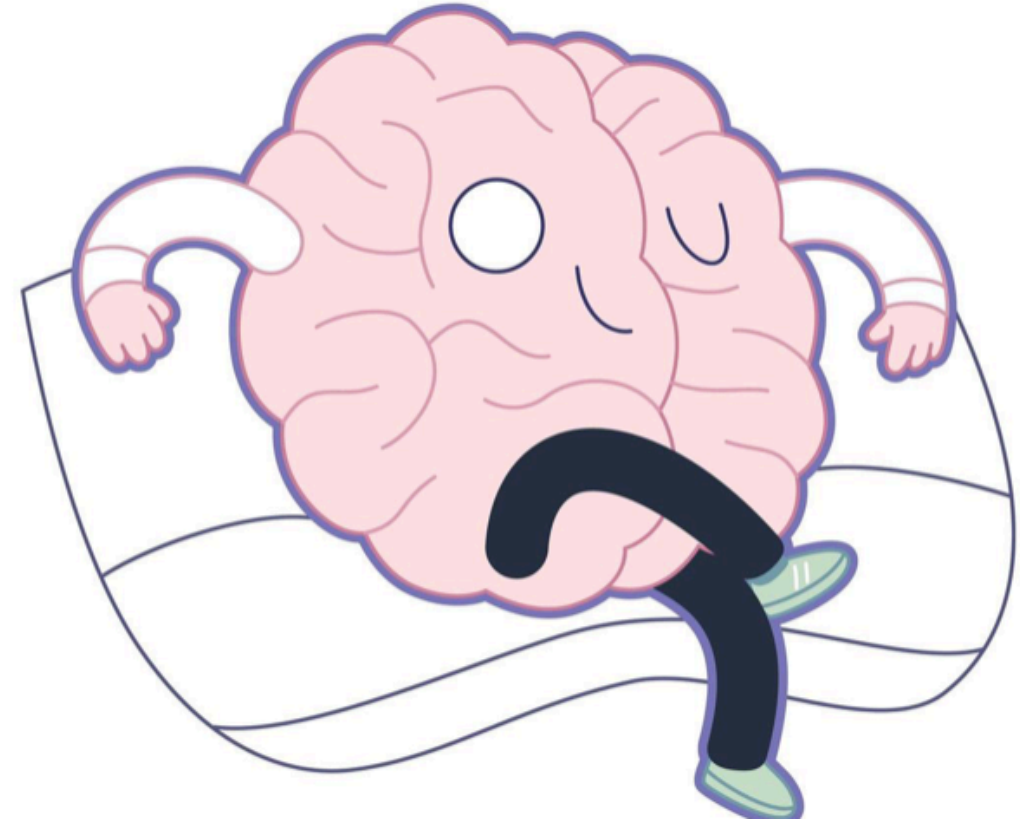
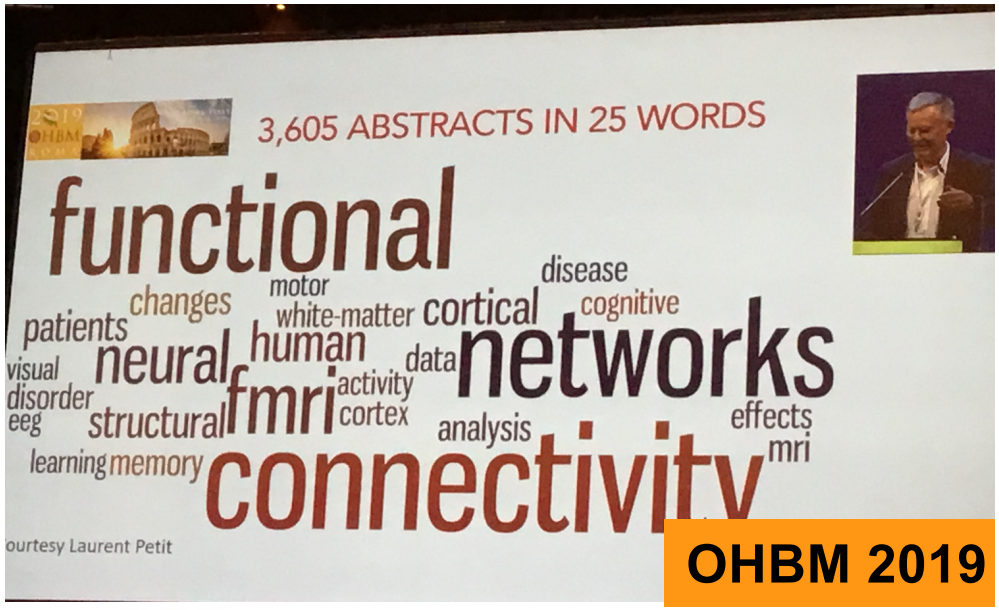
Resting-state functional connectivity profiles established from rest or task-based fMRI paradigms

Marie-Hélène Grosbras , LNC





OHBM 2019

Neuroscience 2022 fMRI abstracts

Resting -state

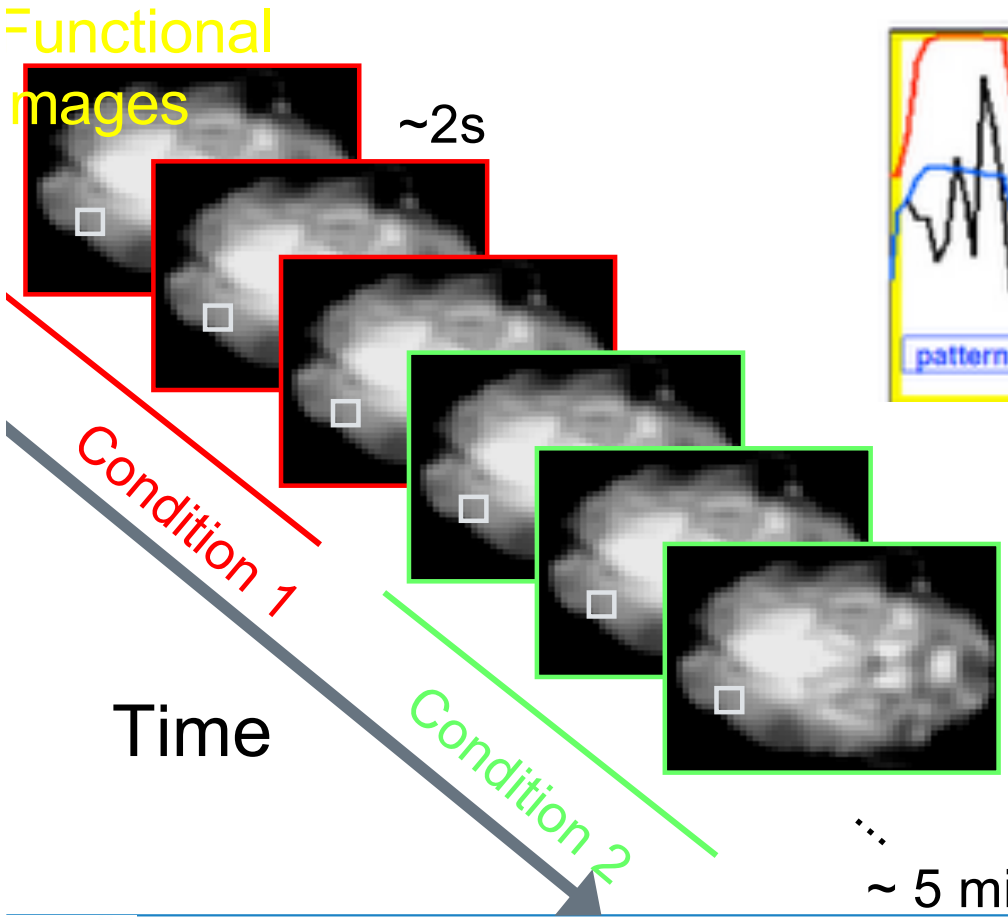
Outline

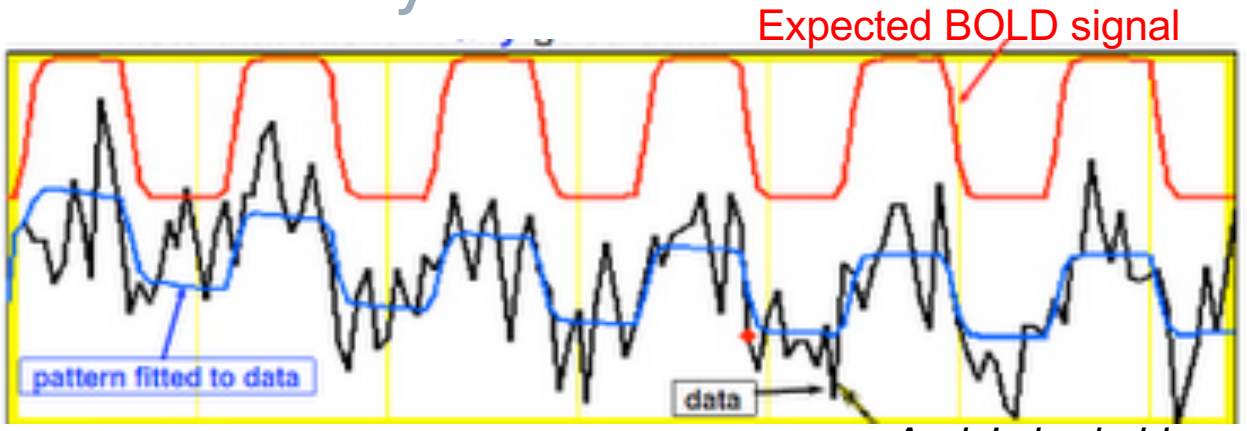
1. Resting-state functional connectivity: What? Why? (How?)
2. Extracting resting-state functional connectivity from “rest” *vs* “task” fMRI scans

fMRI resting-state : early studies

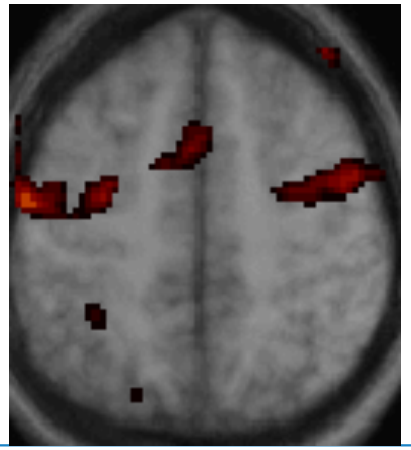
- BOLD = indirect measure of brain activity (Ogawa 1990)
- Used to map *brain activation”

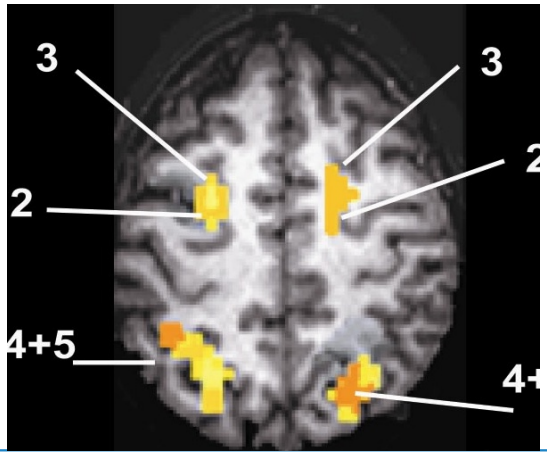
fMRI resting-state : early studies



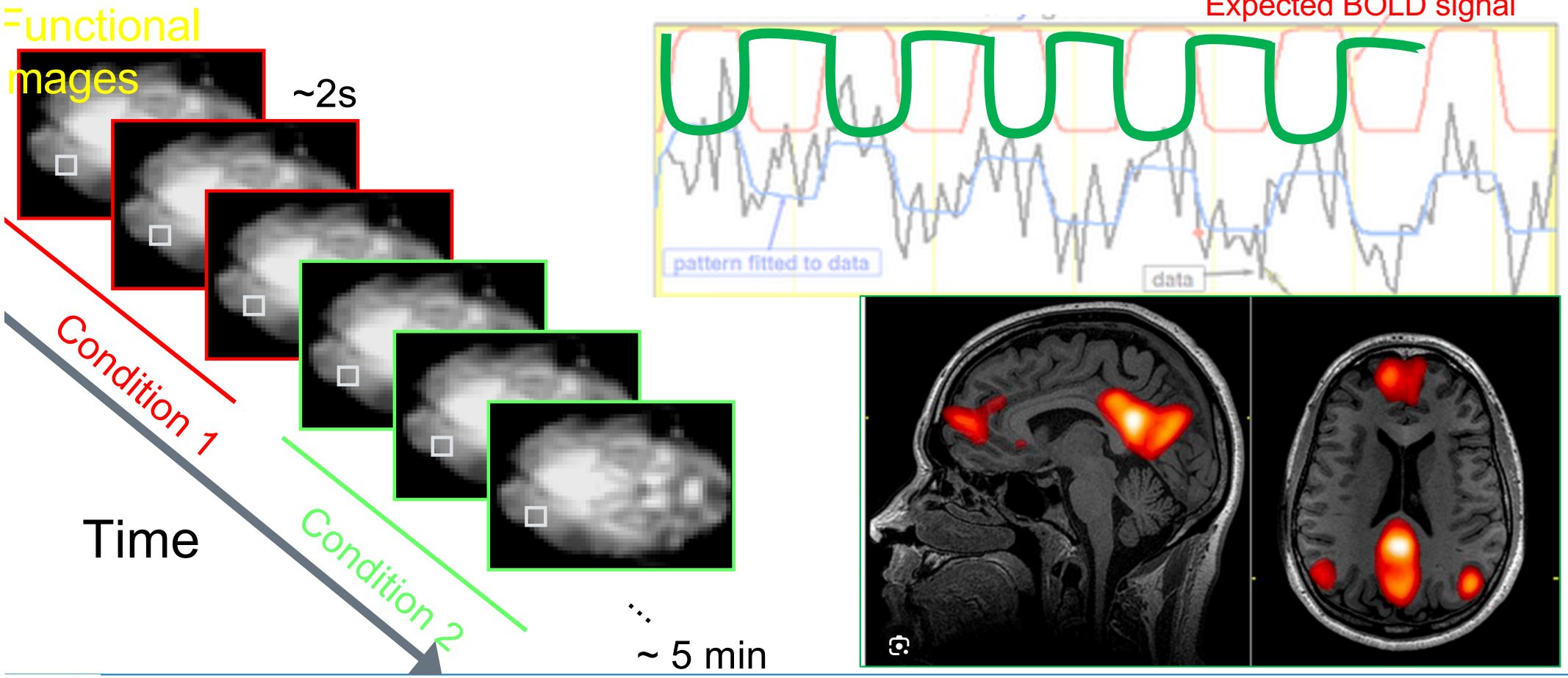


Andy's brain blog





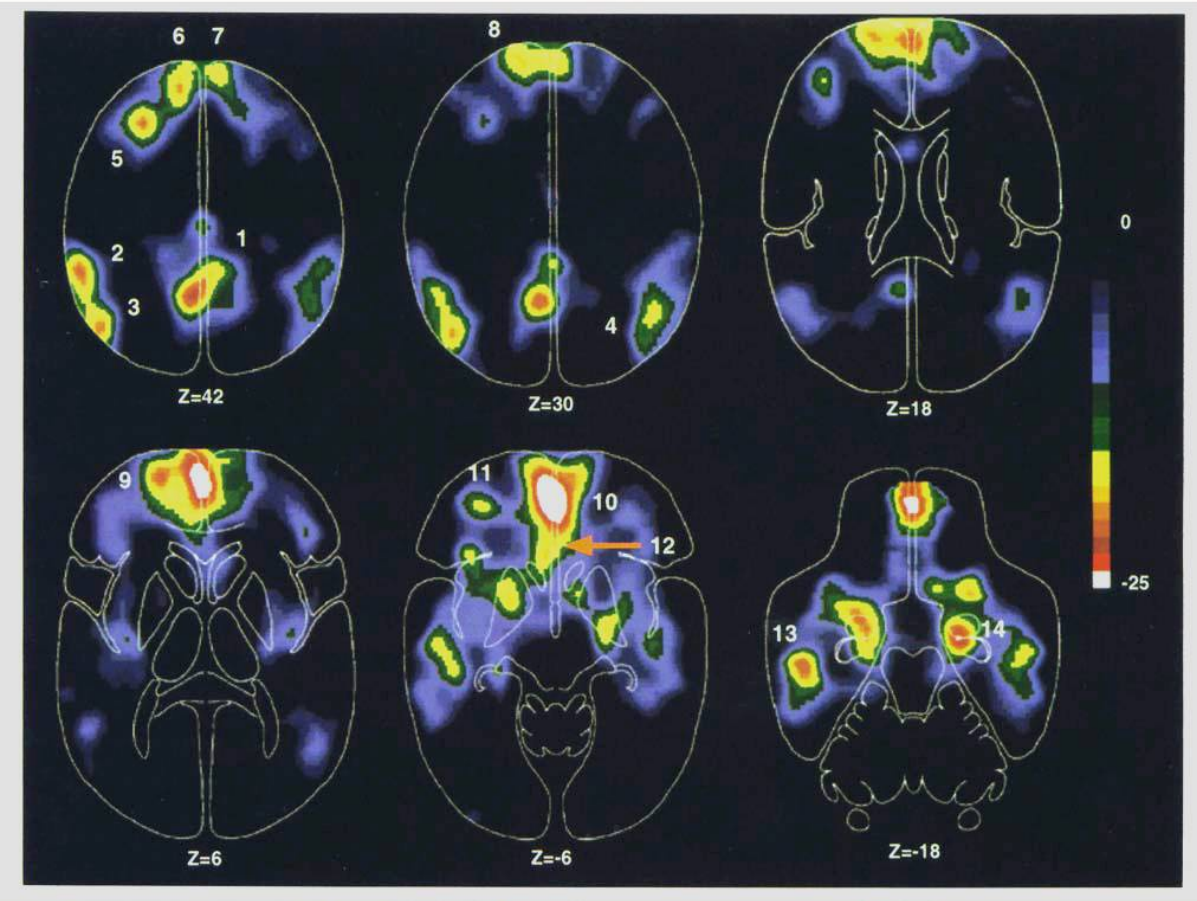
fMRI resting-state : early studies



Common Blood Flow Changes across Visual Tasks: II. Decreases in Cerebral Cortex

Gordon L. Shulman, Julie A. Fiez, Maurizio Corbetta, Randy L. Buckner, Francis M. Miezin, Marcus E. Raichle, and Steven E. Petersen

J Cogn Neurosci 1997



Blood flow decreases in an overall megaimage Active minus Passive conditions (avg 9 studies)

14 foci passed threshold

Common Blood Flow Changes across Visual Tasks: II. Decreases in Cerebral Cortex

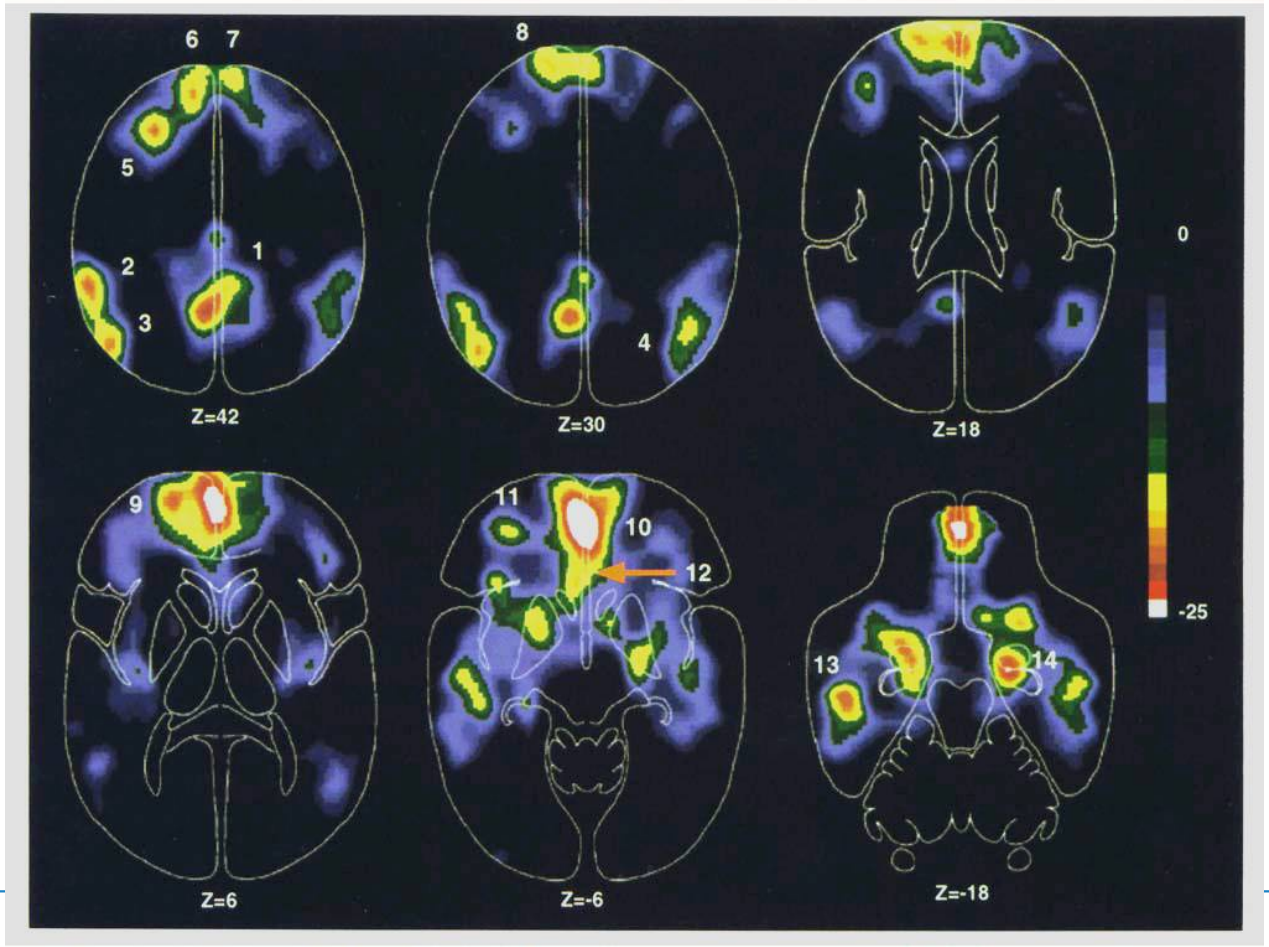
1- decreased activity caused by active task processes that generalize over tasks

Or

2- increased activity caused by passive task processes suspended during the tasks.

-unconstrained verbally mediated thoughts

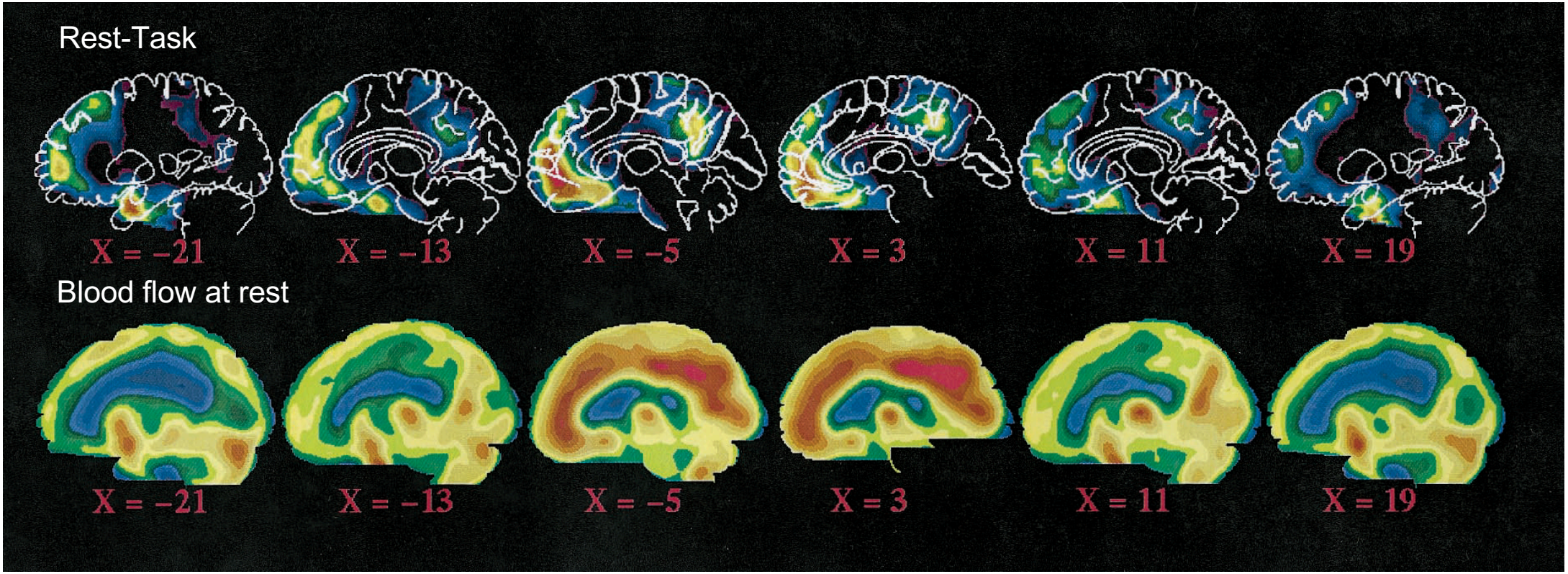
-monitoring of the external environment, body, and emotional state.



A default mode of brain function

Marcus E. Raichle*†, Ann Mary MacLeod*, Abraham Z. Snyder*, William J. Powers‡, Debra A. Gusnard*§, and Gordon L. Shulman‡

PNAS 2001 > 13700 citations

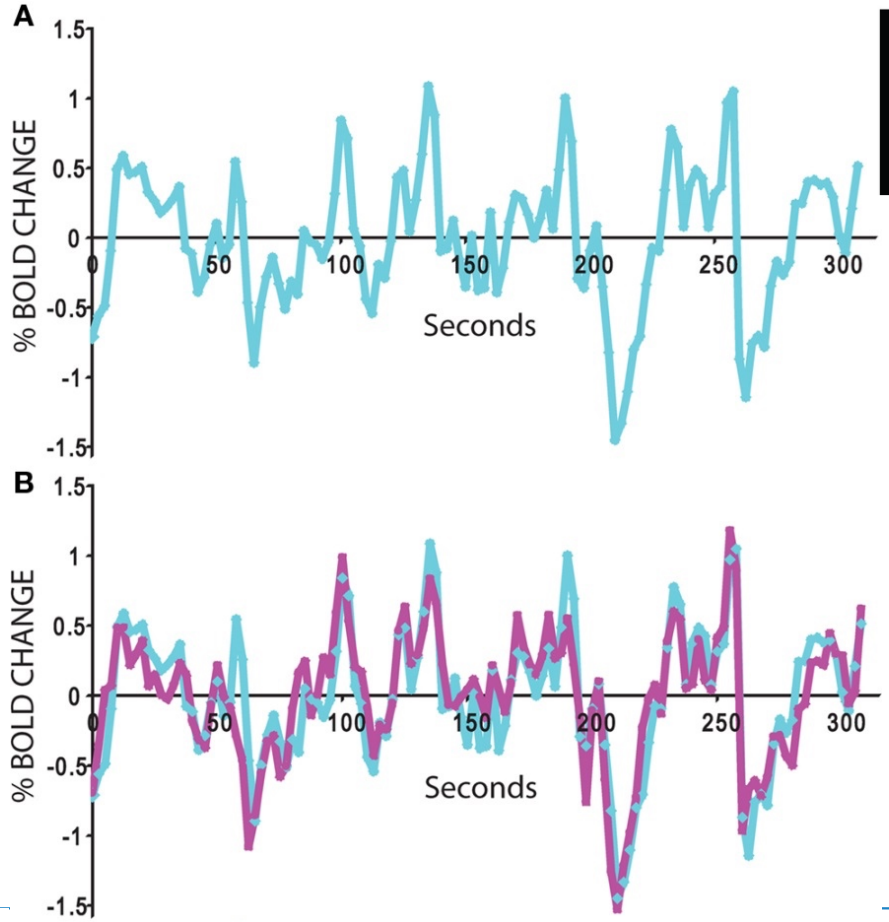


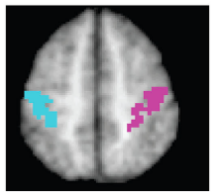
A default mode of brain function

Marcus E. Raichle*†, Ann Mary MacLeod*, Abraham Z. Snyder*, William J. Powers‡, Debra A. Gusnard*§, and Gordon L. Shulman‡

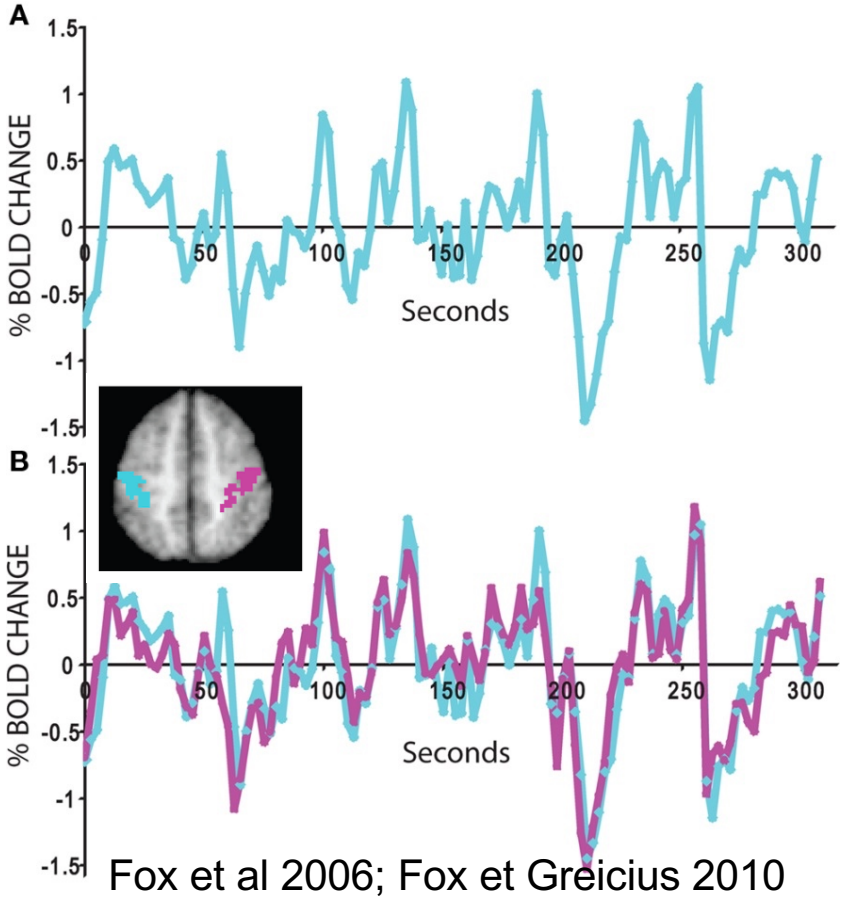
These decreases suggest the existence of an organized, baseline default mode of brain function that is suspended during specific goal-directed behaviors.

fMRI resting-state : early studies





fMRI resting-state : early studies

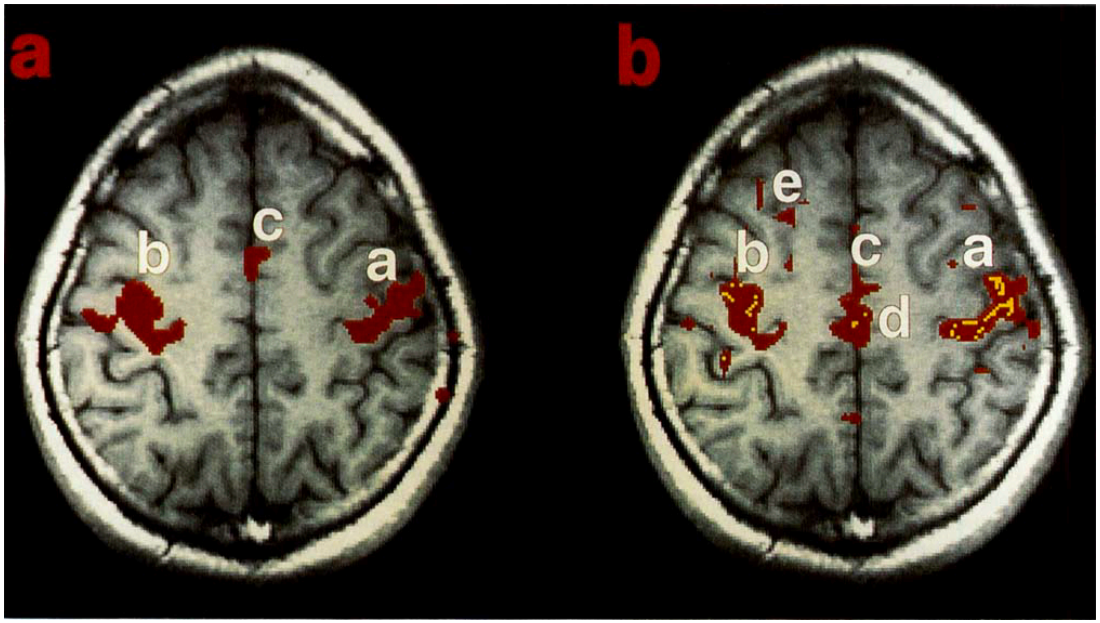


Fox et al 2006; Fox et Greicius 2010

Functional Connectivity in the Motor Cortex of Resting Human Brain Using Echo-Planar MRI

Bharat Biswal, F. Zerrin Yetkin, Victor M. Haughton, James S. Hyde

Magn res in Medicine 1995 10200 citations

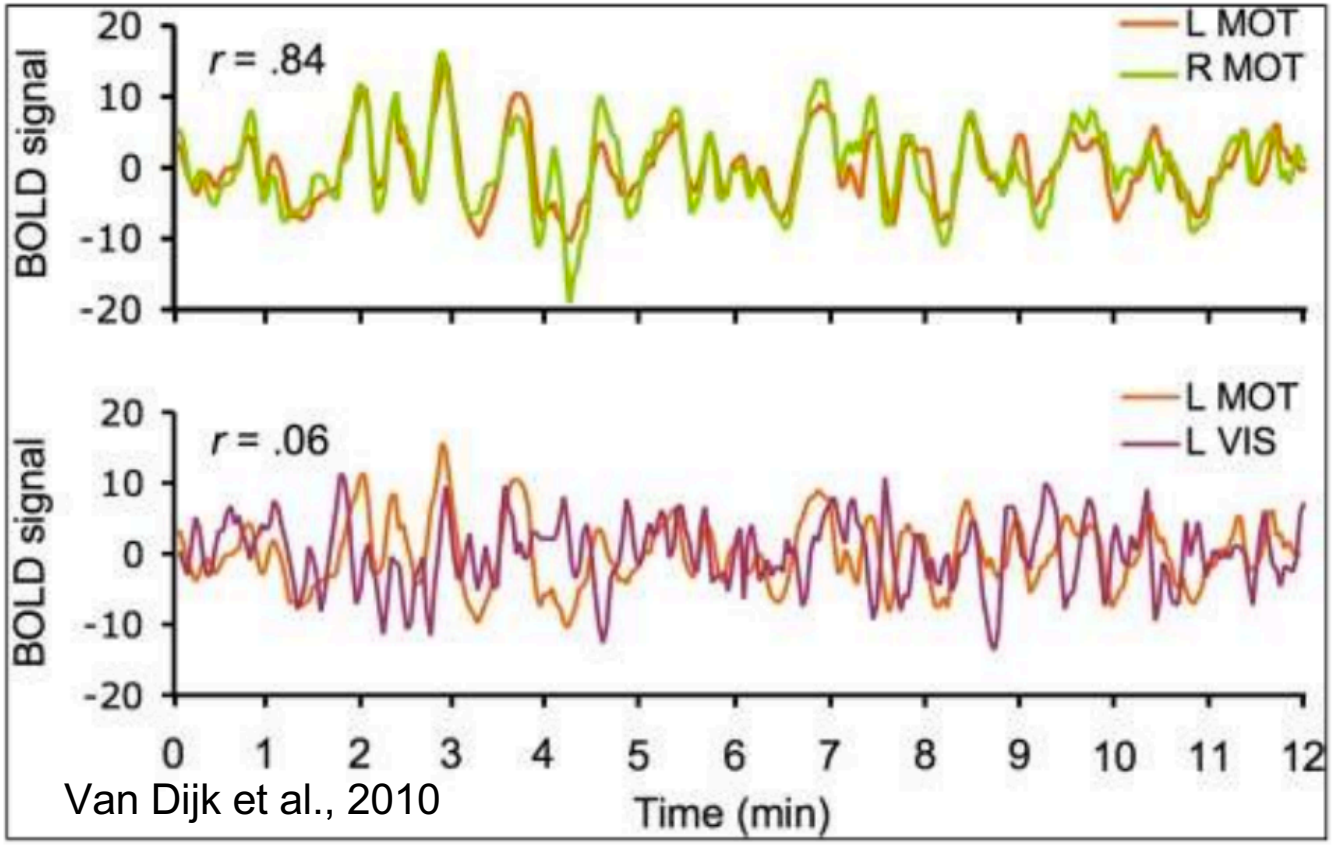


Functional Connectivity in the Motor Cortex of Resting Human Brain Using Echo-Planar MRI

Bharat Biswal, F. Zerrin Yetkin, Victor M. Haughton, James S. Hyde

It is concluded that correlation of low frequency fluctuations, which may arise from fluctuations in blood oxygenation or flow, is a manifestation of functional connectivity of the brain.

fMRI resting-state : early studies



Van Dijk et al., 2010

No correlation with regions involved in visual tasks

correlations in resting state activity can provide insight into the function of neura lsystems even if they are not actively engaged

fMRI resting-state : early studies

- Regions with similar functional properties exhibit coherent BOLD fluctuations even when not exerting this function: Visual, Auditory, Language, Attention (rev in Fox and Greicius 2010)
- Alternative perspective / task-based substraction approach of brain function

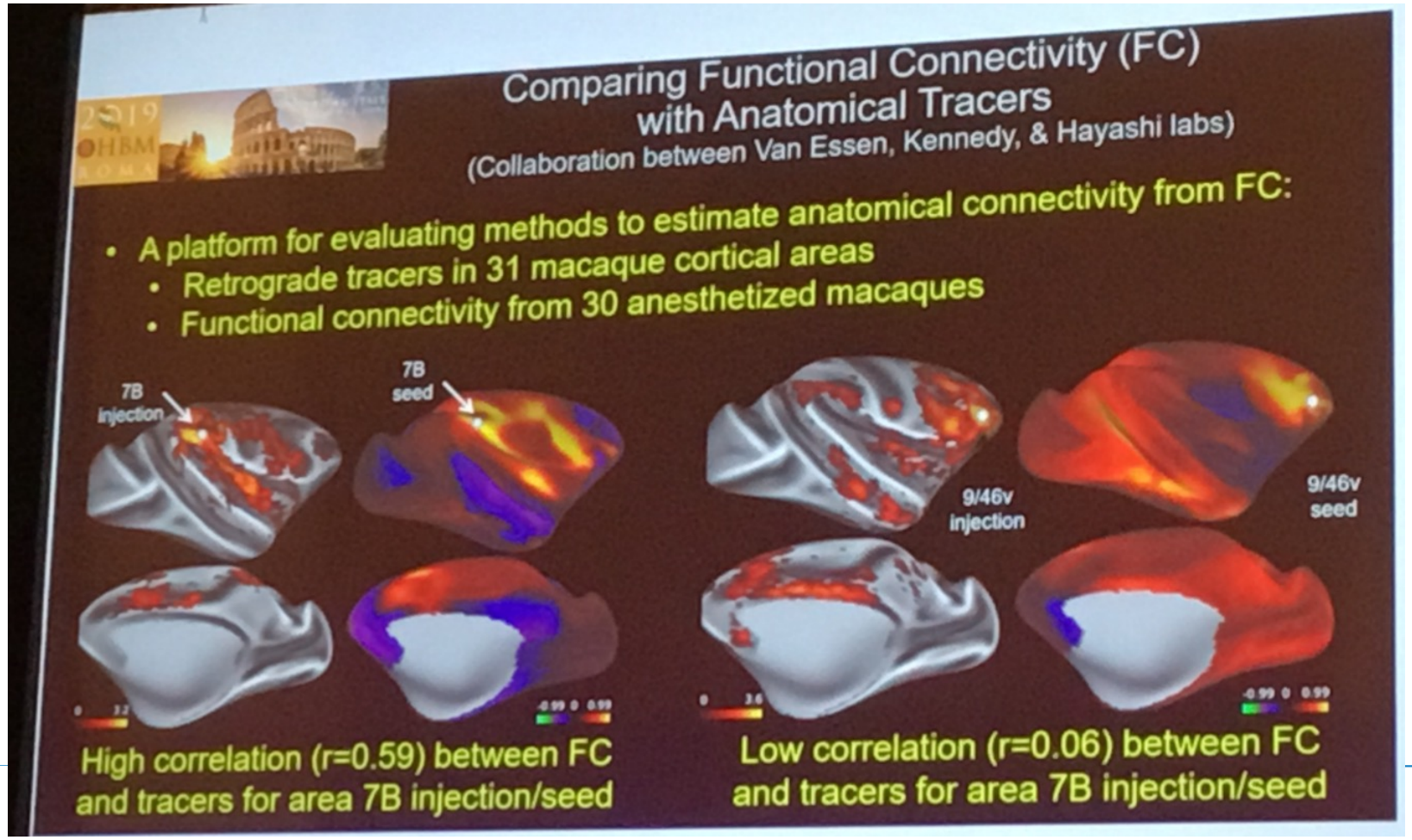
system driven by internal dynamics; modulated by external events

system primarly responding to task demands

Fox et al PNAS 2006; Fox and Greicius , Frontiers 2010, Llinas Science 1988

Rest fMRI : subsequent studies

- Confirmation of neuronal origin of slow fluctuations
  - Nir et al Nat Neuro 08: ECoG + LFP : slow fluctuations correlated across hemispheres
  - Shmuel and Leopold Hum Br Map 08: simultaneous FMRI and electrophy recording in V1 show correlation with large parts of bilateral visual cx
  - Van Essen 2018: in macaques ; Hori et al 2020 in marmosets: concordance with tracers (although region dependant)



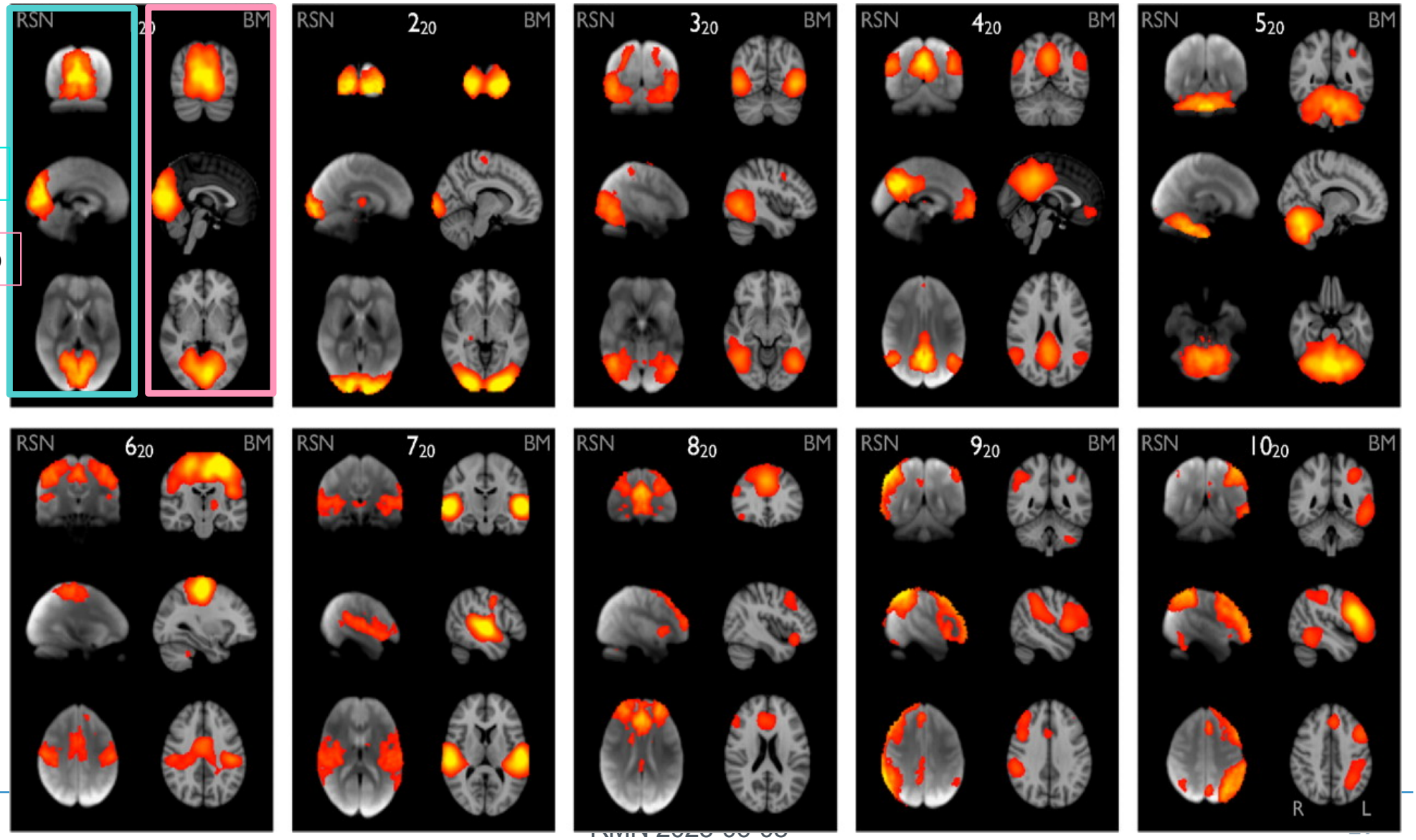
David Van Essen ; Recent advance in neuroanatomy session
Poster Th696

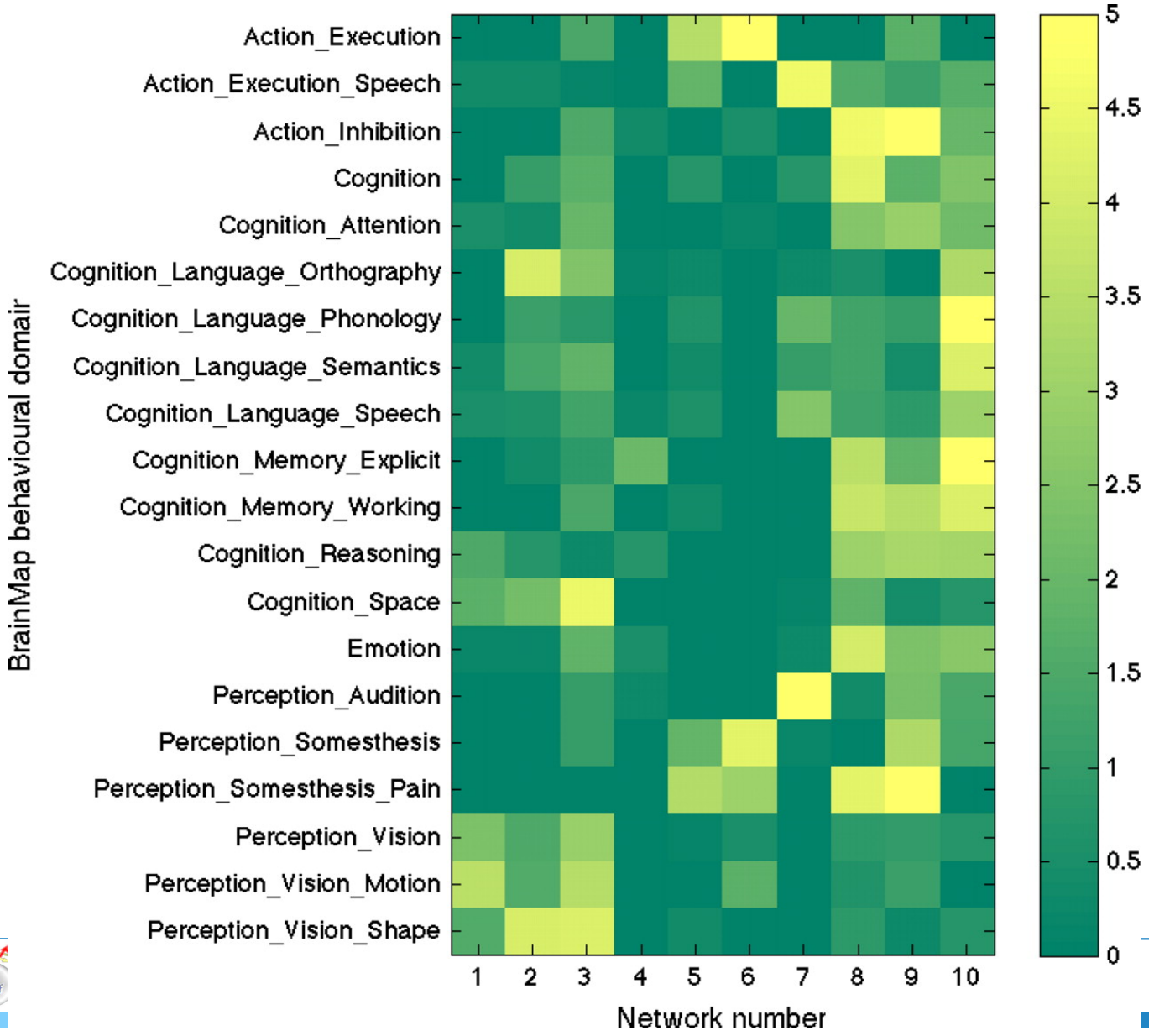
Rest fMRI : subsequent studies

- Confirmation of functional significance
  - Smith et al PNAS 2009:
    - BrainMap database 7340 exp; >30000 subjects
    - fMRI dataset 6 min rest, 36 subjects
    - ICA finds the 20 most repressentative patterns of covariation
    - Spatial cross correlation

Rest fmri

Brainmap



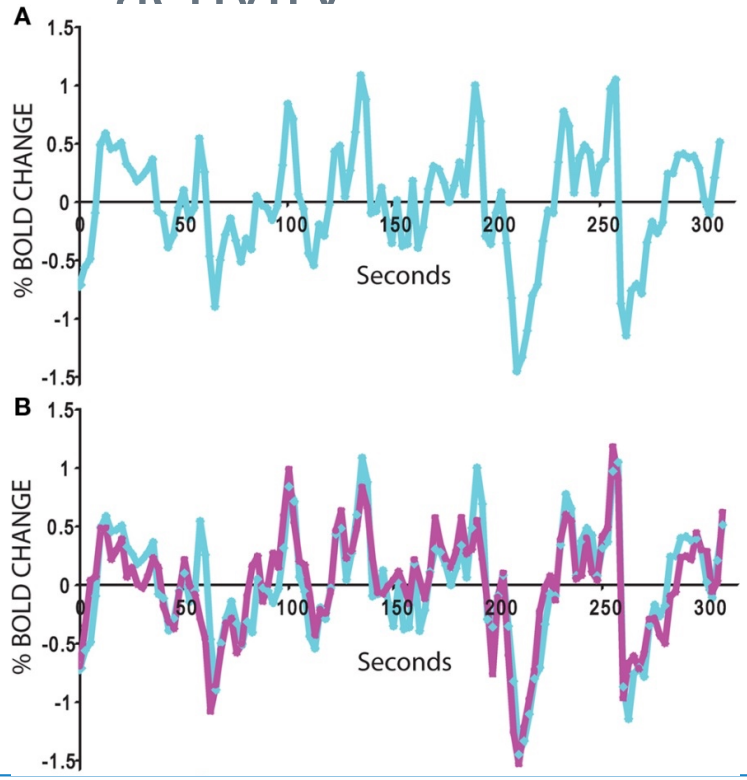

BrainMap behavioural domair
Action_Execution
Action_Execution_Speech
Action_Inhibition
Cognition
Cognition_Attention
Cognition_Language_Orthography
Cognition_Language_Phonology
Cognition_Language_Semantics
Cognition_Language_Speech
Cognition_Memory_Explicit
Cognition_Memory_Working
Cognition_Reasoning
Cognition_Space
Emotion
Perception_Audition
Perception_Somesthesis
Perception_Somesthesis_Pain
Perception_Vision
Perception_Vision_Motion
Perception_Vision_Shape
1 2 3 4 5 6 7 8 9 10
Network number
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0

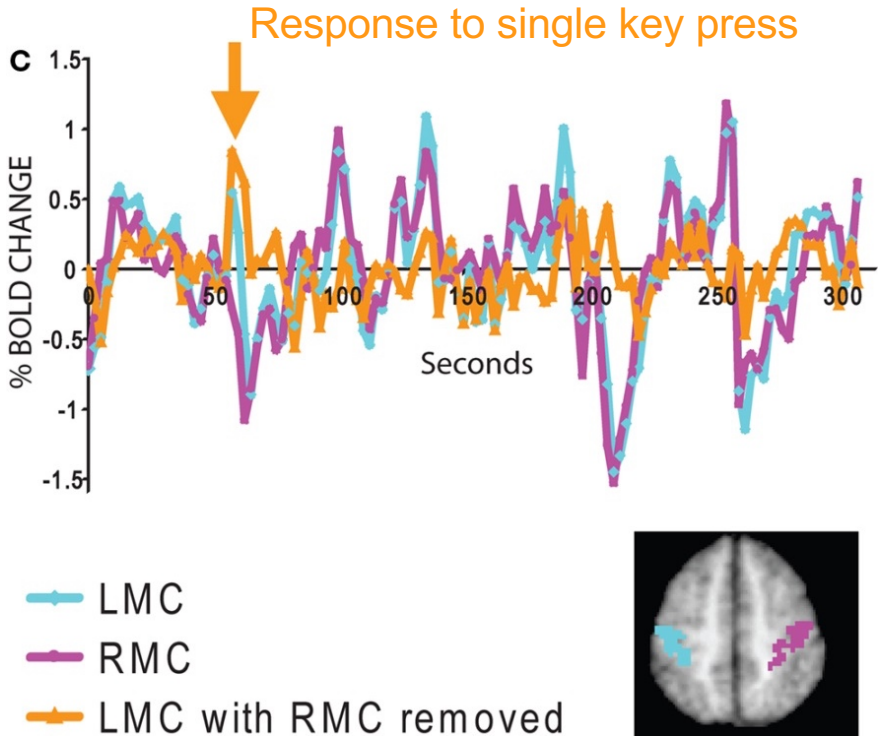
Rest fMRI : later studies

- Improvements of methods (seed based, ICA, graphs, etc)
- Large shared datasets from different populations
- High reproducibility
  - across studies (Power el 2011; Yeo et al
  - across individuals (Damoiseaux et al PNAS 2006)
  - within individuals (Finn et al 2015; Dosenbach et al; Gratton et al 2018; Poldrack et al – but see discussions on # datapoints

Rest fMRI : applications

- Characterize functional networks and their activity

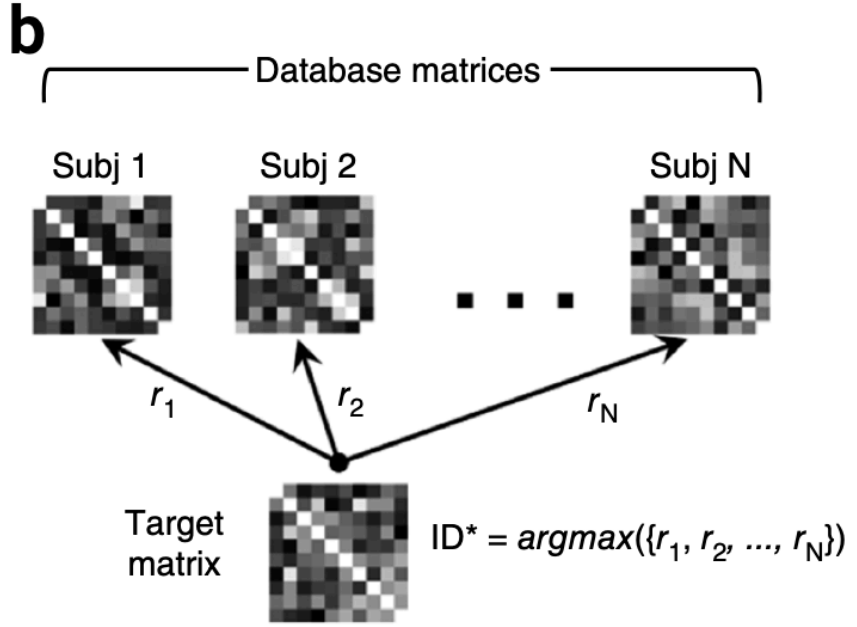




FOX et al 2006, 2010

Rest fMRI : applications

- Fingerprinting: Finn et al Nat Neuro 2015 : can identity an individual based on resting connectivity matrice



SESSION 1

SESSION 2

126 subjects

92.9 % accuracy!

268 nodes

Rest fMRI : applications

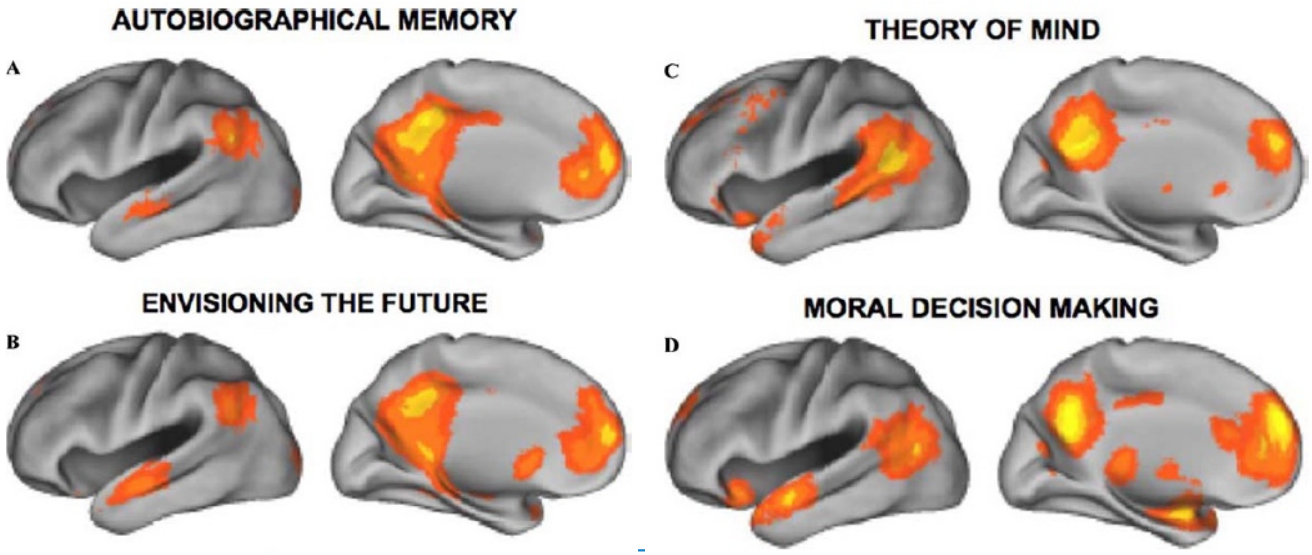
- Fingerprinting: can identity an individual based on resting connectivity matrice (Finn et al Nat Neuro 2015)
- Predicting individual traits incl age (Dosenbach Science 2010; (but see Mareck et al 2022 for discussion on N):
- Characterizing states (Waites et al 2005: effect of prior cognitive task; Tung et al 2013: effect of prior simple motor task; Subsides after 10-15min)
- Used as biomarker (Rev in Fox and Greicius 2010)- Alzheimer ; Mvt disorders; ADHD; Autism; Stroke
- Cross species comparisons

Rest fMRI and resting-state : summary

- Spontaneous fluctuations in BOLD signal at 0.01-0.1Hz may reflect a baseline state of activity
- Factoring out this baseline may increase signal to noise ratio to detect “activation”
- Inter-regional correlations reveal networks that are consistent with functional correlates of behaviours
- Alleviating the burdon on task design, rest-fMRI can be applied widely
- Features of these networks can predict traits and states

Remaining issues

- Rest is a Task
  - Correlation between DMN features and daydreaming propensities
  - Overlap DMN with self-related functions



Buckner et al 2008

Remaining issues

- Rest is a Task
  - Correlation between DMN features and daydreaming propensities
  - Overlap DMN with self-related functions
- Which network(s) features are the more relevant / research question(s)
- State modulation => what is the best state to study individual differences
  - Finn & Bandettini NI 2021: HCP 7T data n=184; Emotion and Cognition scores better predicted by FC connectivity matrices during movie than rest

- change in correlations can be observed even in the absence of a change in coupling *(Friston, 2011)*
  - Changes in correlation between A and B could be caused by a change in correlation elsewhere
  - Changes in correlation could be caused by a change in SNR (e.g., heart rate variability differs between two populations)
  - Changes in correlation could be caused by a change in the amplitude of the fluctuations

Outline

1. Resting-state functional connectivity: What? Why? (How?)
2. Extracting resting-state functional connectivity from “rest” *vs* “task” fMRI scans

Rest vs Background FC

- If task-evoked activity is superimposed on resting-state connectivity, then patterns of connectivity could be retrieved after removing task-evoked activity
  - No need to collect a dedicated rest scan
  - Makes the most of large task-based data sets
  - Possibility to extract networks structure
  - Measure intre-individual differences

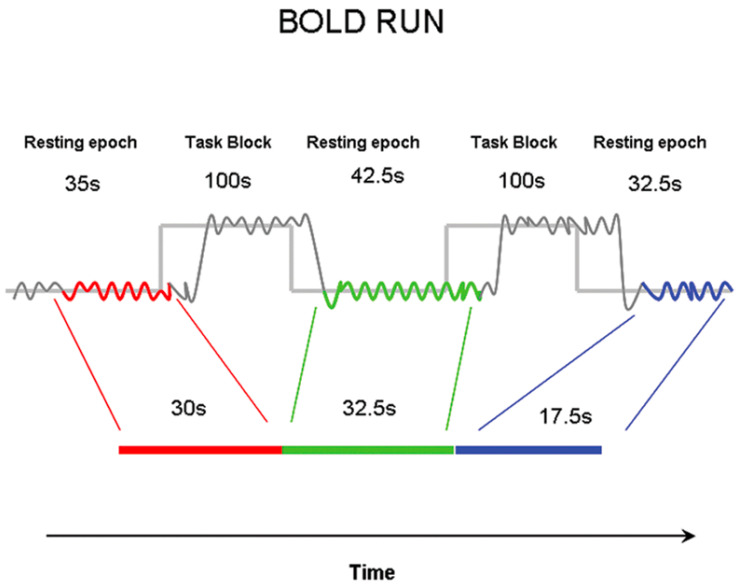
Rest vs Background FC

- Fair et al 2007 3 gps of n=10

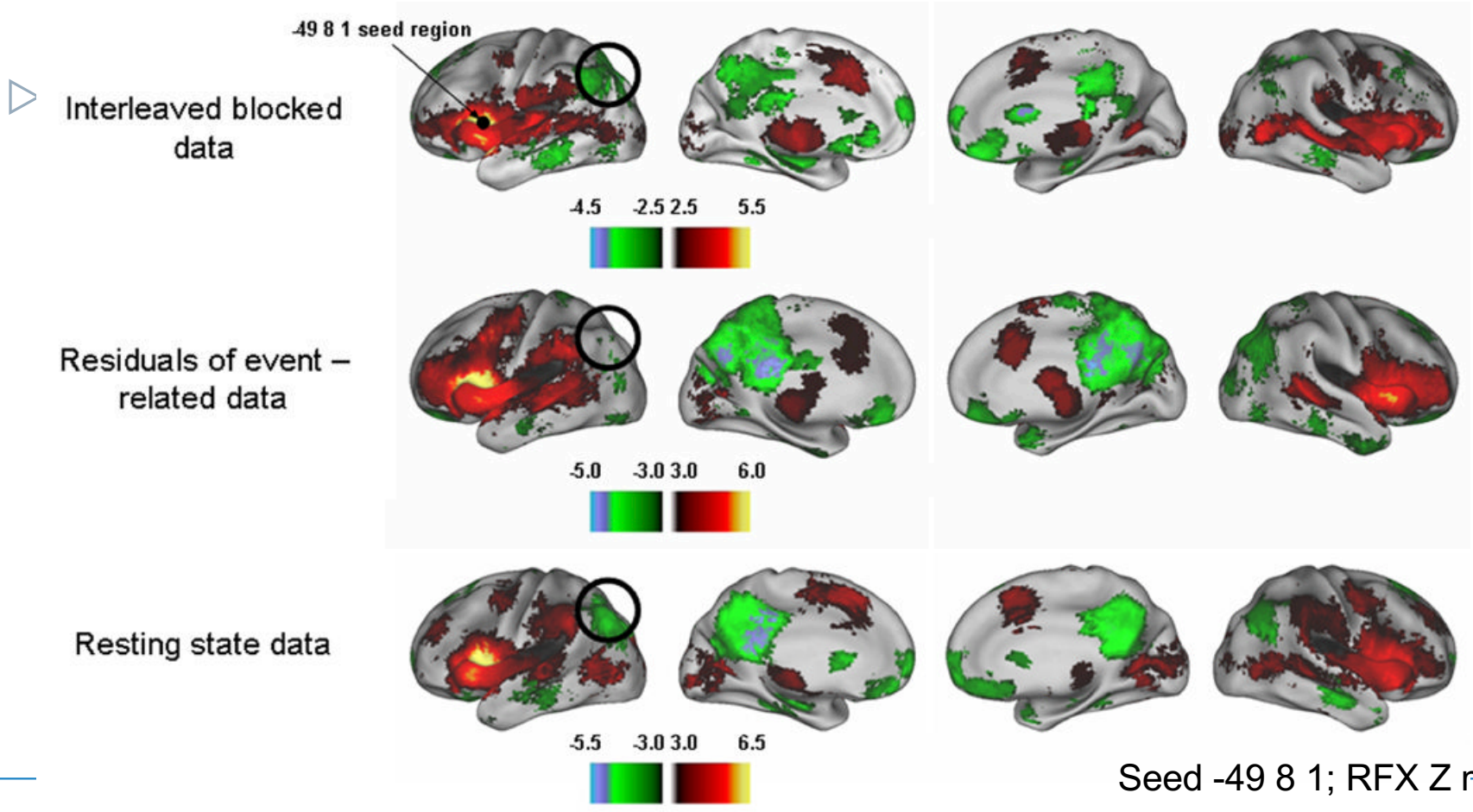
Resting eyes open

Even-related language tasks

Mixed block/event-related



Rest vs Background FC



Seed -49 8 1; RFX Z maps

NeuroImage 270 (2023) 119946

Contents lists available at ScienceDirect

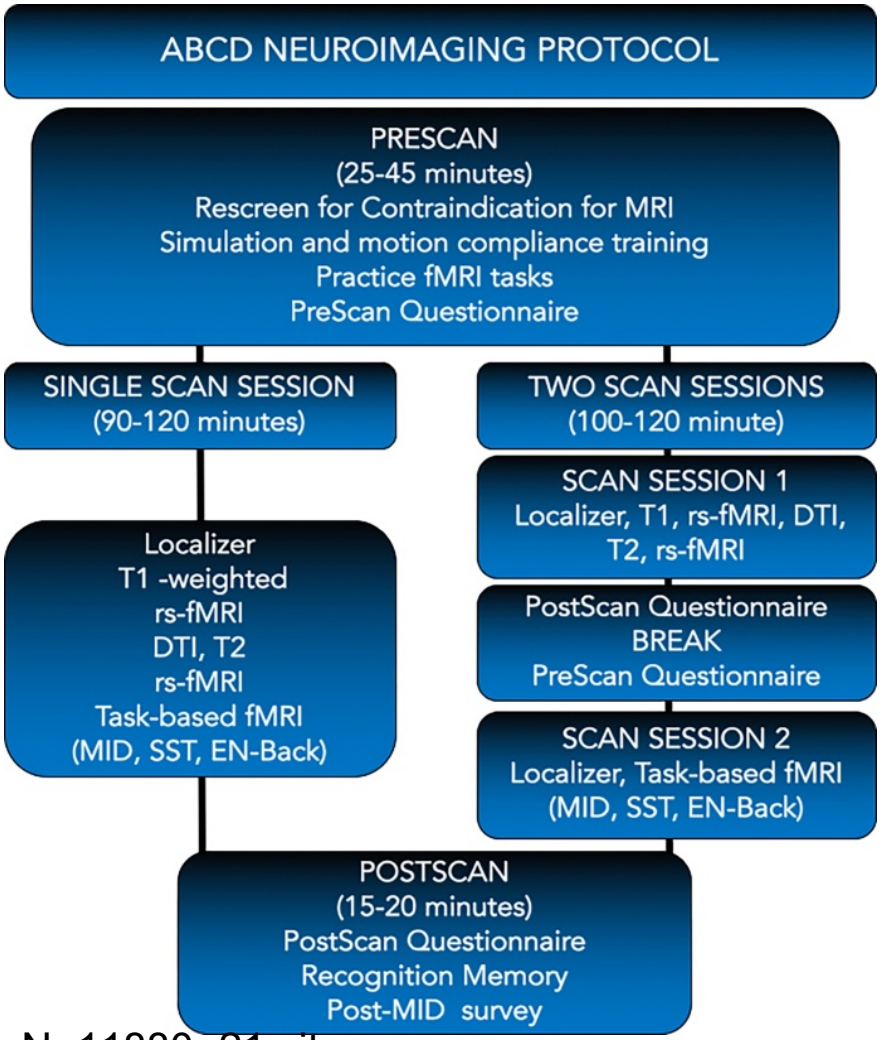
NeuroImage

journal homepage: www.elsevier.com/locate/neuroimage

Task fMRI paradigms may capture more behaviorally relevant information than resting-state functional connectivity

Weiqi Zhao[a,c], Carolina Makowski[b,c], Donald J. Hagler[c], Hugh P. Garavan[d], Wesley K. Thompson[e], Deanna J. Greene[a,c], Terry L. Jernigan[a,b,c,f,i], Anders M. Dale[b,g,h,i,]

See also Greeen et al 2018; Elliott et al 2019)



N=11880- 21 sites

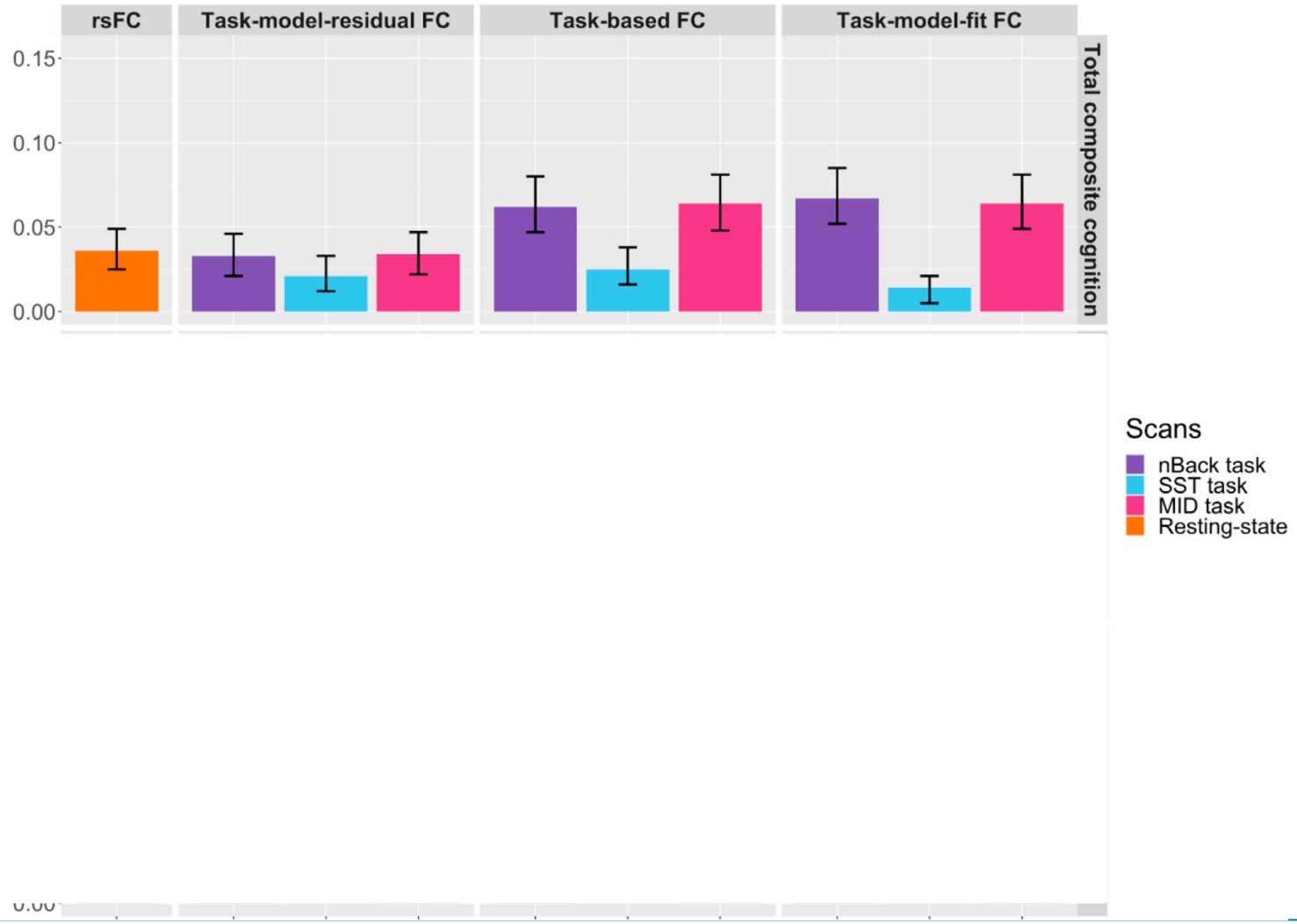
Adolescent Brain Cognitive Development
Teen Brains. Today's Science. Brighter Future.

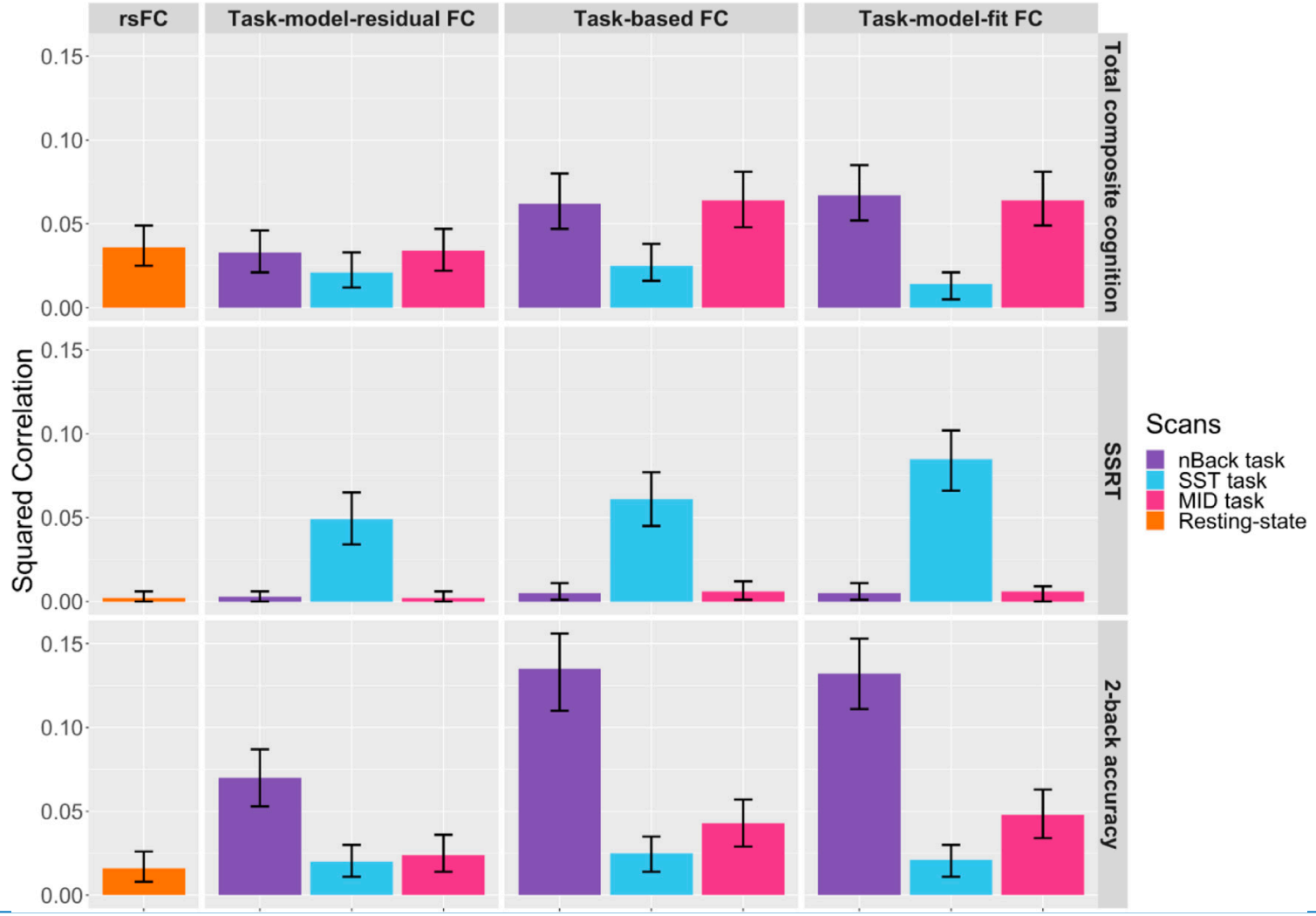
- 3 tasks
  - Emotion N Back
  - Stop Signal
  - Monetary Incentive delay
- 4 x 5 min of rest data over 2 sessions
- Extensive personnal and behavioural (NIH toolbox) data

Prediction of behaviour by FC

FC	*Pairwise correlation of*
Resting-state	fMRI time series at rest
Task-based	complete fMRI time series during task
Task-model-fit	Task design * beta estimates of condition task regressors = time series component explained by the task design
Task-model-residual	task-model-residual time series = task fMRI time series component that cannot be explained by the task design

- FC matrices = pairwise correlations for 352 ROIs (Gordon et al 2016)
- Behavioral prediction with nested 10 folds cross validation scheme after Fast-efficient-mixed effects modeling
- Squared correlation between the predicted and the observed behavioral score was used as the metric for out-of-sample behavioral prediction performance of each imaging measure.


rsFC
Task-model-residual FC
Task-based FC
Task-model-fit FC
Total composite cognition
0.15
0.10
0.05
0.00
Scans
nBack task
SST task
MID task
Resting-state


rsFC
Task-model-residual FC
Task-based FC
Task-model-fit FC
Total composite cognition
SSRT
2-back accuracy
Squared Correlation
0.15
0.10
0.05
0.00
Scans
nBack task
SST task
MID task
Resting-state

Conclusion

- task manipulation accentuates the functional correlation patterns of the brain that are behaviorally relevant (see also Cole et al., 2021).
- task-specific: only fMRI tasks that evoke cognitive demands and content relevant to the behavior of interest confer this advantage

Questions

- Would that work for smaller samples?
  - E.g. for our 52 subjects relating FC to Empathy
- Is whole brain FC more powerful than a selection of regions
- If background FC relates to general cognitive abilities, shouldn't we control for that when using FC as a brain marker
- Would same difference btw rs and task-based FC be observed for classification approach?

Thanks!

Notion to keep in mind

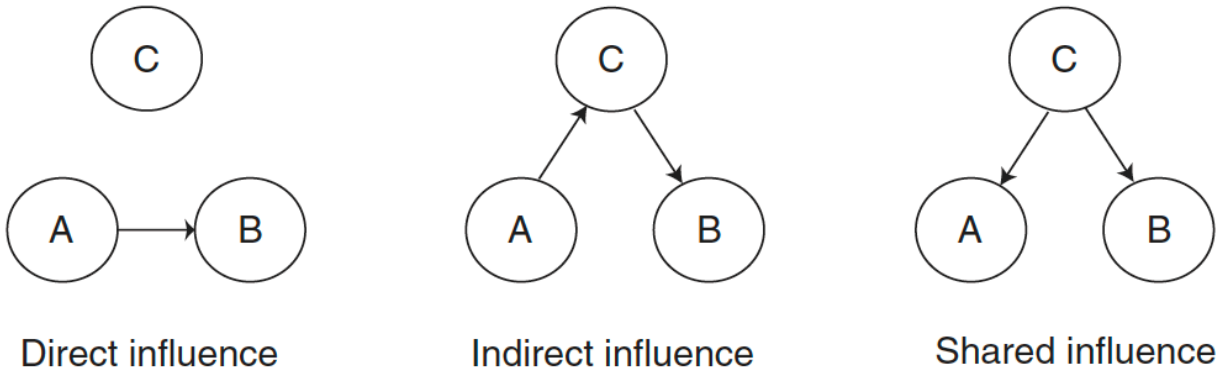
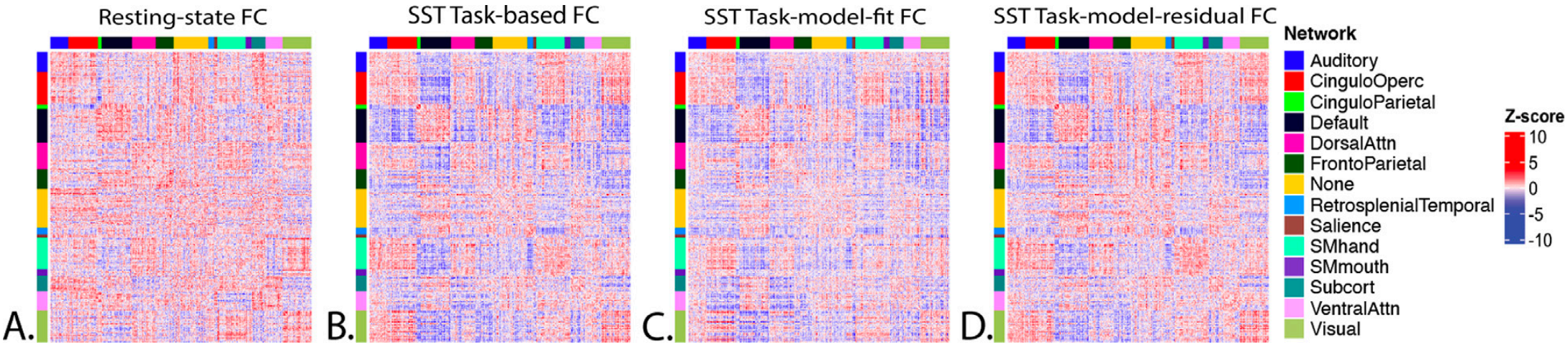
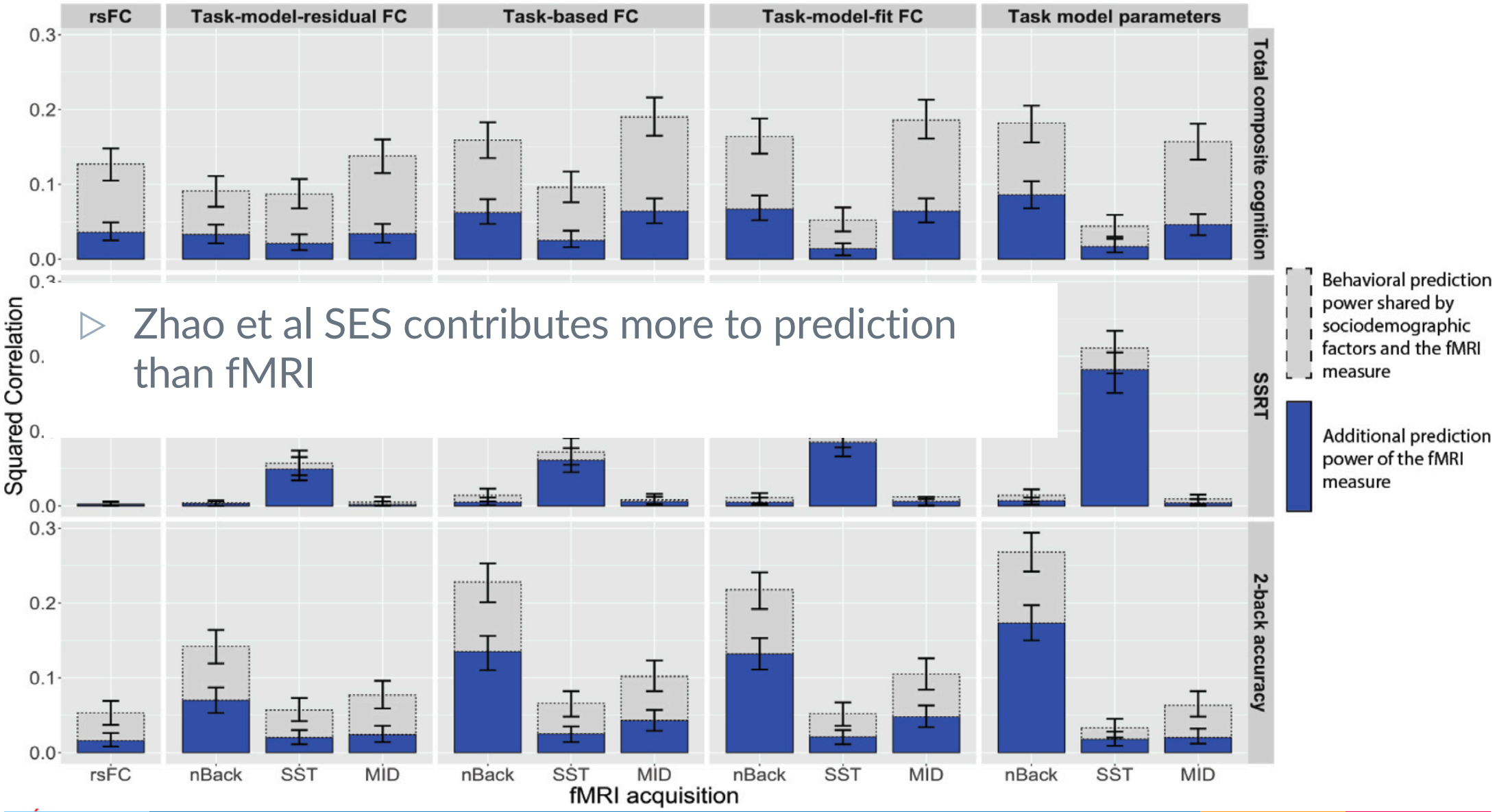


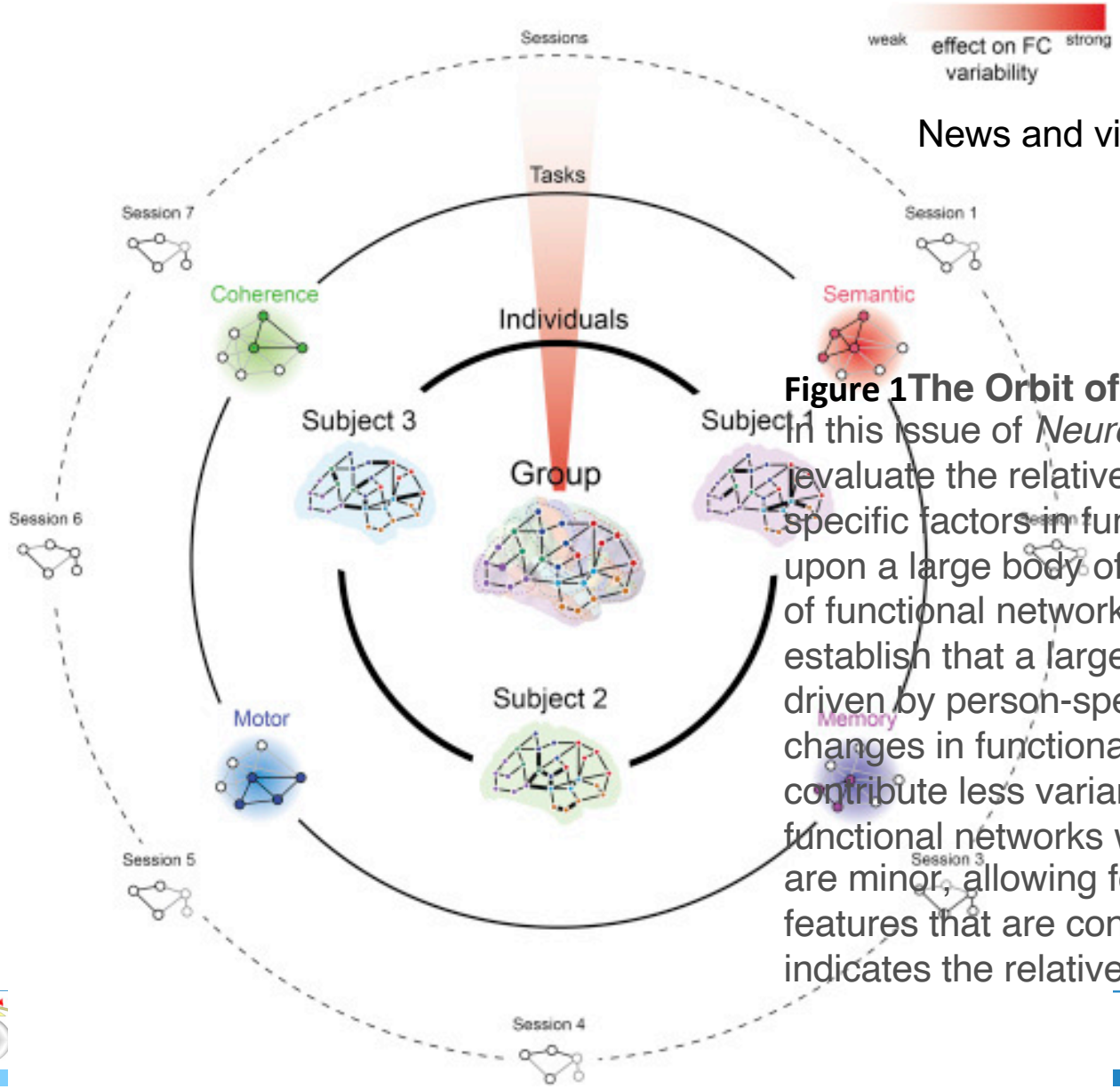
Figure 8.1. A depiction of the various ways in which correlated activity between two regions A and B can arise, either through direct influence (left panel), indirect influence via another region (center panel), or shared influence of a common input region (right panel).

▷ Zhao et al task specific effec



- Zhao et al SES contributes more to prediction than fMRI





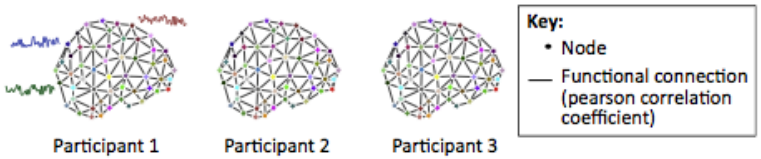
News and views T Satterthwaite , C Xia, D Basset

Figure 1The Orbit of Influence in Functional Network Variabili

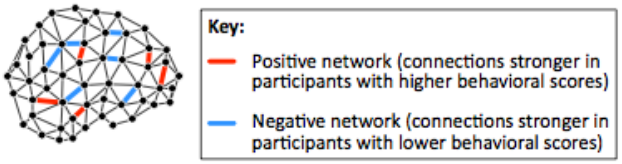
In this issue of *Neuron*, Gratton et al., 2018 evaluate the relative influence of group, individual, and task-specific factors in functional brain networks in humans. Building upon a large body of prior work delineating the average topology of functional networks present in groups (center), Gratton et al. establish that a large amount of variability in functional networks driven by person-specific characteristics (inner ring). In contrast, changes in functional networks associated with cognitive tasks contribute less variance. Finally, with sufficient data, changes in functional networks within individuals across scanning sessions are minor, allowing for identification of person-specific network features that are consistently present over time. Color bar indicates the relative variance explained by each factor.

The Connectome-Based Predictive Modeling Approach (CPM). The CPM.

1. Compute each participant's unique connectivity pattern.



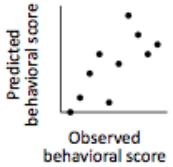
2. Identify behaviorally relevant connections.



3. Build model relating relevant connections to behavior.

Behavioral score = f(positive network connections, negative network connections)

4. Apply model to novel individual's connectivity pattern to predict behavior. Compare predicted and observed behavior to assess predictive power.



Trends in Cognitive Sciences

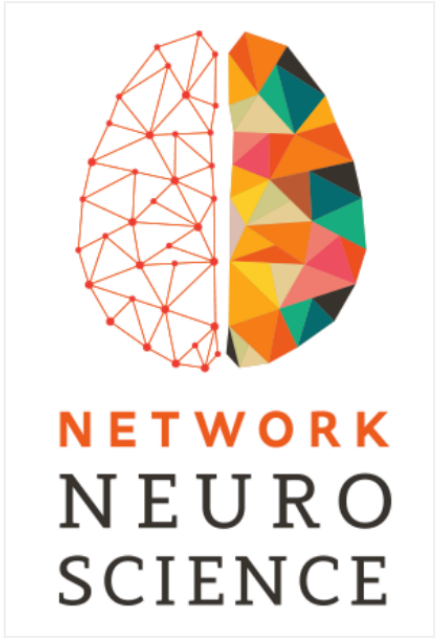
Superiority of task-based resting FC / rest resting FC to predict interindividual differences in behaviours or traits

- Greene, A.S., Gao, S., Scheinost, D. et al. Task-induced brain state manipulation improves prediction of individual traits. Nat Commun 9, 2807 (2018). https://doi.org/10.1038/s41467-018-04920-3
  - Human Connectome Project (n=515 adults) and Pennsylvania Neurodevelopmental cohort (n=571 , 8-21 yo). No model of task design. *By considering task-induced brain state and sex, the best-performing model explains over 20% of the variance in fluid intelligence scores, as compared to <6% of variance explained by rest-based models.*
- "How Tasks Change Whole-Brain Functional Organization to Reveal Brain-Phenotype Relationships":Abigail S. Greene, Siyuan Gao, Stephanie Noble, Dustin Scheinost, R. Todd Constable, Cell Reports, 32 (8) 2020, https://www.sciencedirect.com/science/article/pii/S2211124720310512
  - HCP interindicidual PPI

Time varying connectivity

Volume 4, Issue 1

2020



February 01 2020

Questions and controversies in the study of time-varying functional connectivity in resting fMRI

In Special Collection: CogNet

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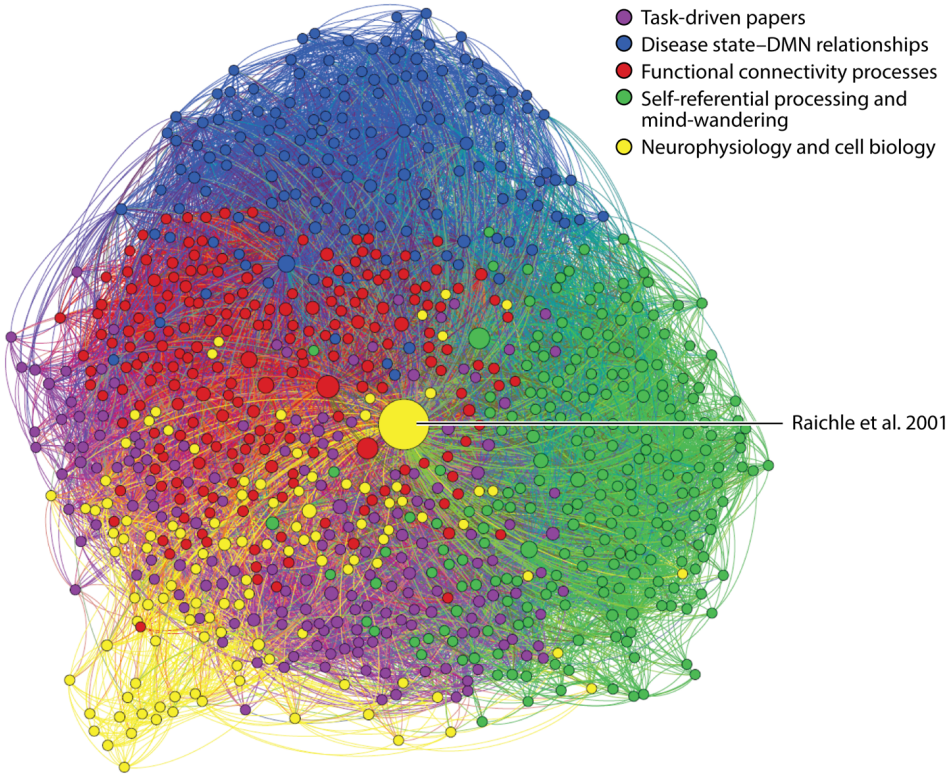
Network Neuroscience (2020) 4 (1): 30–69.

https://doi.org/10.1162/netn_a_00116 **Article history**

Multi-domain interest



Raichle ME. 2015.
Annu. Rev. Neurosci. 38:433–47

Figure 1 The evolving literature on the default mode network (DMN). Search for papers citing Raichle et al. (2001). The search returned 2,988 papers with digital object These data were used to construct a 2,988 × 2,988 binary adjacency matrix, in which each element (i, j) indicated whether paper i cited paper j. Once constructed, the adjacency matrix was imported into Gephi. The number of network modules wasdetermined using a fast, modularity-optimization method Each node was assigned to a specific module, and each module was assigned a unique color for visualization. A topic was assigned to each module by identifying the focus of the highest cited papers within each module. Finally, the size of each node within the graph was weighted according to the node degree. This algorithm represents a data-driven approach to identify clusters of papers with common citation patterns. Each cluster represents a broad topic of investigation in the DMN field. The purple cluster contains task-driven papers typical of cognitive neuroscience. Papers in the blue cluster are broadly focused on the relationship between disease states and the DMN. Papers in the red cluster concentrate on functional connectivity processes. The green cluster is composed of papers on self-referential processing and mind wandering. Articles in the yellow cluster are related to neurophysiology and cell biology.