directed decision making[8] the other (B) with executive functions[9].

Four subsystems with the salience community as a possible intermediary in light of its association with both delay and response inhibition.

Serotonergic modulation of behavior (e.g., in aggression[10]) might be linked with high intra-network communication.

Our meta-analytic findings reinforce insights from behavioural research and provide evidence for the multidimensional nature of impulsivity on the neural level

References: [1] MacKillop,J., et al. (2016) Psychopharmacology, 233(18), 3361-3370.; [2] Eickhoff, S. B., et al. (2012) NeuroImage. 59 (3): 2349-61.; [3] Van Essen, D. C., et al. (2013). NeuroImage, 80, 62–79.; [4] Nooner, K. B., et al. (2012) Frontiers in Neuroscience, 6, 152.; [5] Blondel, V. D., et al. (2008) Journal of Statistical Mechanics: Theory and Experiment, 2008(10), P10008.; [6] Margulies, D. S., et al. (2016) Proceedings of the National Academy of Sciences, 113(44), 12574-12579.; [7] Dukart, J., et al. (2021) Human Brain Mapping, 42(3), 555–566.; [8] Raichle, M. E. (2015) Annual review of neuroscience, 38, 433-447.; [9] Duncan, J. (2010) TiCS. 14 (4): 172-179.; [10] Dalley, J. W., (2012) Neuroscience, 215, 42-58.

Acknowledgments: This study was supported by the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation) – 269953372/GRK2150", Deutsche Forschungsgemeinschaft (69953372/GRK2150, EI816/11-1), Jülich-Aachen Research Alliance (JARA), the National Institute of Mental Health (R01-MH074457), the Helmholtz Portfolio Theme "Supercomputing and Modeling for the Human Brain", and the European Union's Horizon 2020 Research and Innovation Programme under Grant Agreement No. 945539 (HBP SGA3).